Structural Instability in the Pricing-to-Market and Exchange Rate Pass-Through

Ekaterina Kortava

BA, MSc

Submitted in fulfilment of the requirements for the Degree of Doctor of Philosophy

Adam Smith Business School

College of Social Sciences

University of Glasgow

November 2013

Abstract

This thesis examines potential time variance of the Pricing-to-market (PTM) and Exchange rate pass-through (ERPT) from both theoretical and empirical perspectives. We argue that the response of the export and import prices to the exchange rate is time dependent. We develop three models that justify the inconstancy of the PTM and ERPT. The first model represents a partial equilibrium theoretic framework where the existence of the cost of switching between substitutes generates structural breaks in the ERPT parameters. This model is subsequently tested by applying the threshold regression framework of Hansen (1999) to data on the US imports from selected European economies. The second model is a partial equilibrium model of export pricing where consumers dislike price volatility. Through solving the firm's profit maximization problem we show that the volatility of the exchange rate undermines the stability of the response of the export price to currency movements. This model is tested using data on the UK exports to the EU and four out-of-sample forecasting tests, namely fixed, rolling, recursive and random walk coefficient time varying parameter regressions. The third model represents a dynamic stochastic general equilibrium model with subsistence points in consumption and investment. It features two countries and two types of firm – local currency pricing and producer currency pricing. Through maximizing the household's utility and firms' profits we show that the extent of the PTM and ERPT is time varying and depends on the unstable response of the mark-up of price over the marginal cost to currency movements. In order to illustrate the inconstancy of the mark-up for both firm types, we compute the impulse responses of the mark-ups to positive shocks to consumer preferences and production technology. Our findings on the time variance of the PTM and ERPT have important policy implications. Since the degree of the PTM and ERPT into import prices affects the extent of the rise of the domestic price level following the devaluation of the domestic currency, monetary policy should consider potential time evolution of the PTM and ERPT in order to control inflation.

Table of Contents

Acknowledgement

I am grateful to my supervisors Professor Ronald MacDonald and Dr Joseph Byrne for their continuous support for my research ideas and applications for various academic activities, such as conferences, summer schools and peer-reviewed journal publications.

I am grateful to the University of Glasgow's College of Social Sciences (formerly known as the Faculty of Law, Business and Social Sciences) for granting me the Postgraduate Research Scholarship that allowed me to fund my studies and living expenses. I am also grateful to the University of Glasgow's Adam Smith Business School for its financial support for my paper submissions to several peer-reviewed journals.

I am extremely thankful to Dr Nicola Birkin and Dr Alexander Kovalenkov who gave me the opportunity to teach undergraduate courses in the subject of Economics at the Adam Smith Business School. Teaching experience helped me to develop valuable academic and transferrable skills, improve my professional portfolio and enhance my interpersonal skills.

I thank Ms Jane Brittin for her generous help in producing administrative paperwork and resolving maintenance issues. Her high professionalism, efficiency and endless willingness to help students are unmatched.

I am indebted to Professor Martin Uribe from Columbia University, who kindly shared with me the MATLAB codes used in Ravn et al. (2006).

I am also grateful to the CIREQ (Centre Interuniversitaire de Recherche en Economie Quantitative) in Québec (Canada) for providing me with a travel grant in order to present at the 7th CIREQ PhD students' conference in Montréal.

Finally, I thank the examiners of my thesis - Professor Mustafa Çağlayan and Dr Alexandros Kontonikas - for their constructive suggestions to improve this thesis. I am also deeply indebted to Dr Alexander Kovalenkov and Ms Jane Brittin for making viva arrangements.

Author’s Declaration

I declare that this thesis represents my own work, except those cases when explicit references are made to other sources of literature. I confirm that no part of this dissertation has been previously submitted for a different degree, either at the University of Glasgow or elsewhere.

Signature --

Printed name-------------------------------------

Abbreviations

BSEERI – Broad Sterling Effective Exchange Rate Index

DSGE – Dynamic Stochastic General Equilibrium

EC – European Community

ECU – European Currency Unit

ERPT – Exchange Rate Pass-through

EU – European Union

GBP – Great British Pound

GDP – Gross Domestic Product

IMF – International Monetary Fund

IFS – International Financial Statistics

ITCS – International Trade by Commodity Statistics

LCP – Local Currency Pricing

LOP – Law of One Price

LR – Likelihood Ratio

OECD – Organization for Economic Cooperation and Development

OLS – Ordinary Least Squares

PCP – Producer Currency Pricing

PPI – Producer Price Index

PPP - Purchasing Power Parity

PTM – Pricing-to-market

RMSFE – Root Mean Squared Forecast Error

RWCTVP – Random Walk Coefficient Time Varying Parameter

SITC – Standard International Trade Classification

UK –United Kingdom

USD – United States Dollar

Introduction

The phenomena of Pricing-to-market (PTM) and Exchange rate pass-through (ERPT) were developed in the literature to describe the responsiveness of internationally traded goods' prices to exchange rate movements. The ERPT is defined as the percent change in the import price in response to a one percent change in the exchange rate (Campa and Goldberg, 2002). The PTM hypothesis emerged in Krugman (1986) to justify the puzzling evidence suggesting an incomplete ERPT whereby import prices fail to move one-to-one with the exchange rate. Specifically, Krugman (1986) defined the PTM as the policy of price discrimination by foreign firms across export destinations. The purpose of this international price discrimination is to stabilize import prices during the importer's currency appreciation or depreciation. Thus, an incomplete ERPT reflects the presence of the PTM (Obstfeld, 2001).

The motivation behind studying the phenomena of PTM and incomplete ERPT stems from their ability to justify international price differentials. Specifically, they represent a handy tool for explaining one of the major macroeconomic puzzles, i.e. the failure of the Purchasing Power Parity (PPP). PPP implies that the aggregate price level in country A should equal the aggregate price level in country B, if both price levels are converted to a common currency (Rogoff, 1996). The underpinning assumption of the PPP is the Law of One Price (LOP), which suggests that, for any good i, the price paid by customers in country A would equal the price faced by consumers in country B, when both prices are expressed in a common currency.

The LOP holds in the absence of the international price discrimination. The LOP can be represented as

$$p_{it}^{imp} = s_t p_{it}^{\exp}, \tag{1}$$

where s_t denotes the exchange rate in units of the importer's currency per unit of the exporter's currency, p_{it}^{imp} and $p_{it}^{\exp}$ define prices paid by the importer and exporter, respectively, for good *i*. Therefore, the LOP implies that the price differential between the two countries must equal zero, i.e. $p_{it}^{imp} - s_t p_{it}^{\exp} = 0$.

However, international trade is likely to imply additional costs imposed by the existence of trade barriers that are constant over time (Goldberg and Knetter, 1997). Thus, a more realistic version of the LOP suggests that these fixed barriers denoted by α drive a stable disparity between the two prices when expressed in a common currency:

$$p_{it}^{imp} = \alpha s_t p_{it}^{\exp}. \tag{1a}$$

Taking logs and first-differences of the LOP (1a) gives

$$\Delta \log p_{it}^{imp} = \Delta \log\left(s_t p_{it}^{\exp}\right). \tag{2}$$

The first-difference operator, Δ, applied to any variable X is defined as $\Delta X_t = X_t - X_{t-1}$. The log-differenced LOP (2) rules out international price differentials for the same product after the effect of trade barriers, α, has been taken into account.

For instance, consider a US good i exported to the UK and Germany. Normalizing parameter α to1 in the LOP (1a) for the simplicity of exposition gives the following import prices:

$$p_{it}^{GBP} = s_{it}^{GBP,USD} p_{it}^{USD}, \tag{3}$$

$$p_{it}^{EURO} = s_{it}^{EURO,USD} p_{it}^{USD}, \tag{4}$$

where p_{it}^{GBP} and p_{it}^{EURO} denote the import prices in the UK (in Great British Pounds) and Germany (in EURO), respectively. p_{it}^{USD} is the export price expressed in US dollars. $s_{it}^{GBP,USD}$ and $s_{it}^{EURO,USD}$ stand for the exchange rates calculated as the number of units of GBP and EURO, respectively, per one USD. Equations (3) and (4) jointly imply the following relationship between the import prices in the UK and Germany:

$$\frac{p_{it}^{GBP}}{s_{it}^{GBP,USD}} = \frac{p_{it}^{EURO}}{s_{it}^{EURO,USD}}. \tag{5}$$

Equation (5) suggests that the import price paid by the UK customers is equivalent to the import price faced by the German customers when both prices are expressed in USD. Thus, the LOP equalizes import prices across the export destination countries after all prices have been converted to the same currency.

Evidence suggests that the LOP rarely holds in the actual data (Rogoff, 1996). In fact, international price differentials for the same product are large and persistent. Table A displays log-differences of the retail prices of roasted coffee in various importing countries from 2001 to 2011. Annual average price data was obtained from the *International Coffee Organization Statistics.* Roasted coffee was chosen due to its relatively homogeneous nature, whereby the product characteristics do not vary significantly across importing countries. In the absence of substantial product differences across countries, inernational price diffferentials are less likely to occur.

Table A

USD retail prices of roasted coffee in log-differences (2001-2011)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
AT	-0.04	-0.03	0.11	0.05	0.12	0.09	0.03	0.11	0.38	-0.04	0.22
BE	-0.07	0.02	0.16	0.07	0.06	0.05	0.13	0.11	-0.04	-0.02	0.22
CY	0.00	0.12	0.19	0.06	0.01	0.01	0.07	0.07	-0.06	-0.05	0.05
CZ	-0.15	0.03	0.04	0.11	0.09	0.04	0.10	0.27	-0.11	-0.03	0.27
DK	-0.08	-0.03	0.14	0.10	0.08	0.03	0.08	0.11	-0.02	0.03	0.24
FI	-0.15	-0.07	0.15	0.09	0.19	0.04	0.10	0.13	-0.06	0.05	0.37
FR	-0.07	0.04	0.19	0.09	0.01	0.08	0.14	0.12	-0.02	-0.04	0.13
DE	-0.07	0.03	0.15	0.05	0.20	0.06	0.08	0.09	-0.08	0.00	0.07
IT	-0.03	0.05	0.18	0.09	0.02	0.03	0.11	0.11	-0.02	-0.04	0.15
LV	-0.19	-0.02	0.04	0.10	0.05	0.09	0.12	0.20	0.03	0.00	0.35
LU	-0.04	0.05	0.21	0.09	0.04	0.06	0.05	0.10	-0.03	-0.03	0.15
PL	-0.09	-0.20	0.00	0.06	0.13	0.08	0.23	0.24	-0.24	0.04	0.13
PT	-0.03	0.00	0.17	0.06	-0.01	-0.02	0.08	0.11	-0.07	-0.07	0.08
SK	-0.08	-0.03	0.12	0.09	0.03	0.09	0.24	0.26	0.01	-0.05	0.22
SI	-0.15	0.02	0.19	0.00	0.00	0.07	0.13	0.10	-0.04	-0.10	0.11
ES	-0.06	0.02	0.15	0.07	0.00	0.06	0.12	0.11	-0.03	-0.06	0.12
SE	-0.18	0.01	0.14	0.05	-0.03	0.05	0.11	0.06	-0.06	0.12	0.34
JP	-0.41	-0.06	0.01	0.07	-0.06	-0.01	-0.01	0.03	-0.32	0.05	0.14
NO	-0.04	0.08	0.12	0.10	0.07	-0.05	0.14	0.05	-0.15	0.11	0.26
Value range	0.41	0.32	0.2	***0.11***	0.26	0.14	0.25	0.24	***0.7***	0.22	0.32
Vari-ance	0.008	0.004	0.004	***0.001***	0.005	0.002	0.003	0.005	***0.018***	0.003	0.009

Notes: 1. Country abbreviations – AT (Austria), BE (Belgium), CY (Cyprus), CZ (Czech Republic), DK (Denmark), FI (Finland), FR (France), DE (Germany), IT (Italy), LV (Latvia), Luxembourg (LU), Poland (PL), Portugal (PT), Slovakia (SK), Slovenia (SI), Spain (ES), Sweden (SE), Japan (JP), Norway (NO).
2. Log-difference of retail price r_t is computed as $(ln\ r_t - ln\ r_{t-1})$. 3. Data on the retail prices of roasted coffee was obtained from the *International Coffee Organization Statistics.*

Examining data in Table A column by column yields substantial retail price disparities among the countries importing roasted coffee, although the LOP suggests that the log-differences of import prices should be equal across countries in any given year. Two measures of dispersion are considered in Table A – range and variance. The range of values is defined as the distance between the maximum and minimum values of the log-differenced import price among all countries in one year. The largest range of values for the log-differences of the USD coffee prices was observed in 2009 – [-0.32; 0.38]. The smallest range corresponds to 2004 – [0.00; 0.11]. Thus, years 2004 and 2009 offer the smallest and largest levels of the international price dispersion, respectively. Therefore, data for 2004 mimics the LOP more successfully, compared to all other years, since the LOP (2) implies that the international range of values of the log-differenced import prices equals zero, i.e. $\Delta \log p_{it}^{x} - \Delta \log\left(s_{it}^{x,y} p_{it}^{y}\right) = 0$ for each pair of countries, *{x; y}*.

Similarly, the cross-country variance of log-differenced coffee prices should equal zero under the LOP. The last row of Table A reports the annual cross-country variance of coffee prices in log-differences. Denoting the log-difference of retail price in country *i* by x_i, the sample mean average by $\bar{x}$ and the sample size (number of countries) by n, variance is computed as

$$\mathrm{var} = \frac{\sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2}{n-1}. \tag{6}$$

Under the LOP, variance (6) equals zero since $x_i = \bar{x}$ as there are no international price differentials, i.e. $x_1 = x_2 = x_i = ... = x_n$. Variance operator delivers the same conclusion on the international price dispersion as the range measure. Specifically, the largest cross-country variance of prices was observed in 2009, while the smallest variance corresponds to 2004. This finding confirms that the LOP fits the coffee price data for 2004 more accurately than in other periods.

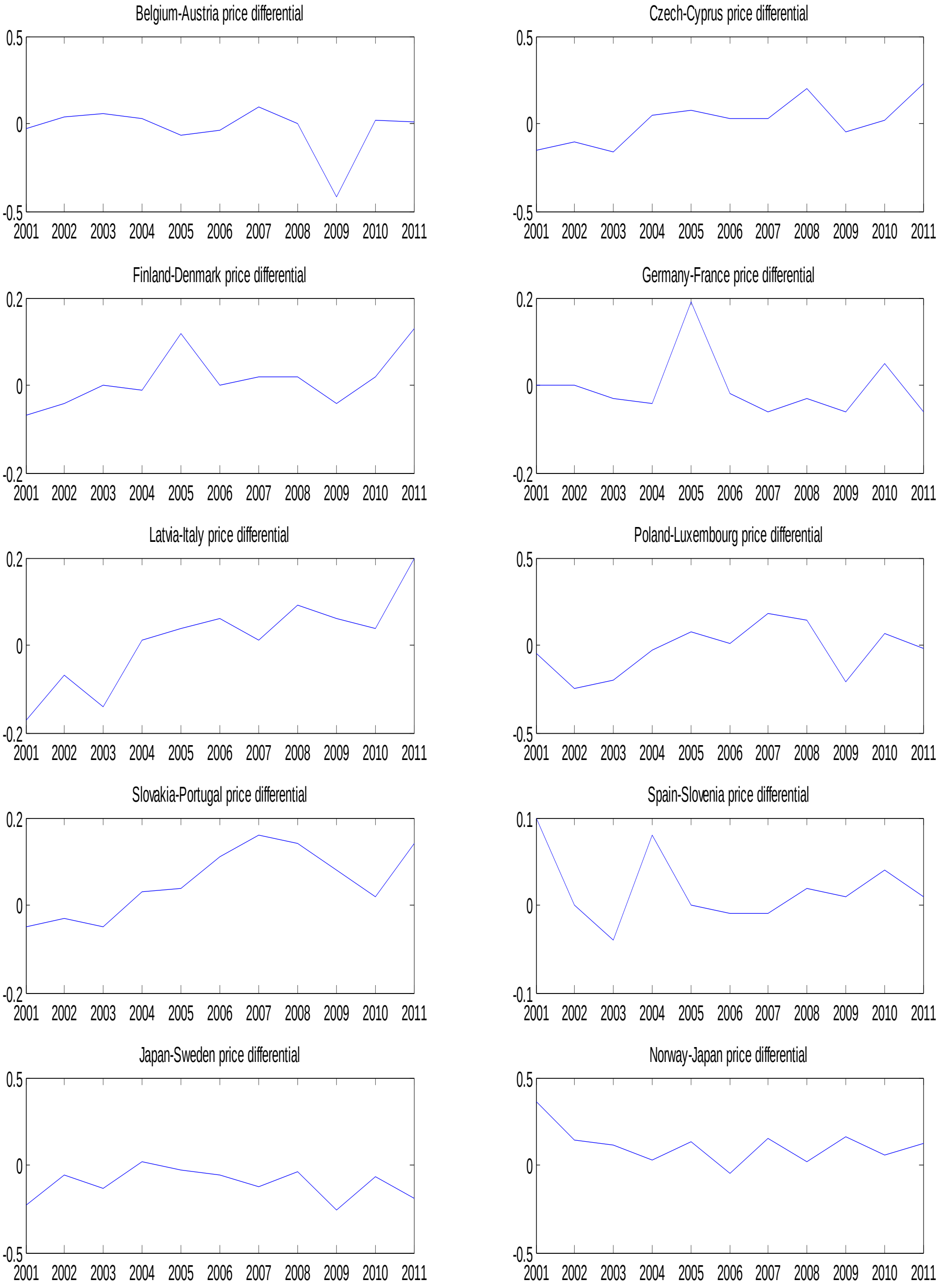
In order to illustrate international price dispersions for roasted coffee, in Figure A we display the log-differenced retail price differentials for ten pairs of importers. Price differential between countries X and Y for good *i* is computed as

$$Differential_{it} = \Delta \log p_{it}^{X,USD} - \Delta \log p_{it}^{Y,USD}. \tag{7}$$

The superscript USD indicates that prices in both countries are expressed in US dollars. The LOP suggests that the international price differential between any two countries is equal to zero. Figure A illustrates that only the Japan-Sweden and Norway-Japan price differentials remain close to the zero boundary. In all others country pairs we observe substantial deviations from the LOP:

Figure A

International retail price differentials for roasted coffee



Note: This figure displays differences between log-differenced import prices of two countries (in USD). Data was retrieved from *International Coffee Organization Statistics*.

The overwhelming evidence on the violations of the LOP and PPP can be justified by employing the theory of PTM and incomplete ERPT. Specifically, the fundamental idea of the PTM hypothesis represents persistent international price differentials for the same commodity due to price discrimination by exporters. Consequently, since a country's consumption basket contains goods that are subject to the PTM, we observe persistent differences in aggregate price levels across countries.

In addition to motivating the deviations from the PPP, the incomplete ERPT has a direct policy implication for the debate on inflation. Specifically, import price movements generate fluctuations in the domestic price level. Intuitively, the larger the proportion of goods exhibiting an incomplete ERPT, the weaker the increase of the home aggregate price index following the domestic currency depreciation (Betts and Devereux, 1996). Likewise, a higher pass-through causes a stronger increase of the aggregate price level following the depreciation. Therefore, a reasonably accurate estimate of the ERPT allows conducting a more informed monetary policy. First, the awareness of the prevailing ERPT degree allows policy makers to accurately assess the impact of planned currency devaluation on domestic inflation. For example, in a country with a low pass-through environment, currency devaluation and the resulting depreciation will generate a relatively small increase in the aggregate price level, since the depreciation of the domestic currency leads to an insignificant rise in the domestic price level. Second, observations on the ERPT enable the central bank to choose a more appropriate inflation target. For example, it may not be feasible to achieve a low inflation target in a country with a high ERPT level while the domestic currency is continuously depreciating.

This thesis attempts to make a theoretical and empirical contribution to the literature by examining the PTM and incomplete ERPT from a non-linear perspective. Specifically, we analyze time variance of the response of traded goods' prices to exchange rate movements and develop new tests of international price discrimination.

This thesis contains 5 Chapters. Chapter 1 reviews benchmark theoretic and empirical models of the PTM and ERPT in order to introduce the linear framework of export pricing before we proceed to developing non-linear tests of incomplete ERPT in subsequent chapters.

Chapter 2 develops a two-regime partial equilibrium model of inconstant ERPT, which features the costs of switching to a substitute variety. We argue that the ERPT follows a two regime process. In the first regime, the ERPT is high because consumers' costs of switching to a different supplier are relatively large. Since the exporter is unlikely to lose customers in this regime, he allows a relatively large pass-through of a currency change into the import price. In the second regime, the ERPT falls because the cost of switching is relatively low. Since the customer is likely to switch to a rival firm, the exporter decreases his mark-up of price over the marginal cost and limits the ERPT into import prices.

This model is tested using the recently developed threshold regression methodology by Hansen (1999). This methodology allows us to detect structural breaks in the ERPT by searching over a grid of potential values for the threshold in order to minimize the concentrated sum of squared errors. The significance of the threshold estimate is tested using bootstrap p-values for the F_1 statistic which is used to test the null hypothesis of no structural change in the ERPT coefficient.

Chapter 3 develops another partial equilibrium model of export pricing. We adopt Krugman's hypothesis about consumers' preference for price stability (Krugman, 1986) and build a time varying relationship between the export price and the exchange rate. We suggest that the response of the export price to currency fluctuations depends on the volatility of the import price. Since the volatility of the import price is likely to be unstable because of an inconstant volatility of the exchange rate, the effect of the exchange rate on the export price is also likely to be time varying.

Time variation of the PTM is tested using a selection of out-of-sample forecasting tests which vary in their degrees of parameter evolution. We chose this class of tests because re-estimating the regression parameters over time is essential when parameter constancy is under question (Rossi, 2006). Our empirical analysis is conducted to answer two research questions. The first question is to determine whether the PTM model offers a significantly lower average forecast error than a rival specification. The statistical significance of the difference between the average prediction errors of rival models is tested using the forecast encompassing test by Clark and McCracken (2001). The second research question is whether regressions with time varying parameters predict export prices better than fixed parameter regressions. A positive answer to both questions will enable us to conclude that selected goods are subject to a time varying PTM.

Chapter 4 builds a two-country dynamic stochastic general equilibrium model of an inconstant PTM and ERPT. We borrow the concept of subsistence points in consumption and investment from Ravn et al. (2006) and consider two types of firm – producer currency pricing and local currency pricing. By solving the optimization problem of the utility maximizing households and profit maximizing firms we show that the degree of the PTM and ERPT is inconstant due to the countercyclical nature of the mark-up of price over the marginal cost. Specifically, the response of the export and import prices to the exchange rate is time varying because it depends on the effect of currency movements on the aggregate demand in the two countries.

In order to illustrate the inconstant and countercyclical nature of the mark-up, we simulate the impulse response of the mark-up of price over the marginal cost to positive shocks to consumer preferences and production technology. The purpose of this simulation is to determine whether the LCP and PCP mark-ups respond to positive shocks differently. We intend to show that both mark-ups fall at the time of the positive shock and gradually increase as the effect of the positive shock fades away. Thus, irrespective of the firm type, the degree of the PTM and ERPT is inconstant in our model, contrary to the stylzed models that predict zero pass-through in the LCP and constant ERPT equal to 1 in the PCP case (Gopinath et al., 2010).

Chapter 5 summarizes the main theoretic and empirical findings of this study and briefly discusses their policy implications. Specifically, we examine whether the effect of a domestic currency devaluation on the home inflation rate depends on structural breaks in the ERPT and PTM. We conclude that failure to take into account potential time evolution in the PTM and ERPT parameters may lead the policy maker to lose the control over the domestic inflation.

1. Chapter 1: Benchmark Models of the PTM and ERPT

1.1 Introduction

This chapter introduces the theory of PTM and ERPT by surveying a selection of the most influential theoretical and empirical contributions to the literature. First, it outlines partial equilibrium models whereby exchange rate changes are viewed as exogenous (Kasa, 1989). Second, it surveys general equilibrium frameworks whereby exchange rates and prices are determined simultaneously. This chapter concludes by reviewing seminal econometric specifications used to estimate the degree of PTM and ERPT.

1.2 Partial equilibrium models

The benchmark theory of PTM was developed by Krugman (1986) in order to justify the increase of the US prices of imported European luxury automobiles despite the US dollar appreciation. He proposed several partial equilibrium frameworks justifying an incomplete ERPT. Section 1.2.1 outlines in detail Krugman's model of the monopolistic price discrimination, since this set-up serves as a basis for subsequent studies of the PTM (Knetter, 1989). Sections 1.2.2 and 1.2.3 discuss alternative frameworks explaining an incomplete ERPT.

1.2.1 Demand elasticity hypothesis (Krugman, 1986)

Consider a European monopolistic firm producing at a constant marginal cost, c^*, which is fixed in European Currency Units (ECU). The monopolist's product is sold either in the European Community (EC) or in the US. The prices paid by the European and American consumers are denoted by P^* (in ECU) and P (in USD), respectively. The exchange rate, e, is measured as the number of ECU per US dollar. The monopolistic firm sets a unique optimal price for each market. In order to determine the optimal pricing rules, the monopolist's profits (1) must be maximized with respect to prices, P^* and P.

The firm's profits, π, represent the difference between the revenues from selling in both markets and the production costs:

$$\pi = D^*\left(P^* - c^*\right) + D\left(eP - c^*\right), \qquad (1)$$

where $D^*\left(P^*\right)$ and $D(P)$ denote the demands in the EC and US, respectively. The optimal level of the price P^* must satisfy the following first-order condition:

$$\frac{\partial \pi}{\partial P^*} = D^* + P^* \frac{\partial D^*}{\partial P^*} - c^* \frac{\partial D^*}{\partial P^*} = 0\,. \qquad (2)$$

Multiplying both sides of the condition (2) by $\left(\frac{P^*}{D^*}\right)$ and denoting the demand elasticity, $\left(-\frac{\partial D^*}{\partial P^*}\frac{P^*}{D^*}\right)$, by E^* yields

$$P^* + P^*\left(-E^*\right) - c^*\left(-E^*\right) = 0\,. \qquad (3)$$

Consequently, the optimal price for the EC market is defined as

$$P^* = \frac{E^*}{E^* - 1} c^*\,. \qquad (4)$$

Thus, within the monopolistic price discrimination, price is modelled as a mark-up over the marginal cost. The extent of the mark-up falls in the demand elasticity, E^*.

Similarly, the optimal level of the price P must correspond to the first-order condition

$$\frac{\partial \pi}{\partial P} = eD + eP \frac{\partial D}{\partial P} - c^* \frac{\partial D}{\partial P} = 0\,. \qquad (5)$$

Multiplying both sides of the condition (5) by $\left(\frac{P}{D}\right)$ and defining the demand elasticity, $\left(-\frac{\partial D}{\partial P}\frac{P}{D}\right)$, by E gives the optimal price for the US market

$$P = \frac{E}{E - 1}\frac{c^*}{e}\,. \qquad (6)$$

Thus, the optimal level of price P represents a mark-up over the marginal cost expressed in the importer's currency (USD). Similarly to the mark-up charged in the EC, the US mark-up (6) decreases in the importer's demand elasticity, E.

The optimal price rule (6) provides an insight into the ERPT into US import prices. Consider an increase in the exchange rate e, i.e. an appreciation of the USD. The optimal price rule (6) suggests that price P is decreasing in the exchange rate e. The extent of the price decrease following the USD appreciation depends on the shape of the demand curve, since the price mark-up, $\frac{E}{E-1}$, may respond to price fluctuations generated by the appreciation. Note that the mark-up represents a function of the price elasticity of the demand, *E*.

If the demand elasticity, E, is constant, price P falls in full proportion to the exchange rate movement. Using the log-transformation of the optimal price (6), the ERPT is computed as the derivative of the log-transformed P with respect to the log-transformed e (Parsley, 1993):

$$\frac{\partial \ln P}{\partial \ln e} = \frac{\partial\left(\ln E - \ln(E-1) + \ln c^* - \ln e\right)}{\partial \ln e} = -1. \tag{7}$$

Thus, assuming a constant demand elasticity yields a complete ERPT (7). Therefore, the degree of the PTM is zero as the exporter does not limit the degree of the ERPT.

If the demand elasticity is not invariant to price, an appreciation of the exchange rate may generate a more or less than proportionate movement in price *P*. For a variable E, the ERPT is defined as

$$\frac{\partial \ln P}{\partial \ln e} = \frac{\partial\left(\ln E - \ln(E-1) + \ln c^* - \ln e\right)}{\partial \ln e} = \frac{\partial \ln P}{\partial \ln e}\left(\frac{\partial \ln E}{\partial \ln P} - \frac{\partial \ln(E-1)}{\partial \ln P}\right) - 1, \tag{8}$$

since the elasticity *E* is a function of price *P*, which in turn depends on the exchange rate *e*. Solving the equation (8) for ERPT gives

$$\frac{\partial \ln P}{\partial \ln e} = -\frac{1}{1 - \frac{\partial \ln E}{\partial \ln P} + \frac{\partial \ln(E-1)}{\partial \ln P}}. \tag{9}$$

Thus, depending on the responsiveness of the demand elasticity to price movements, i.e. $\frac{\partial \ln E}{\partial \ln P}$, the absolute value of the ERPT may either overshoot or undershoot 1.

Therefore, Krugman (1986) suggests that the degree of the ERPT and PTM depends on the monopolist's perception of the demand curve. If the demand is perceived to have a constant elasticity (see 7), a complete ERPT into import prices is observed, since the mark-up is invariant to currency fluctuations. If the perceived shape of the demand curve is linear, the absolute value of the ERPT is *always* less than one-half (see Proof in Appendix 1), since mark-up movements mitigate import price fluctuations.

As Krugman (1986) recognizes himself, the drawback of this PTM model is reflected in its heavy reliance on the assumptions about the shape of the demand schedule. Thus, the predictions of the model are not robust to its assumptions. Nevertheless, mark-up adjustments in response to shifts in the perceived elasticity of demand with respect to price became one of the dominant hypotheses justifying an incomplete ERPT.

1.2.2 Foreign input hypothesis (Campa and Goldberg, 2002)

The partial equilibrium framework outlined in section 1.2.1 concentrates on the effect of the structure of demand and assumes that the exporter's costs are constant and irresponsive to exchange rate realizations. This assumption seems implausible, since the use of foreign inputs is prevalent in the modern globalized economy. Campa and Goldberg (2002) relax the assumption of constant marginal costs and argue that both the demand structure and the proportion of foreign inputs used in the production process are crucial for the degree of ERPT. Similarly to Krugman (1986), the exporter's pricing rule represents a mark-up over the marginal cost:

$$P_t^m = E_t P_t^x = E_t \mu_t^x \left(\frac{P_t^m}{P_t} \right) C_t^x \left(W_t, Y_t, E_t \right), \tag{10}$$

where P_t^m and P_t^x denote the import and export prices at period t. E_t is the nominal exchange rate measured as the number of the importer's currency units per unit of the exporter's currency. An increase in E_t suggests the appreciation of the exporter's currency. The mark-up μ_t^x represents a function of the import price relative to the domestic price index in the importer's country, P_t. The exporter's marginal cost, C_t^x, depends on the labour cost, W_t, the importer's GDP, Y_t, and the exchange rate.

The main difference between this framework and the benchmark model by Krugman (1986) lies in the sensitivity of the marginal cost to currency fluctuations. In order to observe the cost channel of the ERPT, the elasticity of the import price (10) with respect to exchange rate is computed:

$$\begin{aligned} ERPT &= \frac{\partial P_t^m}{\partial E_t} \frac{E_t}{P_t^m} = \gamma = \frac{\partial \left(E_t \mu_t^x \left(\frac{P_t^m(E_t)}{P_t} \right) C_t^x \left(W_t, Y_t, E_t \right) \right)}{\partial E_t} \frac{E_t}{P_t^m} = \\ &= \left[\left(\mu_t^x + E_t \frac{\partial \mu_t^x}{\partial P_t^m} \frac{\partial P_t^m}{\partial E_t} \right) C_t^x + E_t \mu_t^x \frac{\partial C_t^x}{\partial E_t} \right] \frac{E_t}{P_t^m}. \end{aligned} \tag{11}$$

Using the identity $P_t^m = E_t \mu_t^x C_t^x$ and rearranging the terms, the ERPT definition (11) can be simplified as follows:

$$\begin{aligned}\gamma &= \mu_t^x C_t^x \frac{E_t}{P_t^m} + \frac{\mu_t^x}{\mu_t^x} E_t \frac{\partial \mu_t^x}{\partial P_t^m}\frac{\partial P_t^m}{\partial E_t} C_t^x \frac{E_t}{P_t^m} + \frac{C_t^x}{C_t^x} E_t \mu_t^x \frac{\partial C_t^x}{\partial E_t}\frac{E_t}{P_t^m} = \\ &= 1 + \frac{P_t^m}{\mu_t^x}\frac{\partial \mu_t^x}{\partial P_t^m}\gamma + \frac{\partial C_t^x}{\partial E_t}\frac{E_t}{C_t^x}\frac{P_t^m}{P_t^m},\end{aligned} \tag{12}$$

where the second and third terms on the right hand side of the equation have been multiplied by $\frac{\mu_t^x}{\mu_t^x}$ and $\frac{C_t^x}{C_t^x}$, respectively. Denoting $\frac{\partial \mu_t^x}{\partial P_t^m}\frac{P_t^m}{\mu_t^x}$ and $\frac{\partial C_t^x}{\partial E_t}\frac{E_t}{C_t^x}$ by η and λ, respectively, yields

$$\gamma = 1 + \eta\gamma + \lambda = \frac{1+\lambda}{1-\eta}. \tag{13}$$

The ERPT (13) definition shows the crucial role of λ defining the sensitivity of the marginal cost to the exchange rate. Since the marginal cost, C_t^x, is expressed in the exporter's currency, an appreciation of his currency leads to a fall in his expenditures on inputs purchased from the importing country, i.e. $\frac{\partial C_t^x}{\partial E_t} < 0$ and $\lambda < 0$. Thus, a higher responsiveness of costs to currency fluctuations generates a lower ERPT into import prices. Consider a US firm exporting to the Euro zone. Intuitively, when the share of European inputs in the exporter's costs is large, the Euro costs, $E_t C_t^x$, do not fluctuate significantly with currency movements since the price of European inputs is set in Euro. Since the import price represents a mark-up over the Euro costs (see 10), the sensitivity of the Euro price to the exchange rate falls in the share of inputs imported from the Euro zone. Thus, the use of inputs purchased from the importer of the final good stabilizes the import price by mitigating its increase following the importer's currency depreciation.

1.2.3 Depreciation persistence hypothesis (Taylor, 2000)

Both models outlined in the previous two sections represent a static framework that does not discriminate between permanent and temporary changes in the exchange rate. However, Taylor (2000) shows that the degree of the ERPT depends critically on the duration of the currency depreciation. He adopts the price stickiness hypothesis whereby a representative firm producing a differentiated good does not reset its price every period. In contrast, the good's price lasts for four periods following the price adjustment.

Taylor (2000) assumes that a firm sells a differentiated product and maximizes the following expected profit function:

$$\sum_{i=0}^{3} E_t\left[(x_t - c_{t+i})(\varepsilon_{t+i} - \beta(x_{t+i} - p_{t+i}))\right]. \tag{14}$$

The conditional expectations operator, E_t, denotes an expected value, conditional on the information at time t. x_t defines the price of the firm's good and p_t stands for the average market price. A random term ε_t denotes shifts in demand and β is the slope of the linear demand function, $\varepsilon_t - \beta(x_t - p_t)$. c_t is the marginal cost of producing the good. The optimal level of price x_t is found by maximizing the expected profits (14) according to the following first order condition:

$$\frac{\partial\left(\sum_{i=0}^{3} E_t\left[(x_t - c_{t+i})(\varepsilon_{t+i} - \beta(x_{t+i} - p_{t+i}))\right]\right)}{\partial x_t} = \tag{15}$$

$$= \sum_{i=0}^{3}\left(E_t\varepsilon_{t+i} - 2\beta E_t x_{t+i} + \beta E_t c_{t+i} + \beta E_t p_{t+i}\right) = 0.$$

Solving the equation (15) for the expectation of the optimal price gives

$$2\beta\sum_{i=0}^{3} E_t x_{t+i} = \sum_{i=0}^{3}\left(E_t\varepsilon_{t+i} + \beta E_t c_{t+i} + \beta E_t p_{t+i}\right),$$

where we used the condition $x_{t+i}=x_t$, because the firm's price set at time t is assumed to last for four periods, i.e. $\sum_{i=0}^{3} E_t x_{t+i} = 4x_t$. Therefore, the optimal export price equals

$$x_t = \frac{1}{8}\sum_{i=0}^{3}\left(\frac{E_t\varepsilon_{t+i}}{\beta} + E_t c_{t+i} + E_t p_{t+i}\right). \tag{16}$$

Thus, a unit increase in the marginal cost c_t leads to a rise in the optimal price x_t by 0.125 units. If the marginal cost depends on the exchange rate due to foreign input usage, the depreciation of the exporter's currency generates higher expenditures on imported inputs. An increase in the marginal cost will be passed through into the optimal price, but the extent of the price increase will depend on the persistence of the depreciation.

Taylor (2000) suggests modelling the marginal cost as a first order autoregression process with persistence parameter ρ:

$$c_{t+1} = \rho c_t + u_{t+1}, \tag{17}$$

where u_{t+1} is a random term whose expected value equals zero, i.e. $E_t(u_{t+i}) = 0$. Using the cost process (17), the future marginal costs c_{t+2} and c_{t+3} are defined as

$$c_{t+2} = \rho c_{t+1} + u_{t+2} = \rho(\rho c_t + u_{t+1}) + u_{t+2} = \rho^2 c_t + \rho u_{t+1} + u_{t+2}, \tag{18}$$

$$c_{t+3} = \rho c_{t+2} + u_{t+3} = \rho(\rho^2 c_t + \rho u_{t+1} + u_{t+2}) + u_{t+3} = \rho^3 c_t + \rho^2 u_{t+1} + \rho u_{t+2} + u_{t+3}. \tag{19}$$

Given the marginal cost definitions (18) and (19), the cost pass-through into the export price (16) is computed as follows:

$$\frac{\partial x_t}{\partial c_t} = \frac{1}{8} \frac{\partial \left[\left(c_t + \rho c_t + \rho^2 c_t + \rho^3 c_t + \sum_{i=0}^{3} \left(\frac{E_t \varepsilon_{t+i}}{\beta} + E_t p_{t+i} \right) \right) \right]}{\partial c_t} = \frac{1}{8}\left(1 + \rho + \rho^2 + \rho^3\right). \tag{20}$$

The cost pass-through definition (20) sheds light on the importance of the persistence of the exporter's currency depreciation. A smaller ρ, i.e. a lower persistence of the cost increase that follows the exporter's currency depreciation reduces the pass-through (20). According to Taylor (2000), a temporary exchange rate depreciation corresponding to a low persistence ρ will not raise the price x_t substantially. The intuition behind the persistence of the exchange rate change is based on the belief of firms about future movements of the exchange rate (Krugman, 1986). If the exchange rate depreciation is believed to be temporary, firms will refrain from re-setting prices substantially, since the exchange rate is expected to return to the pre-depreciation level shortly. However, a more permanent depreciation reflected in a larger ρ will encourage the firm to adjust the price significantly, since the depreciation is expected to last in the long-run. Thus, the temporary nature of the exporter's currency depreciation mitigates the price increase.

1.3 General equilibrium models (Betts and Devereux, 1996)

Unlike partial equilibrium models of the PTM and ERPT, general equilibrium models have more than one optimizing agent. In addition to profit-maximizing firms, a general equilibrium model features utility-maximizing consumers. Consequently, while the exchange rate is considered to be exogenous within a partial equilibrium framework, a general equilibrium model determines the exchange rate endogenously by solving the agents' optimization problems.

This section outlines the seminal study of the incomplete ERPT in a general equilibrium context by Betts and Devereux (1996). Betts and Devereux (1996) build a two-country model of international price discrimination whereby a fraction s of firms set a separate price for the home and the foreign market. These firms are labelled "pricing-to-market" (PTM) firms. Since these firms set prices in the buyer's currency, they are also referred to in the literature as local-currency-pricing (LCP) firms. The remaining firms denoted by fraction $1-s$ represent non-PTM firms that apply the same price to both markets. This type of firm is commonly defined as producer-currency-pricing (PCP), since prices are set in the exporter's currency. By solving the optimization problems of consumers and firms, Betts and Devereux (1996) show that fraction s defining the share of price-discriminating firms governs the degree of the ERPT into the aggregate price level.

1.3.1 Consumers

The domestic consumers maximize the utility (U) function

$$U = \log C + \frac{\gamma}{1-\varepsilon}\left(\frac{M}{P}\right)^{1-\varepsilon} + \eta \log(1-h) \tag{21}$$

subject to their budget constraint

$$PC + M = wh + \pi + M_0 + TR, \tag{22}$$

where C denotes a basket of consumption goods

$$C = \left(\int_0^1 c(i)^{\frac{\rho-1}{\rho}} di\right)^{\frac{\rho}{\rho-1}} \quad , \tag{23}$$

where $c(i)$ defines the consumption of good i and ρ is price elasticity of the demand. M denotes nominal money balances, P defines the domestic consumer price index, h stands for total hours worked, w represents wage and M_o is the initial money holding. In addition, consumers receive profits π from owning domestic firms and government transfer payments, TR. Parameters γ and ε determine marginal utility of real money holdings. Parameter η governs marginal utility of leisure time, *(1-h)*.

The optimal level of good-specific consumption, $c(i)$, is found by minimizing the total consumption expenditure, $\int_0^1 v(i)c(i)di$, subject to the consumption basket definition (23), where $v(i)$ is the local currency price of good i. This minimization problem is described by the following Lagrangean:

$$L = \int_0^1 v(i)c(i)di + \varphi\left(C - \left[\int_0^1 c(i)^{\frac{\rho-1}{\rho}} di\right]^{\frac{\rho}{\rho-1}}\right). \tag{24}$$

Differentiating the Lagrangean (24) with respect to $c(i)$ yields the first order condition

$$\frac{\partial L}{\partial c(i)} = v(i) - \varphi\frac{\rho}{\rho-1}\left[\int_0^1 c(i)^{\frac{\rho-1}{\rho}} di\right]^{\frac{1}{\rho-1}} \frac{\rho-1}{\rho} c(i)^{-\frac{1}{\rho}} = 0\,. \tag{24a}$$

Raising both sides of the equation (25) to the power $(-\rho)$ and using the definition (23) gives

$$v(i)^{-\rho} = \varphi^{-\rho}C^{-1}c(i)\;. \tag{24b}$$

Solving equation (24b) for consumption $c(i)$ yields

$$c(i) = \left(\frac{v(i)}{\varphi}\right)^{-\rho} C\,. \tag{25}$$

Substituting the optimal level of consumption (25) into the consumption basket definition (23) implies that the Lagrange multiplier, φ , equals the domestic price index, $P = \left[\int_0^1 v(i)^{1-\rho} di\right]^{\frac{1}{1-\rho}}$:

$$\begin{gathered} C = \left(\int_0^1 \left[\left(\frac{v(i)}{\varphi}\right)^{-\rho} C\right]^{\frac{\rho-1}{\rho}} di\right)^{\frac{\rho}{\rho-1}} = C\left(\frac{1}{\varphi}\right)^{-\rho}\left[\int_0^1 v(i)^{-(\rho-1)} di\right]^{\frac{\rho}{\rho-1}} \Rightarrow \\ 1 = \left(\frac{1}{\varphi}\right)^{-\rho}\left[\int_0^1 v(i)^{1-\rho} di\right]^{\frac{\rho}{\rho-1}} \Rightarrow 1 = \frac{1}{\varphi}\left[\int_0^1 v(i)^{1-\rho} di\right]^{\frac{1}{1-\rho}} \Rightarrow \varphi = \left[\int_0^1 v(i)^{1-\rho} di\right]^{\frac{1}{1-\rho}}. \end{gathered} \tag{26}$$

Thus, the optimal level of consumption for good i is defined as

$$c(i) = \left(\frac{v(i)}{P}\right)^{-\rho} C\,. \tag{27}$$

The optimal good-specific level of consumption (27) represents the demand function for good *i,* which suggests that demand falls in the relative price of the good, $\left(\frac{v(i)}{P}\right)$.

In order to derive the ERPT, the optimal level of real money balances must be determined through the consumers' optimization problem described by the Lagrangean

$$L = \log C + \frac{\gamma}{1-\varepsilon}\left(\frac{M}{P}\right)^{1-\varepsilon} + \eta \log(1-h) + \vartheta(PC + M - wh - \pi - M_0 - TR), \tag{28}$$

where ϑ is the Lagrange multiplier. The first order conditions with respect to nominal money balances and consumption are given by

$$\frac{\partial L}{\partial M} = \frac{\gamma(1-\varepsilon)}{1-\varepsilon}\left(\frac{1}{P}\right)^{1-\varepsilon} M^{-\varepsilon} + \vartheta = 0, \tag{29}$$

$$\frac{\partial L}{\partial C} = \frac{1}{C} + \vartheta P = 0. \tag{30}$$

The first order condition (30) implies that the Lagrange multiplier is defined as $\vartheta = -\frac{1}{PC}$.

Substituting this definition into the first order condition (29) gives the optimal level of nominal money balances:

$$\frac{\gamma}{P}\left(\frac{M}{P}\right)^{-\varepsilon} = \frac{1}{PC} \Rightarrow \frac{M}{P} = \left(\frac{1}{C\gamma}\right)^{-\frac{1}{\varepsilon}} = (C\gamma)^{\frac{1}{\varepsilon}}. \tag{31}$$

The optimality condition (31) suggests that real money holdings increase in the consumption level.

Since foreign and domestic households by assumption have identical preferences and budget constraints, the optimal level of foreign nominal money balances is given by

$$\frac{M^*}{P^*} = (C^*\gamma)^{\frac{1}{\varepsilon}}, \tag{32}$$

where M^*, P^* and C^* denote foreign nominal money balances, consumer price index and consumption, respectively. Before we derive the exchange rate from the domestic and foreign real money holdings, let us review the firms' optimization problem.

1.3.2 Firms

Both PTM and non-PTM firms produce according to the linear technology

$$y_i = Ah_i, \tag{33}$$

where y_i denotes firm i's output and A represents a constant technology shock. Consequently, the average total cost of production equals

$$\frac{wh_i}{y_i} = \frac{wh_i}{Ah_i} = \frac{w}{A}. \tag{34}$$

Thus, the average total cost (34) is increasing in the wage rate and falling in the technology shock. Since the PTM and non-PTM firms' profit functions differ, we outline their profit maximization problems separately.

1.3.2.1 PTM firms' profit maximization problem

A domestic PTM firm charges price p_i from domestic consumers and price q_i from foreign buyers. Since the PTM firm faces the demand function specified in (25), it maximizes the following profit function

$$\pi_i = p_i \left(\frac{p_i}{P} \right)^{-\rho} C + eq_i \left(\frac{q_i}{P^*} \right)^{-\rho} C^* - \frac{w}{A} \left(\left(\frac{p_i}{P} \right)^{-\rho} C + \left(\frac{q_i}{P^*} \right)^{-\rho} C^* \right), \tag{35}$$

where e stands for the exchange rate, i.e. units of the national currency per unit of the foreign currency. The first order conditions with respect to p_i and q_i are

$$\frac{\partial \pi_i}{\partial p_i} = (1-\rho) p_i^{-\rho} \left(\frac{1}{P} \right)^{-\rho} C + \frac{w}{A} \rho (p_i)^{-\rho-1} \left(\frac{1}{P} \right)^{-\rho} C = 0. \tag{36}$$

$$\frac{\partial \pi_i}{\partial q_i} = e(1-\rho) q_i^{-\rho} \left(\frac{1}{P^*} \right)^{-\rho} C^* + \frac{w}{A} \rho (q_i)^{-\rho-1} \left(\frac{1}{P^*} \right)^{-\rho} C^* = 0. \tag{37}$$

Solving the first order conditions (36) and (37) for prices yields the following optimal pricing rules

$$p_i = \frac{\rho}{\rho - 1} \frac{w}{A}, \tag{38}$$

$$q_i = \frac{1}{e} \frac{\rho}{\rho - 1} \frac{w}{A}. \tag{39}$$

Thus, optimal prices expressed in the firm's currency, i.e. p_i and eq_i, represent a fixed mark-up over the cost, $\frac{w}{A}$. This mark-up is falling in the price elasticity of demand, ρ, because a more elastic demand implies a weaker market power of the firm. Moreover, it follows from definitions (38) and (39) that the LOP holds, i.e. $p_i = eq_i$.

A foreign PTM firm maximizes an analogous profit function to (35) by charging price p_i^* from domestic customers and q_i^* from foreign customers:

$$\pi_i^* = \frac{1}{e} p_i^* \left(\frac{p_i^*}{P}\right)^{-\rho} C + q_i^* \left(\frac{q_i^*}{P^*}\right)^{-\rho} C^* - \frac{w^*}{A}\left(\left(\frac{p_i^*}{P}\right)^{-\rho} C + \left(\frac{q_i^*}{P^*}\right)^{-\rho} C^*\right). \tag{40}$$

The first order conditions with respect to prices p_i^* and q_i^* are given by

$$\frac{\partial \pi_i^*}{\partial p_i^*} = \frac{1}{e}(1-\rho) p_i^{*-\rho} \left(\frac{1}{P}\right)^{-\rho} C + \frac{w^*}{A}\rho\left(p_i^*\right)^{-\rho-1}\left(\frac{1}{P}\right)^{-\rho} C = 0, \tag{41}$$

$$\frac{\partial \pi_i^*}{\partial q_i^*} = (1-\rho) q_i^{*-\rho} \left(\frac{1}{P^*}\right)^{-\rho} C^* + \frac{w^*}{A}\rho\left(q_i^*\right)^{-\rho-1}\left(\frac{1}{P^*}\right)^{-\rho} C^* = 0. \tag{42}$$

Solving the conditions (41) and (42) for prices p_i^* and q_i^* yields the optimal pricing rule

$$q_i^* = \frac{p_i^*}{e} = \frac{\rho}{\rho-1}\frac{w^*}{A}. \tag{43}$$

Consequently, the LOP holds for the foreign PTM good too, i.e. $p_i^* = eq_i^*$. Therefore, PPP holds in a flexible price environment, i.e. $eP^* = P$, because the LOP holds for both domestic and foreign PTM goods. First, the domestic PTM good's price is identical across the two markets when common currency is used, i.e. $p_i = eq_i$. Second, the foreign PTM good's price is the same in the two markets when expressed in the same currency, $p_i^* = eq_i^*$.

Using the PPP definition, we can find the exchange rate from combining the domestic and foreign real money holdings (31) and (32):

$$e = \frac{P}{P^*} = \frac{M\left(C^*\gamma\right)^{\frac{1}{\varepsilon}}}{M^*\left(C\gamma\right)^{\frac{1}{\varepsilon}}} = \frac{M}{M^*}\left(\frac{C^*}{C}\right)^{\frac{1}{\varepsilon}}. \tag{44}$$

The exchange rate *e* thus depends positively on the ratio between the domestic and foreign nominal money holdings, but falls in the ratio of the domestic consumption to foreign consumption.

1.3.2.2 Non-PTM firms' profit maximization problem

A domestic non-PTM firm charges a unified price p_i in both domestic and foreign markets. Consequently, the non-PTM firm chooses price p_i to maximize its profits

$$\pi_i = \left[p_i - \frac{w}{A}\right]\left[\left(\frac{p_i}{P}\right)^{-\rho} C + \left(\frac{p_i}{eP^*}\right)^{-\rho} C^*\right] \tag{45}$$

Using the PPP identity, $eP^* = P$, the profit function (45) can be re-written as

$$\pi_i = \left[p_i - \frac{w}{A}\right]\left[\left(\frac{p_i}{P}\right)^{-\rho}\left(C + C^*\right)\right]. \tag{46}$$

The first order condition with respect to price p_i is represented by

$$\frac{\partial \pi_i}{\partial p_i} = (1-\rho)p_i^{-\rho}\left(\frac{1}{P}\right)^{-\rho}\left(C + C^*\right) - \frac{w}{A}(-\rho)p_i^{-\rho-1}\left(\frac{1}{P}\right)^{-\rho}\left(C + C^*\right) = 0. \tag{47}$$

Solving the equation (47) for p_i yields the optimal price

$$p_i = \frac{\rho}{\rho - 1}\frac{w}{A}. \tag{48}$$

Therefore, PTM and non-PTM firms (see 38) charge the same price mark-up over the marginal cost in the domestic market.

A foreign non-PTM firm charges a unified price q_i^* from domestic and foreign customers and maximizes the profit function

$$\pi_i^* = \left[q_i^* - \frac{w^*}{A}\right]\left[\left(\frac{q_i^*}{P^*}\right)^{-\rho} C^* + \left(\frac{eq_i^*}{P}\right)^{-\rho} C\right] = \left[q_i^* - \frac{w^*}{A}\right]\left[\left(\frac{q_i^*}{P^*}\right)^{-\rho}\left(C^* + C\right)\right], \tag{49}$$

where the PPP definition, $eP^* = P$, has been used to substitute for the exchange rate. The first order condition with respect to price q_i^* is

$$\frac{\partial \pi_i}{\partial p_i} = (1-\rho)q_i^{*-\rho}\left(\frac{1}{P^*}\right)^{-\rho}\left(C + C^*\right) - \frac{w^*}{A}(-\rho)q_i^{*-\rho-1}\left(\frac{1}{P^*}\right)^{-\rho}\left(C + C^*\right) = 0. \tag{50}$$

Solving the condition (50) for q_i^* gives the optimal export price

$$q_i^* = \frac{\rho}{\rho - 1}\frac{w^*}{A}. \tag{51}$$

Thus, the foreign non-PTM firm sets price as a fixed mark-up over its cost, where the mark-up is identical to that charged by the domestic non-PTM producer. The optimal prices of PTM and non-PTM goods enable us to compute the ERPT into the domestic price level.

1.3.3 ERPT into the domestic price level

In order to derive the ERPT into the domestic price level, we need to transform the following price index:

$$P = \left[\int_0^n p_i^{1-\rho} di + \int_n^{n+(1-n)s} p_i^{*1-\rho} di + \int_{n+(1-n)s}^1 \left(eq_i^*\right)^{1-\rho} di \right]^{\frac{1}{1-\rho}}. \tag{52}$$

Betts and Devereux (1996) use linear approximation around the zero shock equilibrium, where n and $1-n$ denote the shares of domestic and foreign firms, respectively. Linear approximation implies that each variable X must be expressed as a percentage deviation from its steady-state value, $\overline{X}$, i.e. $\hat{X} = \frac{\left(X - \overline{X}\right)}{\overline{X}}$. Thus, the price index (52) may be approximated as

$$\hat{P} = n\hat{p}_i + (1-n)s\hat{p}_i^* + (1-s)(1-n)\hat{e} + (1-s)(1-n)\hat{q}_i^*. \tag{53}$$

Assuming a sticky price environment for computational simplicity gives $\hat{p}_i = 0$, $\hat{p}_i^* = 0$ and $\hat{q}_i^* = 0$. Thus, the response of the aggregate price index to the exchange rate equals

$$\frac{\hat{P}}{\hat{e}} = (1-s)(1-n). \tag{53a}$$

The ERPT (53a) only depends on the share of foreign non-PTM firms, which is denoted by $(1-n)(1-s)$. An increase in the fraction of foreign non-PTM firms leads to a larger rise in the price index (53) following the depreciation of the domestic currency. Intuitively, since import prices of the foreign non-PTM goods fluctuate with the exchange rate, the ERPT increases in the share of these goods in the consumption basket.

The seminal framework of Betts and Devereux (1996) highlighted the importance of currency invoicing for the degree of ERPT by distinguishing between the PTM firms which set prices in the importer's currency and the non-PTM firms that invoice prices in the exporter's currency. However, the fractions of the PTM and non-PTM firms are exogenous constants. Bacchetta and Wincoop (2002) overcome the exogenous nature of the firm type by endogenously determining the optimal pricing strategy of the firm. They show that a representative firm sets prices in the currency that generates the highest expected utility of profits. Engel (2000) further accentuates the importance of the invoicing currency by showing that the choice of the optimal exchange rate regime depends on the share of the foreign non-PTM firms.

1.4 Econometric tests of PTM and ERPT

The majority of econometric tests of the ERPT proposed in the literature consist of regressing a good's import price on the exchange rate and a selection of independent variables contributing to the import price determination (Parsley, 1993). The exchange rate coefficient reflects the degree of the ERPT, since it shows the response of the import price to exchange rate movements. The size of the exchange rate coefficient also reflects the extent of PTM. Specifically, if exporters stabilize import prices against currency fluctuations, the response of the import price to the exchange rate will be reduced. Thus, both ERPT and PTM can be inferred from a regression of the import price on the exchange rate.

Regressions of a good's export price on the exchange rate and a set of independent variables are also widely used to analyze the degree of ERPT and PTM (Feenstra et al., 1996). A statistically significant exchange rate coefficient that shows a decrease in the export price following the exporter's currency appreciation serves as evidence of the PTM by the PCP firms. Specifically, a negative exchange rate coefficient implies that a fall in the export price stabilizes the import price by preventing it from increasing by the full amount of the appreciation.

This section surveys prevailing econometric methodologies for detecting the PTM and incomplete ERPT in traded goods prices.

1.4.1 Fixed effects panel data regression (Knetter, 1989)

Knetter (1989) pioneered the method for testing the PTM and incomplete ERPT using time-series-cross-section data on US and German exports. His framework allows us to distinguish among three cases: (1) perfect competition with no price discrimination across importers; (2) imperfect competition with price discrimination and constant elasticity of demand; (3) imperfect competition with price discrimination and variable demand elasticity. He argues that the exchange rate has a significant impact on the export price only in the third case.

Knetter (1989) considers a firm selling to N export destinations denoted by i and proposes the following fixed effects regression:

$$\ln p_{it} = \theta_t + \lambda_i + \beta_i \ln s_{it} + u_{it} \ , \tag{54}$$

where p_{it} denotes price in the exporter's currency, θ_t defines a time effect, λ_i stands for a country effect, s_{it} is the exchange rate measured in units of the importer's currency per unit of the exporter's currency and u_{it} is an error term. In a perfectly competitive economy, firm sets a single price for all export destinations since the export price should equal the marginal cost of production, i.e. $\lambda_i = 0$. Moreover, since the only determinant of the export price is the marginal cost, which does not depend on currency movements by assumption, the exchange rate coefficient is insignificant under the perfect competition hypothesis, i.e. $\beta_i = 0$. Even if the marginal cost depended on the exchange rate, a time effect, θ_t, would absorb marginal cost swings generated by currency movements, because these cost effects are common across destinations.

In an imperfectly competitive world, export price represents a mark-up over the marginal cost (see 6) whereby the mark-up depends on the price elasticity of demand. Imperfectly competitive firms implement price-discrimination across destinations by generating international price differentials. The extent of this price-discrimination depends on the elasticity of the importer's demand.

If the demand elasticity is constant, the price mark-up over the marginal cost (6) is constant. Therefore, although mark-ups vary across destinations, they remain fixed and irresponsive to exchange rate movements. Thus, the null hypothesis of imperfect competition with constant demand elasticity suggests that $\lambda_i \neq 0$ and $\beta_i = 0$.

However, if the price elasticity of demand is not constant, the destination-specific mark-ups will respond to exchange rate movements. Specifically, an increase in s_{it} reflecting a depreciation of the importer's currency raises the import price, which affects the elasticity of the importer's demand. If the demand elasticity with respect to price increases as import price rises, the optimal mark-up (6) falls. Similarly, a fall in the demand elasticity following the import price rise generates a rise of the mark-up. Thus, the exchange rate coefficient, $\beta_i \neq 0$, reflects the adjustment of the destination-specific mark-up to currency movements, whereby the mark-up responds to fluctuations in the demand elasticity.

Therefore, the presence of the PTM is reflected in the statistical significance of the coefficients λ_i and β_i, since they show the degree of international price discrimination generated by mark-up differences across destinations. The expected sign of coefficient β_i is negative with PTM, since it would be reasonable for firms to protect their market share by a downward mark-up adjustment in order to limit the import price increase following the importer's currency depreciation. However, Knetter (1989) also provides evidence of the increase in the export price despite the importer's currency depreciation. Thus, instead of stabilizing the import price, in certain cases US exporters amplify the effect of the depreciation.

As far as the ERPT is concerned, its dynamics can be predicted from the size of the exchange rate coefficient. A larger absolute magnitude of the negative coefficient β_i implies a lower ERPT, since a downward export price adjustment prevents the import price from increasing in proportion to the exchange rate movement.

The innovation of Knetter (1989) lies in his attempt to avoid a direct measurement of the marginal cost and mark-up with accounting data, which is susceptible to measurement errors. Instead of using highly aggregated data, he designs a fixed effects framework to infer mark-up behaviour from the response of the export price to the exchange rate and country effects. Knetter's seminal study served as basis for subsequent empirical tests of PTM and ERPT.

1.4.2 Three-stage least squares regression (Aw, 1993)

As Knetter (1989), Aw (1993) focuses her attention on the mark-up behaviour, but expands the scope of analysis by attempting to estimate the actual size of the mark-ups charged by Taiwanese footwear exporters in selected destination markets. The mark-up of price (P_t) over marginal cost (MC_t) is modelled as a function of the demand elasticity, η, and the competitiveness of Taiwanese footwear producers in the importer's market, λ:

$$P_t = \frac{\eta}{\eta - \lambda} MC_t = \frac{1}{1 - \lambda / \eta} MC_t . \tag{55}$$

The mark-up (55) increases in firm's competitiveness and falls in the demand elasticity. In perfect competition, individual firms have no competitive advantage, i.e. $\lambda = 0$, and export price equals marginal cost. When parameter λ becomes positive, i.e. exporter receives market power, export price exceeds marginal cost. The deviation of the export price from the marginal cost is thus governed by the competitiveness parameter, λ. Aw (1993) computes the mark-up (55) using estimated parameters from the inverse demand and generalized supply models.

For example, consider Taiwanese footwear exports to Saudi Arabia. The demand for Taiwanese footwear in Saudi Arabia can be estimated as

$$P_t = \alpha_0 + \alpha_1 Q_t e_t + \alpha_2 GDP_t e_t + \alpha_3 S_t e_t + \alpha_4 S_t Q_t e_t + \varepsilon_t, \tag{56}$$

where P_t denotes export price, Q_t defines volume of exports, e_t is exchange rate in Taiwan dollars per Saudi riyal, S_t stands for price of substitute and ε_t is an error term. The supply of Taiwanese footwear in Saudi Arabia can be described as

$$P_t = \beta_1 + \beta_2 Y_t + \beta_3 PK_t + \beta_4 PL_t + \beta_5 PM_t - \lambda(\alpha_1 + \alpha_4 S_t) Q_t e_t + \varpi_t, \tag{57}$$

where Y_t represents the total output of footwear and λ is an index measuring the competitiveness of Taiwanese producers in the Saudi market. PK_t, PL_t and PM_t denote respectively prices of capital, labour and materials used by Taiwanese producers. ϖ_t refers to a disturbance term. Constructing the supply and demand relationships for four export destinations yields a system of 8 equations estimated with three-stage least squares.

Estimated parameters from regressions (56) and (57) are used to construct the Lerner index measuring the mark-up of price over the marginal cost:

$$L = \frac{\lambda}{\eta}, \tag{58}$$

where λ is the estimated competitiveness parameter from (57) and the elasticity η is computed from coefficients in regression (56) as

$$\eta = \frac{\overline{P} / \overline{Q}}{\alpha_1 + \alpha_4 \overline{S}}. \tag{59}$$

A bar over a variable in equation (59) denotes average value over the sample period. Lerner index governs the extent of the mark-up over the marginal cost. Under perfect competition, L is zero because firms have no competitive advantage (i.e. λ is zero) and elasticity η equals infinity as all goods in the industry become perfect substitutes for each other. Consequently, export price (55) equals marginal cost and there is no mark-up over the marginal cost. Under imperfect competition, $L > 0$ because the competitiveness measure, λ , is positive and industry goods are imperfect substitutes for each other, i.e. $\eta < \infty$. Therefore, a positive mark-up of price over the marginal cost is charged. An increase in the Lerner index (58) implies an increase in the mark-up, $\frac{1}{1-\lambda/\eta}$. Thus, Lerner index represents a measure of the exporter's market power.

The empirical test of PTM amounts to determining the statistical significance of the Lerner index (58). If this index is significantly different from zero and varies across export destinations, the exporter is said to price-discriminate among importers by setting distinct mark-ups. Using standard errors evaluated at the sample mean, Aw (1993) finds that only the Lerner index corresponding to Taiwanese exports to Germany is significantly different from zero.

The framework of Aw (1993) also allows drawing implications on the degree of ERPT into local currency prices of imported Taiwanese footwear. For cases exhibiting a zero competitiveness index, λ , the ERPT is likely to be complete, since exporters do not have the market power to absorb currency changes into the export price. This is obvious from the zero response of the export price (57) to exchange rate changes:

$$\frac{\partial P_t}{\partial e_t} = -\lambda(\alpha_1 + \alpha_4 S_t)Q_t. \tag{60}$$

However, a non-zero competitiveness index, λ , in the derivative (60) implies that the import price will fail to move one-to-one with the exchange rate, since the export price will be adjusted to the exchange rate.

These predictions on the degree of the ERPT rest on the assumption that prices are fixed in the exporter's currency. Since the import price equals $\frac{P_t}{e_t}$, knowing the response of the export price, P_t, to the exchange rate is sufficient for finding the degree of the ERPT into the import price. However, prices may also be invoiced in the importer's currency. In order to analyze the ERPT with local currency pricing, instead of regressing the export price, we must regress the import price on the exchange rate and cost terms.

1.4.3 Error correction methodology (Frankel et al., 2012)

Unlike Aw (1993) who predicts the degree of the ERPT into the import price from the response of the export price to the exchange rate, Frankel et al. (2012) directly estimate the ERPT into import prices using the following error correction equation in first-differences:

$$\Delta p_t^{imp} = \beta_1 \Delta s_t + \beta_2 \Delta p_t^{\exp} + \sum_i \lambda_i \Delta s_t X_i + \gamma ECM_{t-1} + \sum_i \alpha_i ECM_{t-1} X_i + D_k^c + D_j^p + \varepsilon_t ,(61)$$

where p_t^{imp} denotes log-transformed import price, s_t defines log-transformed bilateral exchange rate measured in units of importer's currency per unit of exporter's currency, $p_t^{\exp}$ stands for the good's log-transformed price in the exporting country. $ECM_{t-1} = p_{t-1}^{imp} - s_{t-1} - p_{t-1}^{\exp}$ is error correction term measuring the past deviation from absolute price parity known as the LOP. D_k^c and D_j^p refer to country and product dummies, respectively, and ε_t is regression error term. The dummies are included to accommodate omitted variables measuring factors that are specific to country or product. Finally, X_i is a regressor matrix containing 9 additional independent variables: X_1 - time trend, X_2 - difference between the log of importing country's per capita GDP and the log of exporting country's per capita GDP, X_3 - log-transformed tariff in importing country, X_4 - log-transformed distance between importer and exporter, X_5 - difference between the log of importing country's GDP and the log of exporting country's GDP, X_6 - log of real wage in importing country, X_7 - log of inflation in importing country, X_8 - standard deviation of previous log changes in s_t, X_9 - dummy variable for cases when US is importer.

First, Frankel et al. (2012) consider an empty regressor matrix, X_i. The specification (61) allows us to distinguish two exchange rate effects – contemporaneous and past. The ERPT of contemporaneous currency movements is defined by coefficient β_1 showing the response of the log-differenced import price to the current log-differenced exchange rate. The effect of a past log-transformed exchange rate is defined by $(-\gamma)$ where γ represents the speed of long-run reversion to the LOP, $p_t^{imp} = s_t + p_t^{\exp}$.

Successive addition of each regressor from the matrix X_i to the regression (61) allows us to examine the determinants of the ERPT. For example, consider an interaction of X_5 and Δs_t.

The contemporaneous ERPT is given by $(\beta_1 + \lambda_5 X_5)$ where the sign of the parameter λ_5 shows the effect of the GDP differential between importer and exporter on the ERPT. Suppose that X_5 is negative, i.e. importing economy is smaller than exporting economy. A positive λ_5 indicates that a negative GDP differential contributes to reducing the degree of ERPT into import prices. A negative λ_5 implies that the ERPT is relatively large for importers whose GDP is lower than the exporter's GDP. For a positive X_5, a positive λ_5 would indicate an increase in ERPT and a negative λ_5 would imply a reduction of ERPT, compared to the baseline ERPT, β_1. The empirical results of Frankel et al. (2012) suggest that a lower ERPT is observed in rich countries, compared to poor countries.

While the statistical significance of the US dummy, X_9, is interpreted by Frankel et al. (2012) as evidence of PTM for exports to the US, the specification (61) does not allow us to measure the extent of mark-up discrimination due to the absence of a measure for exporter's costs. Therefore, it has become common in recent studies on international price discrimination to incorporate both marginal cost and exchange rate into a price regression, in addition to controlling for other important determinants of ERPT.

1.5 Non-linear models of PTM and ERPT

The benchmark tests of PTM and ERPT assume that the relationship between prices and exchange rates is stable over time. As time-series econometricians developed methods for testing the stability in regression parameters, an interest for non-linearities in the PTM and ERPT emerged.

Nogueira and Leon-Ledesma (2011) argue that the ERPT is higher during periods of macroeconomic instability in the importing country, since firms are concerned with a likely default of the importer. Therefore, firms do not limit substantially the ERPT into import prices, as investing into the loyalty of the market that is about to default does not yield benefits. In contrast, a favourable macroeconomic environment in the importing country is associated with a lower ERPT. Since firms expect a long-term trade with the stable partner, they reduce the ERPT by mark-up adjustment in order to retain customer loyalty. Thus, the ERPT depends non-linearly on the macroeconomic environment of the importing country, whereby some threshold value of the market stability measure allows us to discriminate between favourable and unfavourable conditions.

Nogueira and Leon-Ledesma (2011) test their hypothesis of non-linear ERPT by applying a logistic smooth transition model to Mexico's data. Model parameters are estimated by nonlinear least squares in order to determine how the response of the CPI (Consumer Price Index) change to the exchange rate change differs across the two regimes. The first regime representing an unstable macroeconomic environment is characterized by high (above-threshold) values of EMBI+ spreads and real interest rate differentials with respect to the US. The second regime approximates macroeconomic stability and corresponds to low (below-threshold) values of the aforementioned two transition variables. The estimation results confirm the major predictions of the model. Specifically, Nogueira and Leon-Ledesma (2011) show the existence of a positive non-linear relationship between the Mexican ERPT and the two proposed measures of macroeconomic instability.

While the theoretic model of Nogueira and Leon-Ledesma (2011) a priori assumes a non-linearity in the response of the ERPT to macroeconomic conditions, Gervais and Larue (2009) justify such non-linearity by solving the exporter's profit-maximization problem in the presence of menu costs of price adjustment. Gervais and Larue (2009) argue that the menu costs of changing prices (e.g. translation services and legal advice) lead to non-linear rigidities in the response of prices to exchange rate movements. These fixed menu costs generate boundaries (thresholds) which divide the range of exchange rate fluctuations into two groups - small exchange rate changes and large exchange rate movements. Specifically, if the appreciation of the importer's currency was significantly large (above-threshold), it would be profitable to raise the export price, because the menu cost is not large enough to offset the revenue gain from price adjustment. However, if the extent of appreciation was not big enough to exceed the threshold, it would not be reasonable to increase the export price, because the profit associated with the new price would be lower than the profit generated by the old price due to adjustment costs.

Gervais and Larue (2009) test the non-linearity of the export price response to exchange rate movements using a two-regime threshold regression. Observations are sorted into the first regime if the corresponding absolute value of the exchange rate change, $|\Delta e_t|$, is less than or equal to the threshold, where an increase in e_t denotes the depreciation of the importer's currency. Consequently, the excess of $|\Delta e_t|$ over the threshold defines the second regime. Applying sequential least squares to data on Canadian pork exports to the US and Japan confirms the theoretic predictions of Gervais and Larue (2009). They found that the likelihood ratio statistic rejects the null hypothesis of no threshold in 75% of the cases considered. Thus, the extent of the ERPT into the export price is regime-dependent. The negative sign of the pass-through coefficient in both regimes suggests that the export price falls with the depreciation of the importer's currency. This finding is consistent with the benchmark theory of international price discrimination revisited in Nogueira and Leon-Ledesma (2011) whose model suggests a downward adjustment in the mark-up of price over the marginal cost during periods of the importer's currency depreciation. However, the estimation results of Gervais and Larue (2009) do not enable them to confirm the hypothesis that the export price is insensitive to exchange rate movements in the area between the two thresholds. On the contrary, the absolute value of the ERPT into the export price is larger in the first regime, compared to the second regime, in all equations.

Correa and Minella (2006) explore the ERPT non-linearity caused by business cycle effects using a threshold autoregressive model. Their theoretic hypothesis is similar to the macroeconomic stability proposition by Nogueira and Leon-Ledesma (2011), while their econometric methodology belongs to the same category of tests as that adopted in Gervais and Larue (2009). Correa and Minella (2006) explore three possible factors causing non-linearities in the ERPT – economic growth, exchange rate volatility and the direction of the nominal exchange rate change (appreciation versus depreciation). Thus, their first hypothesis of interest is whether the sensitivity of prices to exchange rates differs across economic booms and slowdowns. Their second research question explores how the extent of ERPT varies depending on the size of the exchange rate volatility. Their third objective is to determine whether the ERPT behaves differently across appreciations and depreciations of the importer's currency.

Adopting Brazilian data on the consumer price inflation, average nominal exchange rates (in units of national currency per US dollar) and output, they estimate the ERPT using three TAR specifications that differ in the threshold variable used to split data into two regimes. The first regime encompasses all observations for which the threshold variable does not surpass the threshold, while the second regime is distinguished by the excess of the threshold variable over its threshold. Correa and Minella (2006) use output gap, exchange rate volatility and nominal exchange rate change as threshold variable and examine regression parameter switching across the two regimes.

The estimation results of Correa and Minella (2006) confirm that the output gap generates non-linearities in the response of the domestic inflation to nominal exchange rates. Specifically, the ERPT is zero in the first regime but significantly positive when the output gap surpasses the threshold. Similarly, their findings suggest an asymmetric effect of exchange rate changes on inflation. In particular, inflation is irresponsive to small depreciations but reacts positively to large depreciations of the domestic currency. Correa and Minella (2006) explain that firms offset the effect of small depreciations on the import price by mark-up adjustment in order to retain their market shares. However, when the depreciation is large, the exporter may refrain from limiting the ERPT because mark-up adjustment causes substantial reductions in profit margins. Finally, prices were found to be irresponsive to exchange rates in periods of low exchange rate volatility. However, during high exchange rate instability the observed ERPT is positive. This finding contradicts the ERPT dynamics expected by Correa and Minella (2006). They suggest that exchange rate instability should lead to a low pass-through because, in an unstable environment, firms perceive exchange rate changes as transitory. Therefore, exporters are reluctant to pass-through short-term currency changes into the local currency price because of costs associated with price adjustment. Nevertheless, Correa and Minella (2006) provide robust evidence of non-linearities in Brazilian ERPT by exploring various sources of such non-linearities.

1.6 Novelty of this study

This thesis contributes to the emerging stream of literature on non-linearities in the ERPT and PTM by proposing three innovative approaches to modelling possible inconstancy in the response of traded goods prices to exchange rate movements.

The first model suggests that consumers’ costs of switching between varities generate thresholds in the ERPT. To the best of our knowledge, while exporter’s costs of price adjustment have been frequently used to justify non-linear ERPT (Gervais and Larue, 2009; Correa and Minella, 2006), switching costs have not been suggested as potential cause of ERPT thresholds. We argue that the ERPT is high when switching costs are relatively high, because the exporter believes that consumer is unlikely to switch to a different supplier. Therefore, the exporter does not find it necessary to limit the ERPT, as his market share is unlikely to shrink. However, when the switching cost becomes relatively low, the exporter limits the import price increase following the importer's currency depreciation because he fears that consumers may switch to a substitute. Thus, switching costs generate a two-regime ERPT. High pass-through regime is consistent with relatively high values of the switching cost, while relatively small switching costs lead to low ERPT.

Our second model is innovative from both theoretic and empirical perspectives. First, we build a partial equilibrium model of export pricing where the volatility of the import price generates an inconstant degree of the PTM. Although the importance of the volatility of the import price for export pricing has been proposed in Krugman (1986), to the best of our knowledge, the link between price volatility and PTM has not been built into a model. We propose a new form of consumption function and solve firms' profit maximization problem to show that the response of the export price to currency movements is unstable because of the import price volatility.

Second, we develop a new empirical method for testing the significance of the PTM effect. Specifically, we examine the predictive content of the exchange rate for export prices using out-of-sample forecasting tests which are robust to parameter evolution – rolling, recursive and random walk coefficient time varying parameter regressions. The null hypothesis of no PTM is rejected if the ENC-NEW forecast encompassing test by Clark and McCracken (2001) suggests that the inclusion of the exchange rate in the model significantly reduces the average forecasting error of the model. The advantage of the out-of-sample forecasting approach is that it enables us to test the null hypothesis of no PTM in the situation when parameter stability is under question. Note that fixed parameter regressions are only suitable to test the PTM when the parameter constancy is ensured. To the best of our knowledge, forecast encompassing tests have not been used previously as test of PTM.

The novelty of our third model lies in its attempt to justify inconstant PTM and ERPT within a general equilibrium framework. Specifically, the seminal general equilibrium model by Betts and Devereux (1996) generates a constant response of trade goods prices to the exchange rate, because the mark-up of price over the marginal cost is constant. In contrast, we adopt a time varying mark-up by borrowing the concept of subsistence consumption from Ravn et al. (2006). Due to the existence of subsistence absorption, the mark-up of price over the marginal cost is countercyclical and falls in the aggregate demand. Therefore, fluctuations in the aggregate demand following currency movements generate variations in the mark-up. By solving the optimization problems of utility maximizing households and profit maximizing firms, we show that the countercyclical nature of the mark-up leads to instability in the degree of the PTM and ERPT irrespective of the currency in which prices are set (local currency or producer currency).

Thus, this thesis attempts to contribute to the literature on non-linear ERPT and PTM in theoretical (both partial equilibrium and general equilibrium) and empirical aspects. First, we develop a new partial equilibrium model of non-linear ERPT with switching costs. Second, we offer a series of new tests of PTM, namely out-of-sample forecasting tests with time varying parameters. Finally, we build a dynamic stochastic general equilibrium model of inconstant PTM and ERPT with subsistence absorption.

2. Chapter 2: Does Competition Lead to Structural Breaks in the ERPT?

2.1 Introduction

This chapter explores potential non-linearities in the ERPT using a threshold regression framework developed in Hansen (1999). In addition, it offers a new model of structural breaks in the ERPT. In this set-up, the sensitivity of the import price to exchange rate movements depends non-linearly on the difference between the consumer's cost of switching to a substitute good and the consumer's gain from switching. This switching gain is defined as the excess of a variety's import price over the import price of a substitute variety. Thus, the switching gain represents the amount that consumer saves by changing to a cheaper supplier.

Specifically, when the switching gain exceeds the switching cost, consumers receive an incentive to switch to a substitute variety. Consequently, a high likelihood of losing customers encourages the existing supplier to limit an import price increase resulting from the importer's currency depreciation. As a result, the ERPT into import prices is weakened by a downward adjustment of the export price in order to retain customers. In contrast, when the switching gain fails to exceed the switching cost, customers are likely to continue buying from the existing supplier due to a relatively large cost of switching to a substitute. Consequently, a larger ERPT is allowed by exporters, since it is not imperative to limit import price rise when the danger of losing customers is low.

Specifically, consider a two-regime process for the price differential between the imported variety and its substitute. In the first regime, the imported good is significantly expensive compared to a substitute variety produced in a different exporting country. The resulting price differential is large enough to exceed the switching cost. Consequently, the importer is likely to switch to a firm producing a cheaper brand in order to save on purchases. As a result, the current supplier is expected to offset the import price increase following the importer's currency depreciation in order to prevent a loss of market share. In the second regime, the imported good's price may also be higher than a substitute variety's price, but this price differential is insufficient to exceed the switching cost. Since in the presence of significant switching costs consumers are unable to switch to a cheaper brand, the exporter is unlikely to protect the import price from an increase. Thus, the extent of ERPT differs across the two regimes.

This study tests for structural breaks in the ERPT into the US import prices of selected European traded commodities. We apply the threshold regression framework derived in Hansen (1999). Compared to other frameworks for inference in the presence of structural breaks, the advantage of this technique is two-fold. First, this framework was developed for cases when the value of the threshold parameter is unknown. Specifically, Hansen (1999) avoids an ad hoc choice of the threshold value by estimating threshold effects using least squares. Second, this methodology enables us to overcome the difficulties caused by a non-standard asymptotic distribution of threshold estimates. Namely, it allows us to test the significance of threshold estimates using the asymptotic distribution of the likelihood ratio test simulated with bootstrap replications.

This paper is structured as follows. Section 2.2 develops a partial equilibrium set-up justifying a two-regime non-linear ERPT using the cost of switching between different varieties of the same product. Section 2.3 describes the threshold regression and bootstrap replication frameworks (see Hansen, 1999) used to estimate the significance of non-linear effects in the import price model. Section 2.4 summarizes the data sources used and Section 2.5 discusses the main empirical findings. Section 2.6 conducts robustness checks against omitted variable bias and serial correlation among regressors. Section 2.7 summarizes the main theoretical and empirical findings of this chapter.

2.2 Model

This section offers a new model of non-linear ERPT featuring two monopolistically competitive foreign firms that produce different varieties of the same good. An exporter based in country i faces the competition from an exporting firm producing in country j, $i \neq j$. The exporter from country i optimally chooses its export price to maximize current profits subject to the importing country's demand. Customers in the importing country have the opportunity to switch from the variety produced in country i to the variety bought from country j, but face the cost of switching between different brands. Klemperer (1987) identifies three types of costs faced by consumers who switch between different brands of the same good: transaction costs, learning costs and contractual costs. For example, transaction costs are incurred by customers during the process of closing an account with their current service provider and opening an account with a new supplier. Examples of learning costs include a cost associated with learning to use new software. Finally, contractual costs represent brand loyalty programmes (e.g. "frequent flyer") imposed by firms to reward their existing customers.

First, this section builds a novel consumption function featuring a non-linear price elasticity of demand. Second, it solves the firm's optimization problem and develops an optimal price-setting mechanism. This section concludes by showing that the non-linear demand elasticity causes non-linearities in the ERPT behaviour by affecting the exporter's mark-up over the marginal cost.

2.2.1 Consumers

This study proposes a novel demand function in order to model structural breaks in the relationship between import price and exchange rate. c_{it}^{m} defines the importer's demand for the variety produced in country i:

$$c_{it}^{m} = \left(\frac{e_{it} p_{it}}{P_t^m}\right)^{-\eta-\lambda^i(d_{it})} x_t \, , \tag{1}$$

where e_{it} refers to the nominal exchange rate representing the units of the importer's currency per unit of the currency adopted by country i. An increase in e_{it} reflects the importer's currency depreciation. p_{it} defines the brand's price in the exporter's currency. Thus, the demand for good i, c_{it}^{m}, is a function of the variety's import price, $e_{it} p_{it}$, relative to P_t^m denoting the consumer price index in the importer's country:

$$P_t^m = \left[(e_{it} p_{it})^{\psi} + (e_{jt} p_{jt})^{\psi}\right]^{\frac{1}{\psi}} , \tag{2}$$

where $\psi = \left(1-\eta-\lambda^i(d_{it})\right)\left(1-\eta-\lambda^j(d_{jt})\right)$. p_{it} and p_{jt} refer to the export prices charged by the firms producing varieties i and j, respectively. Export prices are set in the producer's currency. e_{it} and e_{jt} represent exchange rates measured in units of the importer's currency per unit of the currency adopted by countries i and j, respectively. Thus, the import prices of brands i and j equal $e_{it}p_{it}$ and $e_{jt}p_{jt}$, respectively. In addition, the importer's demand, c_{it}^{m}, is a function of the composite consumption good, x_t, modelled as

$$x_t = \left[\left(c_{it}^{m}\right)^{\omega} + \left(c_{jt}^{m}\right)^{\omega}\right]^{\frac{1}{\varpi}}, \tag{3}$$

where $\omega = \dfrac{\left(\eta + \lambda^{i}\left(d_{it}\right) - 1\right)\left(\eta + \lambda^{j}\left(d_{jt}\right) - 1\right)}{\left(\eta + \lambda^{i}\left(d_{it}\right)\right)\left(\eta + \lambda^{j}\left(d_{jt}\right)\right)}$. Similarly, c_{jt}^{m} denotes the importer's demand for variety j and follows

$$c_{jt}^{m} = \left(\frac{e_{jt}p_{jt}}{P_t^{m}}\right)^{-\eta-\lambda^{j}\left(d_{jt}\right)} x_t, \tag{1a}$$

where d_{it} and d_{jt} denote price differentials between brands i and j, i.e. $d_{it} = e_{it}p_{it} - e_{jt}p_{jt}$ and $d_{jt} = e_{jt}p_{jt} - e_{it}p_{it}$.

For computational simplicity, the composite good (3) only contains two imported varieties, since the primary objective of this study is to investigate whether the ERPT depends on the price differential between two commodities exported by competing countries. This basic case can be extended to a continuum of varieties indexed by $j \in [0,1]$. This extension will not affect the main conclusion of the study. Namely, we will attempt to show that in the case of two competitors the ERPT is reduced by the exporter if the price of his good significantly exceeds the price of the competitor's good, when both prices are expressed in the importer's currency. If the number of competitors is increased, the same reasoning will apply to the ERPT, i.e. pass-through will fall when the good's price becomes less competitive. However, instead of comparing the representative exporter's price to a competitor's price, we will need some aggregate benchmark describing the price level prevailing among the competitors.

The novelty of the demand function (1) lies in its elasticity with respect to the import price, where the elasticity represents a ratio of the relative change in the demand to a relative change in the import price:

$$\left|\frac{\partial c_{it}{}^{m}}{\partial\left(e_{it}p_{it}\right)}\frac{e_{it}p_{it}}{c_{it}^{m}}\right|=\left|\frac{e_{it}p_{it}}{c_{it}^{m}}x_{t}\left(\left(-\eta-\lambda^{i}\left(d_{it}\right)\right)\left(e_{it}p_{it}\right)^{-\eta-\lambda^{i}\left(d_{it}\right)-1}\left(\frac{1}{P_{t}^{m}}\right)^{-\eta-\lambda^{i}\left(d_{it}\right)}\right)\right|=$$

$$=\left|\frac{e_{it}p_{it}}{c_{it}^{m}}\left(\left(-\eta-\lambda^{i}\left(d_{it}\right)\right)\frac{c_{it}^{m}}{\left(e_{it}p_{it}\right)}\right)\right|=\eta+\lambda^{i}\left(d_{it}\right). \tag{4}$$

We assume that all producers are monopolistic competitors. Therefore, the price elasticity of the demand for good i (4) must exceed 1 by the definition of the monopolistic competition. Thus, demand elasticity (4) is assumed to contain two components. The first component is constant and denoted by parameter η. The second component, $\lambda^{i}\left(d_{it}\right)$, is a function of the price differential between two brands and a fixed switching cost, s:

$$\begin{pmatrix} d_{it}\leq s \\ d_{it}>s \end{pmatrix}\Rightarrow\lambda^{i}\left(d_{it}\right)=\begin{Bmatrix} 0 \\ \phi^{i}>0 \end{Bmatrix}. \tag{5}$$

Thus, the time varying component of the demand elasticity (5) follows two regimes. The upper regime encompasses all values of $\lambda^{i}\left(d_{it}\right)$ for which the price differential exceeds the switching cost, i.e. $d_{it}>s$. The lower regime is defined by the inequality $d_{it}\leq s$.

Similarly, the price elasticity of the demand for variety j equals

$$\left|\frac{\partial c_{jt}{}^{m}}{\partial\left(e_{jt}p_{jt}\right)}\frac{e_{jt}p_{jt}}{c_{jt}^{m}}\right|=\eta+\lambda^{j}\left(d_{jt}\right). \tag{4a}$$

The demand elasticity (4a) represents a sum of the constant parameter, η, and a non-linear function of the price differential, d_{jt}:

$$\begin{pmatrix} d_{jt}\leq s \\ d_{jt}>s \end{pmatrix}\Rightarrow\lambda^{j}\left(d_{jt}\right)=\begin{Bmatrix} 0 \\ \phi^{j}>0 \end{Bmatrix}. \tag{5a}$$

Suppose that $d_{it}>0$ because the import price of variety i exceeds that of variety j. Every period the importer has the opportunity to switch between the varieties produced by countries i and j, but there is a fixed cost, s, incurred while switching from brand i to brand j or vice versa. If the importer decides to switch from the variety produced in country i to a cheaper substitute exported by country j, she saves an amount equal to d_{it}, which denotes the price differential between these two brands. However, the switch is costly and requires a payment equal to s. Thus, when the gain from switching to brand j is less than or equal to the switching cost, i.e. $d_{it}\leq s$, the importer does not have incentives to change supplier. It is reasonable to switch from exporter i to exporter j only when the resulting gain exceeds the implied cost.

Thus, the switching cost, s, represents a threshold determining structural change in the price elasticity of the demand (4). The demand elasticity depends non-linearly on d_{it} denoting the gain from switching to variety j from variety i:

$$\begin{pmatrix} d_{it} \leq s \\ d_{it} > s \end{pmatrix} \Rightarrow \left| \frac{\partial c_{it}^m}{\partial (e_{it} p_{it})} \frac{e_{it} p_{it}}{c_{it}^m} \right| = \begin{Bmatrix} \eta > 1 \\ (\eta + \phi^i) > 1 \end{Bmatrix}. \tag{6}$$

The elasticity parameter η must satisfy the condition $\eta > 1$ in both regimes, because good i producer is monopolistic competitor. Moreover, irrespective of the distance between the switching gain and the switching cost, the price elasticity of the demand (6) must exceed one. Specifically, in the lower regime, i.e. $d_{it} \leq s$, the demand elasticity for brand i is lower than in the upper regime, i.e. $d_{it} > s$, since both η and ϕ^i are positive constants. Intuitively, when the benefit from switching to variety j is higher, the importer's incentive to stop purchasing variety i is stronger. Consequently, the demand for brand i is more sensitive to price changes in the upper regime.

Similarly, the price elasticity of the demand for brand j is a non-linear function of the price differential, d_{jt}:

$$\begin{pmatrix} d_{jt} \leq s \\ d_{jt} > s \end{pmatrix} \Rightarrow \left| \frac{\partial c_{jt}^m}{\partial (e_{jt} p_{jt})} \frac{e_{jt} p_{jt}}{c_{jt}^m} \right| = \begin{Bmatrix} \eta \\ \eta + \phi^j \end{Bmatrix}. \tag{6a}$$

Thus, due to a stronger incentive to switch to variety i in the upper regime, i.e. $d_{jt} > s$, the demand elasticity for brand j is larger in the upper regime compared to the lower regime, i.e. $d_{jt} \leq s$.

An increase in the sensitivity of the importer's demand to price changes endangers the exporting firm's market share. Consequently, an optimal price-setting mechanism has to accommodate changes in the demand elasticity. The next section examines the effect of non-linear demand elasticity on the foreign exporters' price-setting policy.

2.2.2 Firms

Consider a monopolistically competitive firm exporting from country i its variety priced in the producer's currency at p_{it}. The firm incurs a fixed marginal cost of production denoted by MC_{it}. The firm's optimization problem is solved by maximizing its profits subject to the importer's demand for variety i (1). Therefore, the firm chooses p_{it} to maximize the following profit function:

$$\Pi_{it} = p_{it}c_{it}{}^{m} - MC_{it}c_{it}{}^{m}. \tag{7}$$

Substituting the demand definition (1) for c_{it}^{m} in the profit function (7) gives

$$\Pi_{it} = \left(p_{it} - MC_{it}\right)\left(\frac{e_{it}p_{it}}{P_t^m}\right)^{-\eta-\lambda^i(d_{it})} x_t\ . \tag{7a}$$

Since the optimal price, p_{it}^{o}, should maximize the profit function (7a), p_{it}^{o} must satisfy the first order condition with respect to price p_{it}, i.e. $\frac{\partial \Pi_{it}}{\partial p_{it}} = 0$. Substituting the profits definition (7a) for Π_{it} in this first order condition yields

$$\begin{aligned} \frac{\partial \Pi_{it}}{\partial p_{it}} &= \left(1-\eta-\lambda^i\left(d_{it}\right)\right)p_{it}^{1-\eta-\lambda^i(d_{it})-1}\left(\frac{e_{it}}{P_t^m}\right)^{-\eta-\lambda^i(d_{it})} x_t\ - \\ &-\left(-\eta-\lambda^i\left(d_{it}\right)\right)MC_{it}\,p_{it}{}^{-\eta-\lambda^i(d_{it})-1}\left(\frac{e_{it}}{P_t^m}\right)^{-\eta-\lambda^i(d_{it})} x_t\ = 0. \end{aligned} \tag{8}$$

Solving the first order condition (8) for the optimal price gives

$$p_{it}^{o}\ = \frac{\eta+\lambda^i(d_{it})}{\eta+\lambda^i(d_{it})-1}MC_{it} = \mu_{it}MC_{it}\,, \tag{9}$$

where $\mu_{it} = \frac{\eta+\lambda^i(d_{it})}{\eta+\lambda^i(d_{it})-1}$ denotes the price mark-up over the marginal cost. Similarly, the optimal export price for variety j satisfies the first order condition $\frac{\partial \Pi_{jt}}{\partial p_{jt}} = 0$:

$$\begin{aligned} \frac{\partial \Pi_{jt}}{\partial p_{jt}} &= \left(1-\eta-\lambda^j\left(d_{jt}\right)\right)p_{jt}^{1-\eta-\lambda^j(d_{jt})-1}\left(\frac{e_{jt}}{P_t^m}\right)^{-\eta-\lambda^j(d_{jt})} x_t\ - \\ &-\left(-\eta-\lambda^j\left(d_{jt}\right)\right)MC_{jt}\,p_{jt}{}^{-\eta-\lambda^j(d_{jt})-1}\left(\frac{e_{jt}}{P_t^m}\right)^{-\eta-\lambda^j(d_{jt})} x_t\ = 0. \end{aligned} \tag{8a}$$

The optimal export price, p_{jt}^{o}, that satisfies the first order condition (8a) is defined by

$$p_{jt}^{o} = \frac{\eta + \lambda^{j}(d_{jt})}{\eta + \lambda^{j}(d_{jt}) - 1} MC_{jt} = \mu_{jt} MC_{jt} \,. \tag{9a}$$

Thus, the optimal export price represents a non-linear mark-up over the marginal cost, since monopolistic competitors have market power. If firms had no market power, the price elasticity of the demand for their good, $\eta + \lambda^{j}\left(d_{jt}\right)$, would be infinitely large. Rearranging the mark-up, μ_{jt} , into $\left(1 + \frac{1}{\eta + \lambda^{j}(d_{jt}) - 1}\right)$ shows that the mark-up approaches 1 as the demand elasticity in the denominator becomes infinitely large. Consequently, the export price approaches the marginal cost, i.e. the condition of the perfect competition. However, monopolistic competition implies that the demand elasticity, $\eta + \lambda^{j}\left(d_{jt}\right)$, lies in the range between 1 and positive infinity. Therefore, the mark-up exceeds unity, i.e. $\mu_{jt} > 1$, because $\eta + \lambda^{j}\left(d_{jt}\right) > \eta + \lambda^{j}\left(d_{jt}\right) - 1$.

Thus, the optimal mark-up, μ_{it}, follows one of the following two regimes depending on the difference between the switching gain, d_{it}, and the cost, s:

$$\begin{pmatrix} d_{it} \le s \\ \\ d_{it} > s \end{pmatrix} \Rightarrow \mu_{it}\left(\lambda^{i}\left(d_{it}\right)\right) = \begin{Bmatrix} \dfrac{\eta}{\eta - 1} \\ \dfrac{\eta + \phi^{i}}{\eta + \phi^{i} - 1} \end{Bmatrix}. \tag{10}$$

Rearranging the lower regime and upper regime mark-ups into $1 + \frac{1}{\eta - 1}$ and $1 + \frac{1}{\eta + \phi^{i} - 1}$, respectively, suggests that the mark-up falls when the price differential exceeds the threshold, *s:*

$$\frac{\eta}{\eta - 1} > \frac{\eta + \phi^{i}}{\eta + \phi^{i} - 1} \tag{11}$$

Similarly, the mark-up μ_{jt} represents a two-regime process featuring the threshold s :

$$\begin{pmatrix} d_{jt} \le s \\ \\ d_{jt} > s \end{pmatrix} \Rightarrow \mu_{jt}\left(\lambda^{j}\left(d_{jt}\right)\right) = \begin{Bmatrix} \dfrac{\eta}{\eta - 1} \\ \dfrac{\eta + \phi^{j}}{\eta + \phi^{j} - 1} \end{Bmatrix}, \tag{10a}$$

where $\frac{\eta}{\eta-1} > \frac{\eta+\phi^j}{\eta+\phi^j-1}$. Thus, the mark-up is larger in the lower regime compared to the upper regime. Intuitively, in the lower regime, the exporter enjoys a greater market power, since the consumer is unlikely to switch to a substitute when the switching gain does not exceed the switching cost. Thus, the producer is able to exploit his market power by setting a larger mark-up. However, in the upper regime, the exporter's market power is weakened by the importer's incentive to shift to a cheaper variety, since the switching gain outweighs the cost. Consequently, the mark-up falls to generate a price decrease, which is intended to prevent a loss of customers.

Given the non-linearity of the mark-up, μ_{it}, variety i's export price follows a two-regime process:

$$\begin{pmatrix} d_{it} \le s \\ \\ d_{it} > s \end{pmatrix} \Rightarrow p_{it}^0 = \begin{Bmatrix} \frac{\eta}{\eta-1} MC_{it} \\ \frac{\eta+\phi^i}{\eta+\phi^i-1} MC_{it} \end{Bmatrix}. \tag{12}$$

Likewise, variety j's export price is defined by the following threshold function:

$$\begin{pmatrix} d_{jt} \le s \\ \\ d_{jt} > s \end{pmatrix} \Rightarrow p_{jt}^0 = \begin{Bmatrix} \frac{\eta}{\eta-1} MC_{jt} \\ \frac{\eta+\phi^j}{\eta+\phi^j-1} MC_{jt} \end{Bmatrix}. \tag{12a}$$

Similarly to the mark-ups, the optimal export prices, p_{it}^o and p_{jt}^o, depend non-linearly on the price differentials d_{it} and d_{jt}. Specifically, the export price is higher in the lower regime, since the importer is locked into his current consumption pattern and unable to switch to an alternative supplier due to a relatively large switching cost, s. Consequently, the exporter may charge a higher export price as he does not face the risk of losing customers. However, in the upper regime, the producer reduces the export price to discourage customers from replacing its product with a cheaper substitute due to a relatively large switching gain.

In this section we modelled structural breaks in the export price-setting mechanism. Intuitively, any non-linearity in the export prices, p_{it} and p_{jt}, is transmitted into the import prices, $e_{it} p_{it}$ and $e_{jt} p_{jt}$, since the export price functionally determines the import price. Consequently, the ERPT defining the response of the import price to exchange rate movements follows a non-linear process. The next section examines structural breaks in the ERPT into the import prices of brands i and j.

2.2.3 Exchange Rate Pass-through (ERPT)

In this section, we compute the ERPT as the derivative of the import price with respect to the exchange rate, i.e. $\frac{\partial(e_{it}p_{it})}{\partial e_{it}}$ and $\frac{\partial(e_{jt}p_{jt})}{\partial e_{jt}}$. Substituting the optimal export price (9) into variety i's import price, i.e. $e_{it}p_{it}$, gives

$$e_{it}p_{it}^{o} = \frac{\eta+\lambda^{i}(d_{it})}{\eta+\lambda^{i}(d_{it})-1}MC_{it}e_{it} = \mu_{it}MC_{it}e_{it}. \tag{13}$$

More specifically, the optimal import price (13) represents a two-regime process due to the non-linearity of the mark-up, μ_{it}:

$$\begin{pmatrix} d_{it} \le s \\ \\ d_{it} > s \end{pmatrix} \Rightarrow e_{it}p_{it}^{o} = \left\{ \begin{matrix} \frac{\eta}{\eta-1}MC_{it}e_{it} \\ \frac{\eta+\phi^{i}}{\eta+\phi^{i}-1}MC_{it}e_{it} \end{matrix} \right\}. \tag{13a}$$

The import price, $e_{it}p_{it}^{o}$, is higher in the lower regime, as opposed to the upper regime, since the mark-up corresponding to the upper regime is smaller than that of the lower regime.

Similarly, variety j's optimal import price, $e_{jt}p_{jt}^{o}$, is larger in the lower regime, compared to the upper regime:

$$\begin{pmatrix} d_{jt} \le s \\ \\ d_{jt} > s \end{pmatrix} \Rightarrow e_{jt}p_{jt}^{o} = \left\{ \begin{matrix} \frac{\eta}{\eta-1}MC_{jt}e_{jt} \\ \frac{\eta+\phi^{j}}{\eta+\phi^{j}-1}MC_{jt}e_{jt} \end{matrix} \right\}. \tag{13b}$$

Differentiating the import price (13a) with respect to the exchange rate gives the ERPT into variety i's optimal import price:

$$\begin{pmatrix} d_{it} \le s \\ \\ d_{it} > s \end{pmatrix} \Rightarrow \frac{\partial(e_{it}p_{it}^{o})}{\partial e_{it}} = \left\{ \begin{matrix} \frac{\eta}{\eta-1}MC_{it} \\ \frac{\eta+\phi^{i}}{\eta+\phi^{i}-1}MC_{it} \end{matrix} \right\}. \tag{14}$$

Similarly to the import price level, the magnitude of the ERPT (14) differs across the two regimes. Specifically, the lower regime is characterized by a higher pass-through, as opposed to the upper regime. Intuitively, when a large switching cost prevents the consumer of variety i from joining supplier j, firm i does not have to protect its market share by limiting the rise of variety i's import price following the importer's currency depreciation. However, in the upper regime, the ERPT (14) is smaller relative to the lower regime. Intuitively, since the importer's incentive to switch to a cheaper supplier increases when the switching gain exceeds the cost, exporter i limits the ERPT by adjusting the mark-up, μ_{it}, downwards and offsetting the import price increase either partially or completely.

Likewise, the ERPT into variety j's optimal import price is greater in the lower regime compared to the upper regime:

$$\begin{pmatrix} d_{jt} \leq s \\ \\ d_{jt} > s \end{pmatrix} \Rightarrow \frac{\partial\left(e_{jt} p^{o}_{jt}\right)}{\partial e_{jt}} = \begin{Bmatrix} \dfrac{\eta}{\eta - 1} MC_{jt} \\ \dfrac{\eta + \phi^{j}}{\eta + \phi^{j} - 1} MC_{jt} \end{Bmatrix} \tag{14a}$$

This section developed a partial equilibrium model of export pricing by monopolistically competitive firms to justify possible non-linearities in the ERPT into import prices. We showed that a non-linearity of the price elasticity of the demand induces structural breaks in the firm's mark-up over the marginal cost. Through affecting the product's export and import prices, the non-linearity of the mark-up generates structural breaks in the response of the import price to currency movements. The following section outlines the econometric methodology adopted in this study to test for structural breaks in the relationship between import price and exchange rate.

2.3 Econometric Methodology

This study employs the threshold regression methodology developed in Hansen (1999) to test for threshold effects in the regression parameters of non-dynamic panels. This section proceeds as follows. First, it builds an import price model used to estimate structural breaks in the ERPT. Second, it outlines the computation algorithm for estimating the value and statistical significance of threshold estimates.

2.3.1 Econometric specification

The econometric specification adopted in this study is based on the import price model (13). Specifically, since the ERPT represents the response of the import price to exchange rate changes, this paper estimates the non-linear pass-through by performing a threshold regression of the import price on the exchange rate and selected regressors.

In order to determine the linear regression specification, the optimal import price (13) must be log-transformed:

$$\ln\left(e_{it} p_{it}^{o}\right) = \ln MC_{it} + \ln\left(\frac{\eta + \lambda^{i}(d_{it})}{\eta + \lambda^{i}(d_{it}) - 1} e_{it}\right). \tag{14b}$$

The purpose of the log-transformation of the threshold model is two-fold. First, it allows us to estimate the individual effect of each regressor on the import price. Second, log-transformation facilitates the search for an optimal threshold estimate by reducing the range of possible values of the threshold.

Thus, the log-transformed import price (14b) gives the following log-linearized reduced form regression of the import price, ${p_{kt}}^{i}$:

$$\begin{bmatrix} \ln d_{kt} \le \gamma \\ \ln d_{kt} > \gamma \end{bmatrix} \Rightarrow \ln p_{kt}^{i} = \begin{Bmatrix} \mu_k + \alpha_1 \ln MC_{kt} + \alpha_2 \ln e_{kt} + \xi_{kt} \\ \mu_k + \alpha_1 \ln MC_{kt} + \alpha_3 \ln e_{kt} + \xi_{kt} \end{Bmatrix}. \tag{15}$$

Equation (15) defining a two-regime process for the log-transformed import price can be re-written as:

$$\ln {p_{kt}}^{i} = \mu_k + \alpha_1 \ln MC_{kt} + \alpha_2 \ln e_{kt} I(\ln d_{kt} \le \gamma) + \alpha_3 \ln e_{kt} I(\ln d_{kt} > \gamma) + \xi_{kt}, \tag{16}$$

where α_1, α_2 and α_3 are parameters. Subscript k denotes exporting country, i.e. $k = 1,2,3,...,K$. $\ln {p_{kt}}^{i}$ represents the log of variety k 's import price whose theoretic counterpart is $\ln(e_{kt} p_{kt})$, $k = i, j$ (see 13 and 13b). There are K countries exporting a distinct brand of the same good to the USA. Thus, the log of the product's import price is regressed on $\ln MC_{kt}$ and $\ln e_{kt}$ denoting the log-transformed marginal cost of production in exporting country k and the log-transformed bilateral exchange rate between exporter k and the USA, respectively. In addition, since the specification (15) corresponds to a panel dataset, it includes unobservable individual effects, μ_k. Examples of unobservable exporter-specific factors include the quality of country k 's product relative to the quality of commodities produced by the remaining $K-1$ exporters. Parameter γ stands for threshold whose theoretic counterpart is the log-transformed switching cost, $\ln s$ (see 14a). $I(\cdot)$ denotes an indicator function that sorts observations into one of the two regimes defined in (15). The error term, ξ_{kt}, is modelled as an independent and identically distributed ($i.i.d.$) process with mean zero and variance σ_{ξ}^{2}.

Therefore, the ERPT represented by the exchange rate coefficients, α_2 and α_3, follows a two-regime process where the log-transformed switching gain, $\ln d_{kt}$, acts as a threshold variable. In order to clarify the dependence of the ERPT, α_2 and α_3, on the threshold function, $\lambda^i(d_{it})$, let us note that the threshold variable, d_{it}, represents a function of the exchange rate, e_{it}, i.e. $d_{it} = e_{it} p_{it} - e_{jt} p_{jt}$. Therefore, the log-transformed import price (14b) may be rewritten as

$$\ln\left(e_{it} p_{it}^{o}\right) = \ln MC_{it} + \ln\left(\frac{\eta + \lambda^i\left(d_{it}\left(e_{it}\right)\right)}{\eta + \lambda^i\left(d_{it}\left(e_{it}\right)\right) - 1}\right) + \ln e_{it}. \tag{14c}$$

Moreover, the ratio $\dfrac{\eta + \lambda^i\left(d_{it}\left(e_{it}\right)\right)}{\eta + \lambda^i\left(d_{it}\left(e_{it}\right)\right) - 1}$ can be rearranged into $1 + \dfrac{1}{\eta + \lambda^i\left(d_{it}\left(e_{it}\right)\right) - 1}$ in order to simplify the differentiation operation.

Using the import price definition (14c), the degree of the ERPT can be computed as the derivative of the log-transformed import price with respect to the log of the exchange rate:

$$\frac{\partial \ln\left(e_{it} p_{it}^{o}\right)}{\partial \ln e_{it}} = \frac{1}{1 + \dfrac{1}{\eta + \lambda^i\left(d_{it}\left(e_{it}\right)\right) - 1}} \frac{\partial \lambda^i}{\partial d_{it}} \frac{\partial d_{it}}{\partial \ln e_{it}} + 1, \tag{14d}$$

where the dependence of the price differential, d_{it}, on the log-transformed exchange rate, $\ln e_{it}$, is evident from the following version of the price gap definition: $d_{it} = e^{\ln e_{it}} p_{it} - e_{jt} p_{jt}$. Therefore, the ERPT (14d) is non-linear and depends on the relative magnitude of the switching cost, *s*, since the exchange rate elasticity of the import price (14d) is determined by the value of the threshold function (5a), $\lambda^i(d_{it})$, which depends non-linearly on the cost of switching to variety *j*.

The null hypothesis of interest implies no structural change in the regression coefficients, i.e. $\alpha_2 = \alpha_3$. Thus, under the null, the position of the log-transformed switching gain with respect to the threshold is irrelevant for determining the extent of the ERPT. The alternative hypothesis is consistent with the theoretic model developed in this study (see 14) and suggests a non-linear process for the exchange rate coefficient, i.e. $\alpha_2 \neq \alpha_3$.

Suppose that a depreciation of the US dollar led to an increase in $\ln e_{kt}$. Under the alternative hypothesis, the ERPT defining the increase of the import price following the depreciation crucially depends on the deviation of the switching gain from its threshold. When the gain from shifting to an alternative supplier exceeds the switching cost, i.e. $d_{it} > s$ and i=k in (14), the log-transformed switching gain rises above the threshold, i.e. $\ln d_{kt} > \gamma$ in (15). Therefore, an exporter from country k will limit the ERPT by a downward mark-up adjustment (10) to prevent the US importer from switching. However, when the switching gain is insufficient to overshoot the switching cost and encourage the importer to switch, i.e. $d_{kt} \leq s$, the log-transformed shifting gain fails to exceed the threshold, i.e. $\ln d_{kt} \leq \gamma$. Consequently, the exporter receives no incentive to limit the ERPT by a downward mark-up adjustment. Therefore, the theory developed in the previous section predicts that the degree of the ERPT corresponding to the lower regime exceeds that observed in the upper regime, i.e. $\alpha_2 > \alpha_3$.

In order to estimate the magnitude and statistical significance of the threshold effect in the ERPT, this study employs a modified version of the specification (16):

$$\begin{aligned}\ln p_{kt}{}^{i} &= \mu_k + \beta_1 \ln MC_{kt-1} + \beta_2 \ln D_{kt-1} + \beta_3 \ln MC_{kt-1} \ln D_{kt-1} + \\ &\beta_4 \ln e_{kt-1} I(\ln D_{kt-1} \leq \gamma) + \beta_5 \ln e_{kt-1} I(\ln D_{kt-1} > \gamma) + \zeta_{kt},\end{aligned} \tag{17}$$

where $\zeta_{kt} \sim i.i.d.(0, \sigma_\zeta^2)$. There are four differences between the import price models (17) and (16).

First, all time variant regressors in (17) are lagged by one period in order to accommodate possible price stickiness. Bils and Klenow (2004) documented that some prices persist over one year before being re-set. If firms are unable to adjust prices instantaneously following any fluctuation in the explanatory variables, current prices are governed by the past values of the regressors.

Second, the switching gain is denoted by D_{kt-1} and computed as the ratio between the price of country k 's variety and the world price of the good under consideration, i.e. $p_{kt-1}{}^{i} / p_{wt-1}{}^{i}$. The superscript i indicates that both prices are expressed in the importer's currency and the subscript w refers to world. This measure of the switching gain was preferred due to its ability to provide a sensible proxy for the price differential, $d_{it} = e_{it} p_{it} - e_{jt} p_{jt}$, from the theoretic model, since the log-transformation of D_{kt-1} gives $\ln D_{kt-1} = \ln p^i_{kt-1} - \ln p^i_{wt-1}$. Thus, the price differential $\left(\ln p_{kt}{}^i - \ln p_{wt}{}^i\right)$ differs in two aspects from its theoretic counterpart, $e_{it} p_{it} - e_{jt} p_{jt}$. First, each import price is presented in a log-transformed state. Second, instead of considering only one competitor's price, i.e. $e_{jt} p_{jt}$, $\ln D_{kt}$ presents a more comprehensive measure of competition by taking into account the world market price for the commodity, $p_{wt}{}^i$. The world market price is taken as the benchmark against which each brand's price is compared, since the existence of multiple competitors necessitates a single benchmark indicating an average price prevailing among competitors.

Third, the specification (17) contains the log of the previous switching gain, i.e. $\ln D_{kt-1}$, in order to separate the linear effect of the gain on the import price (see β_2) from the non-linear (threshold) impact of $\ln D_{kt-1}$ on the ERPT (see β_4 and β_5).

Finally, a non-linear interaction term, $\ln MC_{kt-1} \ln D_{kt-1}$, is added to alleviate spurious correlations that may be induced by omitted variables bias.

Since to the best of the author's knowledge data on consumer's switching cost is unavailable, the import price specification (17) replaces the measure of the switching cost, $\ln s$, with an unobserved threshold parameter, γ, which can be estimated using the least squares method by Hansen (1999). The ability of this methodology to overcome the unavailability of switching cost data represents the main reason for choosing the threshold regression algorithm by Hansen (1999). For instance, time variance in the ERPT could be estimated using regime-switching time-series models. For example, an extension of the Markov-switching framework by Hamilton (1989) could be applied in order to model two unobserved states of the ERPT, i.e. large and small pass-through. Similarly, a logistic mixture model (Wong and Li, 2001) could be applied to distinguish between the states of low and high pass-through. However, the aforementioned non-linear approaches represent significant computation challenges, since they require us to estimate the probabilities of the state of the unobserved process by adopting restrictive assumptions on the distribution of the probability of the occurence of a given state. In contrast, the approach in Hansen

(1999) allows us to test for structural breaks in the ERPT by estimating the unobserved threshold parameter with an optimization mechanism that does not rely on the assumptions about the probability density functions corresponding to different regimes.

The following sub-section outlines the computation algorithm for estimating the parameter set $\{\mu_k, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \gamma\}$ from (17). In addition, it explains the bootstrap replication procedure for estimating the asymptotic p-values used in testing the significance of the threshold effect.

2.3.2 Computation algorithm

This section describes the five-step computation algorithm for estimating the ERPT using the two-regime regression of the import price (17). The computation procedure is conducted by splitting the observations into two samples in order to determine whether the regression coefficients are significantly different across the two regimes. In addition to estimating the coefficients, the objective of the computation process is to estimate the magnitude and statistical significance of the threshold γ defining a structural break.

The computation algorithm is performed in five steps. First, a threshold estimate, $\hat{\gamma}$, is obtained using the least squares regression applied to a grid of potential threshold values. Second, an estimated coefficient vector, $\{\hat{\beta}_1, \hat{\beta}_2, \hat{\beta}_3, \hat{\beta}_4(\hat{\gamma}), \hat{\beta}_5(\hat{\gamma})\}$, corresponding to the least squares estimate of the threshold, is delivered. Third, a likelihood ratio (LR) test statistic is constructed to test the null hypothesis of no structural change against the alternative hypothesis of parameter instability. Fourth, bootstrap replications are conducted to construct asymptotic p-values for the LR statistic under the null hypothesis. Finally, asymptotic confidence intervals for the threshold parameter, γ, are formed to determine the precision of the threshold estimate.

2.3.2.1 Step 1: Estimating the threshold parameter

Before proceeding to the estimation, a fixed effects transformation is used to remove from (17) the time-invariant effects, μ_k, denoting unobservable constant characteristics of the exporters. Fixed effects are eliminated in order to allow for a consistent estimation of the regression coefficients. One of the conventional procedures for eliminating the individual-specific effects requires transforming the variables into their deviations from individual-specific averages over time t (Hausman and Taylor, 1981):

$$\begin{aligned}\left(\ln p_{kt}{}^{i}\right)^{*} &= \beta_1\left(\ln MC_{kt-1}\right)^{*} + \beta_2\left(\ln D_{kt-1}\right)^{*} + \beta_3\left(\ln MC_{kt-1}\ln D_{kt-1}\right)^{*} + \\ &\beta_4\left(\ln e_{kt-1} I\left(\ln D_{kt-1} \le \gamma\right)\right)^{*} + \beta_5\left(\ln e_{kt-1} I\left(\ln D_{kt-1} > \gamma\right)\right)^{*} + \zeta_{kt}^{*},\end{aligned} \tag{18}$$

where the demeaned variables are denoted by superscript "*" and defined as follows:

$$\left(\ln p_{kt}^{i}\right)^{*} = \ln p_{kt}^{i} - \frac{1}{T-1}\sum_{t=2}^{T}\ln p_{kt}^{i} \tag{18a}$$

$$\left(\ln MC_{kt-1}\right)^{*} = \ln MC_{kt-1} - \frac{1}{T-1}\sum_{t=1}^{T-1}\ln MC_{kt-1} \tag{18b}$$

$$\left(\ln D_{kt-1}\right)^{*} = \ln D_{kt-1} - \frac{1}{T-1}\sum_{t=1}^{T-1}\ln D_{kt-1} \tag{18c}$$

$$\left(\ln MC_{kt-1}\ln D_{kt-1}\right)^{*} = \ln MC_{kt-1}\ln D_{kt-1} - \frac{1}{T-1}\sum_{t=1}^{T-1}\left(\ln MC_{kt-1}\ln D_{kt-1}\right) \tag{18d}$$

$$\left(\ln e_{kt-1} I\left(\ln D_{kt-1} \le \gamma\right)\right)^{*} = \ln e_{kt-1} I\left(\ln D_{kt-1} \le \gamma\right) - \frac{1}{T-1}\sum_{t=1}^{T-1}\ln e_{kt-1} I\left(\ln D_{kt-1} \le \gamma\right) \tag{18e}$$

$$\left(\ln e_{kt-1} I\left(\ln D_{kt-1} > \gamma\right)\right)^{*} = \ln e_{kt-1} I\left(\ln D_{kt-1} > \gamma\right) - \frac{1}{T-1}\sum_{t=1}^{T-1}\ln e_{kt-1} I\left(\ln D_{kt-1} > \gamma\right) \tag{18f}$$

$$\zeta_{kt}{}^{*} = \zeta_{kt} - \frac{1}{T-1}\sum_{t=2}^{T}\zeta_{kt} \tag{18g}$$

In order to facilitate the exposition of the computation algorithm, stack the data over K exporting countries:

$$P^{i*} = \begin{bmatrix} \begin{Bmatrix} \left(\ln p_{12}^{i}\right)^{*} \\ \ldots \\ \ldots \\ \left(\ln p_{1T}^{i}\right)^{*} \end{Bmatrix} \\ \ldots \\ \begin{Bmatrix} \left(\ln p_{k2}^{i}\right)^{*} \\ \ldots \\ \ldots \\ \left(\ln p_{kT}^{i}\right)^{*} \end{Bmatrix} \\ \ldots \\ \begin{Bmatrix} \left(\ln p_{K2}^{i}\right)^{*} \\ \ldots \\ \ldots \\ \left(\ln p^{i}{}_{KT}\right)^{*} \end{Bmatrix} \end{bmatrix}, \qquad X^{*}(\gamma) = \begin{bmatrix} \begin{Bmatrix} \left(\bar{x}_{11}(\gamma)\right)^{*} \\ \ldots \\ \ldots \\ \left(\bar{x}_{1T-1}(\gamma)\right)^{*} \end{Bmatrix} \\ \ldots \\ \begin{Bmatrix} \left(\bar{x}_{k1}(\gamma)\right)^{*} \\ \ldots \\ \ldots \\ \left(\bar{x}_{kT-1}(\gamma)\right)^{*} \end{Bmatrix} \\ \ldots \\ \begin{Bmatrix} \left(\bar{x}_{K1}(\gamma)\right)^{*} \\ \ldots \\ \ldots \\ \left(\bar{x}_{KT-1}(\gamma)\right)^{*} \end{Bmatrix} \end{bmatrix}, \qquad \zeta^{*} = \begin{bmatrix} \begin{Bmatrix} \zeta_{12}^{*} \\ \ldots \\ \ldots \\ \zeta_{1T}^{*} \end{Bmatrix} \\ \ldots \\ \begin{Bmatrix} \zeta_{k2}^{*} \\ \ldots \\ \ldots \\ \zeta_{kT}^{*} \end{Bmatrix} \\ \ldots \\ \begin{Bmatrix} \zeta_{K2}^{*} \\ \ldots \\ \ldots \\ \zeta_{KT}^{*} \end{Bmatrix} \end{bmatrix},$$

(19)

where $\left(\bar{x}_{kt-1}(\gamma)\right)^{*}$ represents a 1×5 vector of explanatory variables:

$$\left(\bar{x}_{kt-1}(\gamma)\right)^{*} = \begin{Bmatrix} \left(\ln MC_{kt-1}\right)^{*} \\ \left(\ln D_{kt-1}\right)^{*} \\ \left(\ln MC_{kt-1} \ln D_{kt-1}\right)^{*} \\ \left(\ln e_{kt-1} I\left(\ln D_{kt-1} \le \gamma\right)\right)^{*} \\ \left(\ln e_{kt-1} I\left(\ln D_{kt-1} > \gamma\right)\right)^{*} \end{Bmatrix}'. \tag{20}$$

Substituting the variable definitions (19) and (20) into the regression (18) gives a neat specification of the import price

$$P^{i*} = X^{*}(\gamma)\bar{\beta} + \zeta^{*}, \tag{21}$$

where $\bar{\beta}$ defines a 5×1 vector of regression coefficients

$$\bar{\beta} = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ \beta_4(\gamma) \\ \beta_5(\gamma) \end{bmatrix}. \tag{22}$$

Thus, only exchange rate coefficients, β_4 and β_5, depend on the value of the threshold parameter, while the remaining coefficients are regime-independent. The subsequent exposition of the estimation algorithm uses the specification (21) to explain computation steps.

The threshold parameter, γ, is estimated using the least squares method suggested in Chan (1993) and Hansen (2000). This approach implies an optimization search for the estimate $\hat{\gamma}$ over distinct values of the threshold variable**.** In order to reduce the duration of this computation procedure, this study restricts the search to specific quantiles by using a grid containing 50 quantiles, i.e. $[0\%, 2\%, 4\%, ..., 100\%]$. In addition, trimming the smallest and largest observations on the threshold variable yields a further reduction in the number of regressions by limiting the search to the most likely points for structural break. Current study adopts the grid $[10\%, 12\%, 14\%, ..., 90\%]$, where 10 % of the observations is eliminated from each tail of the data on $\ln D_{kt-1}$**,** which is sorted in the ascending order.

After constructing the grid for optimization search, the regression (21) is estimated by ordinary least squares for each of the 40 quantiles specified in the grid to deliver the following matrix of coefficient estimates:

$$\hat{\hat{\beta}}(\gamma) = \begin{bmatrix} \hat{\beta}_1(\gamma_1), \hat{\beta}_1(\gamma_2), \hat{\beta}_1(\gamma_3), ..., \hat{\beta}_1(\gamma_{40}) \\ \hat{\beta}_2(\gamma_1), \hat{\beta}_2(\gamma_2), \hat{\beta}_2(\gamma_3), ..., \hat{\beta}_2(\gamma_{40}) \\ \hat{\beta}_3(\gamma_1), \hat{\beta}_3(\gamma_2), \hat{\beta}_3(\gamma_3), ..., \hat{\beta}_3(\gamma_{40}) \\ \hat{\beta}_4(\gamma_1), \hat{\beta}_4(\gamma_2), \hat{\beta}_4(\gamma_3), ..., \hat{\beta}_4(\gamma_{40}) \\ \hat{\beta}_5(\gamma_1), \hat{\beta}_5(\gamma_2), \hat{\beta}_5(\gamma_3), ..., \hat{\beta}_5(\gamma_{40}) \end{bmatrix}, \tag{23}$$

where $\hat{\beta}_1(\gamma_1) = \hat{\beta}_1(\gamma_2) = ... = \hat{\beta}_1(\gamma_{40})$, $\hat{\beta}_2(\gamma_1) = \hat{\beta}_2(\gamma_2) = ... = \hat{\beta}_2(\gamma_{40})$ and $\hat{\beta}_3(\gamma_1) = \hat{\beta}_3(\gamma_2) = ... = \hat{\beta}_3(\gamma_{40})$. Thus, the estimates of the regression coefficients may vary across quantiles. Therefore, we consider 40 possible values for the threshold parameter, out of which only one value is optimal. The optimal value of the threshold parameter is represented by the value of γ which minimizes the concentrated sum of squared errors:

$$\hat{\gamma} = \arg\min_{\gamma} \left[P^{i*} - X^{*}(\gamma)\hat{\hat{\beta}}(\gamma) \right]' \left[P^{i*} - X^{*}(\gamma)\hat{\hat{\beta}}(\gamma) \right] = \arg\min_{\gamma} \left[\hat{\zeta}^{*}(\gamma)' \hat{\zeta}^{*}(\gamma) \right]. \tag{24}$$

2.3.2.2 Step 2: Deriving the estimated coefficient vector

This step uses the estimated threshold parameter (24) to determine the estimated coefficient vector, $\hat{\bar{\beta}}(\hat{\gamma})$. This task does not require additional computation, since $\hat{\bar{\beta}}(\hat{\gamma})$ represents a vector of estimated coefficients corresponding to the threshold estimate, $\hat{\gamma} \in [\gamma_1, \gamma_2, \gamma_3, ..., \gamma_{40}]$. Thus, the estimated coefficient vector, $\hat{\bar{\beta}}(\hat{\gamma})$, represents specific column from the matrix of coefficient estimates (23):

$$\hat{\bar{\beta}}(\hat{\gamma}) = \begin{bmatrix} \hat{\beta}_1 \\ \hat{\beta}_2 \\ \hat{\beta}_3 \\ \hat{\beta}_4(\hat{\gamma}) \\ \hat{\beta}_5(\hat{\gamma}) \end{bmatrix}. \tag{23a}$$

The estimated regression coefficients that are functionally determined by the estimated threshold parameter represent regime-specific ERPT coefficients.

2.3.2.3 Step 3: Testing the H_0 of no structural change

The objective of this stage is to determine the statistical significance of the threshold estimate, $\hat{\gamma}$, obtained in Step 1. This aim is achieved by testing the null hypothesis of no threshold effect:

$$H_0 : \beta_4 = \beta_5 = \beta_e. \tag{25}$$

Thus, the null hypothesis (25) suggests the following restricted regression:

$$\begin{gathered}(\ln p_{kt}{}^{i})^{*} = \beta_1(\ln MC_{kt-1})^{*} + \beta_2(\ln D_{kt-1})^{*} + \beta_3(\ln MC_{kt-1} \ln D_{kt-1})^{*} + \\ \beta_e(\ln e_{kt-1})^{*} + \zeta^{*}_{kt}.\end{gathered} \tag{26}$$

The alternative hypothesis, i.e. $H_a : \beta_4 \neq \beta_5$, corresponds to the unrestricted regression

$$\begin{gathered}(\ln p_{kt}{}^{i})^{*} = \beta_1(\ln MC_{kt-1})^{*} + \beta_2(\ln D_{kt-1})^{*} + \beta_3(\ln MC_{kt-1} \ln D_{kt-1})^{*} + \\ \beta_4(\ln e_{kt-1} I(\ln D_{kt-1} \le \hat{\gamma}))^{*} + \beta_5(\ln e_{kt-1} I(\ln D_{kt-1} > \hat{\gamma}))^{*} + \zeta^{*}_{kt}.\end{gathered} \tag{27}$$

First, the restricted model (26) is estimated by OLS to deliver the sum of squared errors denoted by $\tilde{\zeta}^{*\prime}\tilde{\zeta}^{*}$. Second, using $\{\hat{\zeta}^{*}(\hat{\gamma})'\hat{\zeta}^{*}(\hat{\gamma})\}$ which defines the concentrated sum of squared errors from the unrestricted regression (27), the following LR test is constructed:

$$F_1 = K(T-2)\left[\frac{\tilde{\zeta}^{*\prime}\tilde{\zeta}^{*}}{\hat{\zeta}^{*}(\hat{\gamma})'\hat{\zeta}^{*}(\hat{\gamma})}-1\right]. \tag{28}$$

Finally, the value of the LR test statistic, F_1, is compared against the relevant critical value. The null hypothesis of no structural change is rejected if the statistic value exceeds the critical value corresponding to the desired confidence level. The existence of an unidentified nuisance parameter, γ, under H_0 renders the tabulation of critical values impossible due to a non-standard asymptotic distribution of F_1. The next section describes a bootstrap procedure used to approximate actual critical values for F_1 by constructing asymptotic p-values under the null hypothesis (see Hansen, 1996).

2.3.2.4 Step 4: Computing the bootstrap p-values for F_1 under H_o

The asymptotic p-values for the F_1 statistic under the null hypothesis are constructed by conducting 300[1] bootstrap replications. A bootstrap sample is created using an error matrix, which consists of the unrestricted regression residuals grouped by exporting country:

$$\hat{\zeta}^{*B} = \begin{pmatrix} \hat{\zeta}^{*}_{12}, \hat{\zeta}^{*}_{22}, \ldots, \hat{\zeta}^{*}_{k2}, \ldots\ldots\ldots, \hat{\zeta}^{*}_{K2} \\ \hat{\zeta}^{*}_{13}, \hat{\zeta}^{*}_{23}, \ldots, \hat{\zeta}^{*}_{k3}, \ldots\ldots\ldots, \hat{\zeta}^{*}_{K3} \\ \ldots\ldots, \ldots\ldots, \ldots\ldots\ldots\ldots\ldots\ldots\ldots, \ldots\ldots \\ \ldots\ldots, \ldots\ldots, \ldots\ldots\ldots\ldots\ldots\ldots\ldots, \ldots\ldots \\ \hat{\zeta}^{*}_{1T}, \hat{\zeta}^{*}_{2T}, \ldots, \hat{\zeta}^{*}_{kT}, \ldots\ldots\ldots, \hat{\zeta}^{*}_{KT} \end{pmatrix} = \left(\hat{\zeta}^{*}_{1}, \hat{\zeta}^{*}_{2}, \ldots, \hat{\zeta}^{*}_{k}, \ldots\ldots\ldots, \hat{\zeta}^{*}_{K}\right). \tag{29}$$

First, a random sample of size K is drawn (with replacement) from the empirical distribution of unrestricted errors, $\hat{\zeta}^{*B}$ (29). Using these random errors, we create a bootstrap sample under the null:

[1] This study follows Hansen (1999) in choosing the appropriate number of bootstrap replications.

$$P^{i*B} = \begin{bmatrix} \begin{Bmatrix} \left(\ln p^i_{12}\right)^{*B} \\ \ldots \\ \ldots \\ \left(\ln p^i_{1T}\right)^{*B} \end{Bmatrix} \\ \ldots \\ \begin{Bmatrix} \left(\ln p^i_{k2}\right)^{*B} \\ \ldots \\ \ldots \\ \left(\ln p^i_{kT}\right)^{*B} \end{Bmatrix} \\ \ldots \\ \begin{Bmatrix} \left(\ln p^i_{K2}\right)^{*B} \\ \ldots \\ \ldots \\ \left(\ln p^i{}_{KT}\right)^{*B} \end{Bmatrix} \end{bmatrix}. \tag{30}$$

Each element of the bootstrap sample, P^{i*B}, is computed by using an error $\hat{\zeta}_r^{*B}$, which is drawn randomly from (29) to augment the predicted values of the dependent variable under the null hypothesis:

$$\begin{aligned} \left(\ln p_{kt}{}^i\right)^{*B} &= \hat{\beta}_1\left(\ln MC_{kt-1}\right)^* + \hat{\beta}_2\left(\ln D_{kt-1}\right)^* + \hat{\beta}_3\left(\ln MC_{kt-1} \ln D_{kt-1}\right)^* + \\ &\hat{\beta}_e\left(\ln e_{kt-1}\right)^* + \hat{\zeta}_r^{*B}. \end{aligned} \tag{30a}$$

Second, the bootstrap values of the dependent variable are regressed according to the following unrestricted (31) and restricted (32) models of import price:

$$\begin{aligned} \left(\ln p_{kt}{}^i\right)^{*B} &= \beta_1\left(\ln MC_{kt-1}\right)^* + \beta_2\left(\ln D_{kt-1}\right)^* + \beta_3\left(\ln MC_{kt-1} \ln D_{kt-1}\right)^* + \\ &\beta_4\left(\ln e_{kt-1} I\left(\ln D_{kt-1} \le \hat{\gamma}\right)\right)^* + \beta_5\left(\ln e_{kt-1} I\left(\ln D_{kt-1} > \hat{\gamma}\right)\right)^* + \zeta_{kt}^{*BB}, \end{aligned} \tag{31}$$

$$\begin{aligned} \left(\ln p_{kt}{}^i\right)^{*B} &= \beta_1\left(\ln MC_{kt-1}\right)^* + \beta_2\left(\ln D_{kt-1}\right)^* + \beta_3\left(\ln MC_{kt-1} \ln D_{kt-1}\right)^* + \\ &\beta_e\left(\ln e_{kt-1}\right)^* + \zeta_{kt}^{*BB}. \end{aligned} \tag{32}$$

Third, a bootstrap value of the F_1 statistic is constructed:

$$F_1^B = K(T-2)\left[\frac{\tilde{\zeta}^{*BB'}\tilde{\zeta}^{*BB}}{\hat{\zeta}^{*BB}(\hat{\gamma})'\hat{\zeta}^{*BB}(\hat{\gamma})} - 1\right], \tag{33}$$

where $\left\{\tilde{\zeta}^{*BB'}\tilde{\zeta}^{*BB}\right\}$ and $\left\{\hat{\zeta}^{*BB}(\hat{\gamma})'\hat{\zeta}^{*BB}(\hat{\gamma})\right\}$ define the sums of squared errors from the restricted (32) and unrestricted (31) regressions, respectively.

This three-step procedure is conducted 300 times following repeated random draws from the empirical distribution of unrestricted errors, $\hat{\zeta}^{*B}$. The bootstrap estimate of the asymptotic p-value for F_1 under the null hypothesis is found by dividing the number of cases where the simulated statistic, $F_1^{\,B}$, exceeded the actual value of F_1 by the total number of replications:

$$PV_B = \frac{\sum_{b=1}^{300} I\left(F_{1,b}^{B} > F_1\right)}{300}, \text{ where } I(\bullet) = \begin{cases} 1 \\ 0 \end{cases} if \begin{cases} F_{1,b}^{B} > F_1 \\ F_{1,b}^{B} \leq F_1 \end{cases}. \tag{34}$$

In order to test the null hypothesis of no structural change, the bootstrap p-value, PV_B (34), must be compared to the desired significance level. This study adopts the 95% confidence level. Therefore, the null hypothesis of coefficient stability is rejected if $PV_B < 0.05$.

An alternative way to test the null hypothesis suggests comparing the value of the F_1 statistic to the bootstrap critical value corresponding to the chosen significance level. The bootstrap critical values for the 90%, 95% and 99% confidence levels are found by sorting the bootstrap values of the simulated statistic, $F_1^{\,B}$, in ascending order and extracting the 270$^{\text{th}}$, 285$^{\text{th}}$ and 297$^{\text{th}}$ elements, respectively. If the actual value of the F_1 statistic exceeds the chosen critical value, the null hypothesis of no structural change is rejected in favour of the alternative hypothesis suggesting a threshold framework.

2.3.2.5 Step 5: Constructing confidence intervals

In order to determine the precision of the threshold estimate, $\hat{\gamma}$, asymptotic confidence intervals for γ are constructed with an LR statistic, $F_2(\gamma)$, which uses the residual sequence computed in Step 1:

$$F_2(\gamma) = K(T-2)\left[\frac{\hat{\zeta}^*(\gamma)'\,\hat{\zeta}^*(\gamma)}{\hat{\zeta}^*(\hat{\gamma})'\,\hat{\zeta}^*(\hat{\gamma})} - 1\right]. \tag{35}$$

The $F_2(\gamma)$ statistic enables us to test the null hypothesis that the observed threshold value is equal to the true threshold, i.e. $H_0 : \gamma = \gamma_0$. For each value of γ, the $F_2(\gamma)$ statistic compares the resulting sum of squared errors, $\hat{\zeta}^*(\gamma)'\,\hat{\zeta}^*(\gamma)$, against $\hat{\zeta}^*(\hat{\gamma})'\,\hat{\zeta}^*(\hat{\gamma})$ which denotes the sum of squared errors corresponding to the estimated threshold, $\hat{\gamma}$. Thus, the $F_2(\gamma)$ test assumes the consistency of $\hat{\gamma}$ for γ_0 in the presence of a threshold effect (see Hansen, 2000 and Chan, 1993).

If the value of the $F_2(\gamma)$ statistic exceeds the critical value at the chosen level of significance, the null hypothesis is rejected. The critical value for $F_2(\gamma)$ at α significance level is computed as

$$c(\alpha) = -2\ln\left(1-\sqrt{1-\alpha}\right). \tag{36}$$

Critical values (36) are used in constructing the following asymptotic confidence interval for γ:

$$\Omega = I(\bullet)\left[\gamma_1(F_2(\gamma_1)), \gamma_2(F_2(\gamma_2)), ..., \gamma_{40}(F_2(\gamma_{40}))\right], \tag{37}$$

where $I(\bullet)$ is an indicator function defined as

$$I(\bullet) = \begin{cases} 1 \\ 0 \end{cases} if \begin{cases} F_2(\gamma) \le c(\alpha) \\ F_2(\gamma) > c(\alpha) \end{cases}. \tag{38}$$

The asymptotic confidence interval (37) represents the “no-rejection” region encompassing all values of γ that satisfy the null hypothesis, $H_0 : \gamma = \gamma_0$. A narrow confidence interval reflects a high precision of the threshold estimate.

This section outlined the econometric methodology that we use to estimate threshold effects in the ERPT. It also explained the bootstrap method for testing the statistical significance of the threshold estimate by constructing asymptotically valid p-values of the LR test statistic. Finally, we showed the procedure for forming asymptotic confidence intervals that are used to judge the uncertainty implied by the point estimate of the threshold. The following section describes the data sources used to test for structural breaks in the ERPT into US import prices.

2.4 Data sources

This section identifies the databases used to collect time series data on import prices, p^i_{kt} and p^i_{wt}, marginal costs, MC_{kt}, and bilateral exchange rates, e_{kt}.

Import prices are approximated by import unit-values computed for each traded commodity as a ratio of import value to import quantity. Export and import unit-values represent a common tool for approximating unavailable series on export and import prices (Berthou and Emlinger, 2011). To the best of the author's knowledge, the only accessible database providing bilateral trade data for a diverse range of countries and commodities is the *OECD International Trade by Commodity Statistics (ITCS).* Since the ITCS database offers annual trade data on value, net weight and quantity only, we compute annual import unit-values.

We consider the following 12 commodities imported by the USA from selected European countries: (1) Spirits and liqueurs (henceforth Spirits); (2) Cigarettes containing tobacco (henceforth Cigarettes); (3) Pigments, paints, varnishes and related materials (henceforth Pigments); (4) Parts of footwear (henceforth Footwear); (5) Materials of rubber (pastes, plates, sheets, etc.) (henceforth Rubber); (6) Builders' joinery and carpentry of wood (henceforth Joinery); (7) Cartons, bags, other containers, of paper, paperback, etc. (henceforth Cartons); (8) Tubes, pipes and fittings, of iron or steel (henceforth Tubes); (9) Peripheral units, including control and adapting units (henceforth Peripheral units); (10) Sailboats, not inflatable, with auxiliary motor or not (henceforth Sailboats); (11) Stockings, ankle-socks and the like (henceforth Stockings); (12) Trade advertising material, commercial catalogues, etc (henceforth Catalogues).

Table 1 in the Appendix summarizes the availability of import unit-value data for each commodity and exporter considered in the empirical analysis. For some trade partners and years, it was not possible to construct unit-values due to the absence or incompleteness of quantity series. Therefore, the set of trade partners and the number of years are different for each product regression, since the methodology applied in this study requires balanced panels. Specifically, an exporting country is dropped from the regression analysis, if there are missing observations associated with it. Similarly, a year is omitted from the beginning or end of the sample period if missing data is observed in that year. Table 2 displays sample periods for all products studied. The longest sample spans a period from 1995 to 2011 (see Spirits and Sailboats). The shortest sample period is observed for Stockings (1996 to 2006).

European exporters are preferred over alternative trade partners due to the availability of detailed data on industry-specific marginal costs of the European Union producers. We approximate marginal costs using annual data on the Industry Producer Price Index (2005=100) (henceforth PPI) retrieved from the *Eurostat Short-term Business Statistics* database. PPI is commonly used as a proxy for marginal cost in the empirical literature on the ERPT (Bussière and Peltonen, 2008). Table 3 displays the set of industries for which the PPI data has been collected. Since none of the accessible PPI databases use the product disaggregation method employed in the *OECD ITCS* dataset, we approximate unavailable series on a commodity marginal cost using PPI data for the industry to which the chosen commodity belongs.

Annual nominal exchange rates measured as the amount of US dollars per 1 Euro or ECU were retrieved from the *Eurostat Economy and Finance* database. For the years preceding the exporter's adoption of the Euro, bilateral nominal exchange rates between the US dollar and the European partner's currency were computed using the *IMF International Financial Statistics* (*IFS*) country data on national currency units per ECU. For example, the bilateral nominal exchange rate between the US dollar and the Austrian shilling was computed as

$$e_{US,AT} = \frac{e_{US,ECU}}{e_{AT,ECU}}, \tag{39}$$

where $e_{US,AT}$ denotes US dollars per Austrian Shilling, $e_{US,ECU}$ represents US dollars per ECU and $e_{AT,ECU}$ stands for Austrian Shillings per ECU. Table 4 shows the Euro adoption date of each trade partner.

2.5 Empirical results

This section summarizes the empirical results from applying the threshold regression methodology outlined in Section 2.3 to the US import data. It proceeds as follows. First, this section reports estimated regression parameters from (18) to infer the contribution of each explanatory variable to the import price. Second, it examines the sign of the ERPT coefficients, β_4 and β_5, and reconciles these estimation results with the benchmark theory of international price discrimination (Knetter, 1989). Third, we report threshold parameter estimates and corresponding bootstrap critical values for the F_1 LR test statistic (see 28), in order to challenge the linearity of the ERPT coefficients. Finally, we illustrate the precision of the obtained threshold estimates by plotting their asymptotic confidence intervals, in order to visualize the level of our certainty about the non-linearity of the ERPT.

Before discussing the estimation results, let us outline the expected signs of the regression coefficients in the estimated specification

$$\begin{aligned}\left(\ln p_{kt}{}^{i}\right)^{*} &= \beta_1\left(\ln MC_{kt-1}\right)^{*} + \beta_2\left(\ln D_{kt-1}\right)^{*} + \beta_3\left(\ln MC_{kt-1}\ln D_{kt-1}\right)^{*} + \\ &\beta_4\left(\ln e_{kt-1} I\left(\ln D_{kt-1} \le \gamma\right)\right)^{*} + \beta_5\left(\ln e_{kt-1} I\left(\ln D_{kt-1} > \gamma\right)\right)^{*} + \zeta_{kt}^{*}.\end{aligned} \tag{18}$$

It follows from the optimal import price (13a) that the expected effect of the marginal cost on the import price is positive. Therefore, $\beta_1 > 0$ as producers have to raise the price of their good in order to cover the increased cost of production.

The price differential, $\left(\ln D_{kt-1}\right)^{*} = \left(\ln p_{kt-1}^{i} - \ln p_{wt-1}^{i}\right)^{*}$, is expected to have a negative effect on the import price. Specifically, an increase in $\ln D_{kt-1}$ suggests that the firm's price becomes less attractive compared to the world price for this commodity. Since consumers are likely to switch to a cheaper supplier, the exporter should decrease the price for his good in order to align it with the world price level, i.e. $\beta_2 < 0$.

The expected sign of the coefficient β_3 is ambiguous, since the two variables comprising the interaction term, $\left(\ln MC_{kt-1}\ln D_{kt-1}\right)^{*}$, have opposite effects on the import price. While the log of the previous marginal cost, $\ln MC_{kt-1}$, has a positive effect on the import price, the log of the lagged price differential, $\ln D_{kt-1}$, generates a negative effect. Therefore, the ultimate sign of the coefficient β_3 depends on the relative magnitudes of these two effects.

The expected signs of the ERPT coefficients are positive, i.e. $\beta_4 > 0, \beta_5 > 0$. The optimal import price (13) suggests that the depreciation of the importer's currency, i.e. an increase in $\ln e_{kt-1}$, raises the import price. This result follows from the assumption of producer currency pricing, whereby the export price equals *X* units of the exporter's currency. The depreciation of the importer's currency implies that more units of the importer's currency are required to purchase *X* units of the exporter's currency. Therefore, the import price rises with the depreciation of the importer's currency. Thus, the sign of both ERPT coefficients is positive, but $\beta_4 > \beta_5$. We showed in Section 2.2 that the ERPT is lower in the upper regime, compared to the lower regime, because consumers are more likely to switch to a cheaper supplier when the switching gain exceeds the switching cost, $d_{it} > s$, i.e. $\ln D_{kt} > \gamma$. Thus, firms reduce the ERPT in the upper regime by cutting the mark-up of price over the marginal cost to prevent consumers from leaving their market (see 14a).

Table 5 presents estimated coefficient values and standard errors from running the unrestricted regression corresponding to the optimal threshold, $\hat{\gamma}$ (27). In order to determine the appropriate critical value for the 2-tail T-test at the desired confidence level, Table 5 reports the degrees of freedom, which are calculated as

$$df = (T-2)K - 5, \tag{40}$$

where "5" reflects the number of regressors and $2K$ denotes the degrees of freedom that are used up as a result of constructing time-demeaned and lagged variables.

The estimation results provide strong evidence of the importance of the nominal exchange rate for determining the import unit-value. This suggests that the ERPT into the US import prices is significantly different from zero. Thus, for 9 out of 12 commodities, the statistical significance of the exchange rate coefficient is confirmed for either the lower or the upper regime. The sign of the statistically significant coefficients on the exchange rate is predominantly positive. This finding on the positive ERPT is consistent with the producer currency pricing, whereby prices are set in the exporter's currency. Therefore, the importer's currency depreciation leads to an increase of the price in the importer's currency, i.e. $\beta_4 > 0, \beta_5 > 0$.

However, the exchange rate coefficients are significantly negative for Rubber, Joinery, Cartons and Peripheral units. This finding implies that despite the US dollar appreciation, which enables the US consumers to purchase the same number of ECU (Euro) as before with fewer US dollars, US import prices increase. Although negative ERPT contradicts the producer currency hypothesis, the increase of the US import prices despite the US dollar's appreciation has been widely documented (Krugman, 1986).

The negative ERPT documented in this study can be justified by the pricing-to-market that causes an excessive fall in the European exporters' mark-ups following the US dollar's depreciation. For instance, we showed that the exporter's mark-up over the marginal cost (10) falls when the importer's demand elasticity increases. We also suggested that sufficiently large depreciation of the importer's currency leads to an increase in the demand elasticity (6a) by raising the price differential, d_{it}, above the threshold. Thus, there is a negative relationship between the extent of the importer's currency depreciation and the size of the mark-up, which is explained by the reduction of the firm's market power during the depreciation. Specifically, since the depreciation causes an increase in the import price of a good whose price is set in the exporter's currency, this good becomes relatively expensive compared to brands imported from other countries. Therefore, the importer's currency depreciation endangers the exporter's market share in the importing country. In order to protect their market share abroad, exporting firms reduce the mark-up of price over the marginal cost. Essentially, firms attempt to stabilize the import price of their good by limiting its increase with a downward mark-up adjustment.

However, firms may overshoot their target level of the import price by an excessively large mark-up adjustment. For example, holding the marginal cost constant, suppose that at the end of the first period a sudden depreciation, Δe_k, led to an increase in the import price, i.e. $(e_{k1} + \Delta e_k)\mu_{k1} MC_k > e_{k1}\mu_{k1} MC_k$. In order to stabilize the import price and return it to the pre-depreciation level, $e_{k1}\mu_{k1} MC_k$, exporter k must decrease the export price by cutting his mark-up, μ_{k1}. Specifically, the next period mark-up must equal $\tilde{\mu}_{k2} = \dfrac{e_{k1}\mu_{k1} MC_k}{(e_{k1} + \Delta e_k) MC_k}$, where $e_{k1} + \Delta e_k = e_{k2}$. However, if the actual mark-up, μ_{k2}, undershoots its target level, $\tilde{\mu}_{k2}$, the resulting import price will fall below its initial level instead of equalling it, i.e. $(e_{k1} + \Delta e_k)\mu_{k2} MC_k < e_{k1}\mu_{k1} MC_k$. This inequality is reflected empirically in the negative sign of the exchange rate coefficients in the restricted (26) and unrestricted (27) regressions of the import price.

Table 5 also reports that, for the majority of commodities considered, the Industry PPI has a positive effect on the import unit value. This evidence is consistent with the optimal import price (13), whereby a higher marginal cost leads to an increase in the import price. However, the marginal cost coefficient is significantly negative for two commodities - Cigarettes and Joinery. The negative pass-through of the marginal cost into the import price can be justified by the exporter's mark-up adjustment in the same way as the aforementioned negative ERPT. Specifically, holding the exchange rate fixed, suppose that an increase in the marginal cost, ΔMC_k, raises the import price from $\mu_{k1} MC_{k1} e_k$ to $\mu_{k1}(MC_{k1} + \Delta MC_k)e_k$. Since an increase in the import price leads to a rise in the demand elasticity (4), the optimal mark-up (10) charged by the firm falls. In order to restore the initial import price level, the next period mark-up must equal $\tilde{\mu}_{k2} = \frac{\mu_{k1} MC_{k1} e_k}{(MC_{k1} + \Delta MC_k) e_k}$, where $MC_{k1} + \Delta MC_k = MC_{k2}$. If the actual mark-up undershoots the required level, i.e. $\mu_{k2} < \tilde{\mu}_{k2}$, the next period import price will fall below the first period level, i.e. $\mu_{k2}(MC_{k1} + \Delta MC_k) e_k < \mu_{k1} MC_{k1} e_k$. Thus, mark-up undershooting may deliver a negative pass-through of the marginal cost change into the import price and explain negative coefficients on PPI in Table 5.

Table 5 also shows that the log of the price differential, $\ln D_{kt}$, is predominantly insignificant for determining the import prices of commodities, except Tubes, Stockings, and Catalogues. This result is consistent with the import price definition (13a), since our model does not predict a linear effect of the price differential on the import price. Within our theoretic framework, the switching gain, d_{kt}, has only a threshold effect on prices via the mark-up channel. Therefore, since the log of the price differential, $\ln D_{kt}$, represents a threshold variable, its effect should be assessed by examining the statistical significance of the threshold estimate, $\hat{\gamma}$.

Table 6 displays threshold parameter estimates and corresponding values of the F_1 LR test statistic (28). In addition, the bootstrap critical values and the bootstrap p-values for F_1 under the null hypothesis are reported. This study finds strong evidence for structural breaks in the ERPT into the import prices of Spirits and Pigments. For both categories, the LR F_1-test statistic is statistically significant at the 99% confidence level with bootstrap p-values of 0.003 and 0.010, respectively. In addition, the threshold effect is close to being statistically significant at the 10% significance level for Rubber, Joinery, Cartons, Stockings and Catalogues, as the bootstrap p-values of the F_1-test do not exceed 0.2.

The point estimates of the threshold parameter suggest that the sign of the threshold effect varies across commodities. For example, the threshold estimate for Spirits equals -0.14, yielding a statistically significant exchange rate coefficient of 0.55 in the lower regime and an insignificant exchange rate coefficient of -0.01 in the upper regime. This result is consistent with the ERPT definition (14). Thus, when the world price of Spirits exceeds the import price of European Spirits substantially, i.e. $\ln D_{kt} < \hat{\gamma}$, the ERPT is high and statistically significant. Intuitively, the importer has no incentive to search for alternative suppliers, since the US import price of the European Spirits is lower than the world price of this commodity. Therefore, as the European exporters do not need to prevent the importer from switching by stabilizing import prices, the observed ERPT is large and significant. However, as the negative difference between the log of the European Spirits' import price and the log of the world Spirits' price approaches zero in the upper regime, the exchange rate coefficient becomes insignificant. The insignificance of the exchange rate coefficient can be explained by the local currency price stability ensured by the European exporters. Specifically, since in the upper regime the price advantage of the European exporters over competitors is not as strong as in the lower regime, the importer may seek an alternative trade partner. Therefore, the European exporters may decide to insulate the import price from the importer's currency depreciation in order to avoid a further increase in the import prices of the European Spirits relative to competitors' prices. As a result of the local currency price stabilization by European firms, the exchange rate may become insignificant for determining US import prices.

In contrast, the threshold estimate for Pigments is positive and statistically significant. The corresponding exchange rate coefficients for the lower and upper regimes equal -0.04 and 0.14, respectively. Out of these two exchange rate coefficients, only the upper-regime coefficient is statistically significant. This result can also be reconciled with our ERPT model (14). Specifically, since in the upper regime the US import price of the European Spirits significantly exceeds the world price of this commodity, the European exporters may choose to stabilize the import price either fully or partially in order to decrease the importer's incentive to switch to a cheaper substitute. As a result of the local currency price stabilization, in the upper regime we observe a low ERPT coefficient, indicating that only a small percentage of the importer's currency depreciation is passed through into the US import prices of the European Spirits.

In order to effectively illustrate the asymptotic confidence intervals for the threshold and the uncertainty about the nature of structural breaks in the ERPT, Figures 1-12 plot the LR function, $F_2(\gamma)$(35), for each value of the threshold parameter. The point estimate of the threshold, i.e. $\hat{\gamma}$, is defined as the threshold parameter value that satisfies the condition $F_2(\gamma)=0$. This result follows from the LR definition (35) which shows that the $F_2(\gamma)$ statistic equals zero at $\gamma=\hat{\gamma}$. The significance of the point estimate of the threshold can be visualized by plotting its asymptotic confidence interval that represents a set of all threshold values for which the LR function, $F_2(\gamma)$, does not exceed the horizontal line. This horizontal line shows the critical value for $F_2(\gamma)$ at the 0.05 significance level. Figures 1 (Spirits) and 3 (Pigments) display narrow asymptotic confidence intervals for the threshold. This observation suggests a high precision of the threshold estimates for Spirits and Pigments, where the threshold effect was found to be statistically significant. For reporting purposes, we also plot the LR function, $F_2(\gamma)$, for the cases that generated a statistically insignificant threshold effect (see Figures 2, 4-12). However, since the confidence interval construction is based on the assumption that the threshold effect is statistically significant, the precision of threshold estimates cannot be inferred from Figures 2 and 4-12.

Overall, our empirical results from Table 5 are consistent with the theoretical model (14b) in suggesting that the exchange rate plays an important role in determining the import price, since for 75% of the products considered the coefficient on the exchange rate, β_4 or β_5, is statistically significant in either upper or lower regime. The evidence in favour of the significance of the marginal cost effect, β_1, is weaker, but we were still able to reject the null hypothesis of the coefficient insignificance in approximately 50% of cases. In contrast, the linear effect of the price differential, β_2, and the coefficient on the interaction term, β_3, are predominantly insignificant at all confidence levels. However, since our theoretical model (14b) predicts neither the linear impact of the price differential, d_{it}, nor the role of the product term, $MC_{it}d_{it}$, the insignificance of the aforementioned two coefficients should not represent a major concern.

Although the statistical significance of the threshold effect has been confirmed for only 16% of cases, the p-value of the structural break test is close to the region of the rejection of the null hypothesis implying no structural change in 60% of cases (see Table 6). This finding suggests that using data with a broader time span and higher frequency is likely to increase the ability of our threshold framework to capture structural breaks in the ERPT.

2.6 Robustness checks

In this section we examine the sensitivity of our estimation results to the chosen import price specification. Specifically, we consider two modifications of the import price model

(18). First, we eliminate the variables $\left(\ln D_{kt-1}\right)^{*}$ and $\left(\ln MC_{kt-1} \ln D_{kt-1}\right)^{*}$ from the model in order to eliminate potential serial correlation between the price differential, $\left(\ln D_{kt-1}\right)^{*}$, and the exchange rate, $\left(\ln e_{kt-1}\right)^{*}$. Specifically, since $\left(\ln D_{kt-1}\right)^{*}$ represents a difference between two import unit-values, any shock affecting the exchange rate may be transmitted to the price differential. Second, we introduce several additional non-linear terms to alleviate potential spurious correlations that result from omitted variables bias. Namely, we augment the import price model (18) with the terms $\left[\left(\ln MC_{kt-1}\right)^{*}\right]^{2}$, $\left[\left(\ln MC_{kt-1}\right)^{*}\right]^{3}$, $\left[\left(\ln D_{kt-1}\right)^{*}\right]^{2}$ and $\left[\left(\ln D_{kt-1}\right)^{*}\right]^{3}$. Using these two modified specifications of the import price, we repeat the five-step estimation algorithm outlined in Section 2.3 and report the parameter estimates.

It is worth noting that many empirical economists have been concerned with possible existence of a unit root in exchange rate series (MacDonald, 1995). While we acknowledge the importance of stationarity for the validity of our statistical inference, unit root tests have not been conducted in this study for two reasons. First, the small number of years in our data sample does not allow us to include a sufficient number of lags into the unit root test regression. On the one hand, using an insufficient number of lags is known to distort the size of a unit root test (Cavaliere et al., 2012). On the other hand, having a larger number of lags aborts the unit root test due to the problem of an insufficient number of observations. Second, the results of a unit root test applied to a short time-span are likely to be unreliable, because the rejection of the null hypothesis of the unit root necessitates a large number of time observations in order to analyse the mean reversion of the variable (MacDonald, 1996).

Although our robustness checks do not address the unit root issues, a joint test of the linearity of the ERPT and the stationarity of data series is an interesting avenue for research that we wish to explore in the future with a more appropriate data sample.

2.6.1 Checks for possible serial correlation among regressors

In this section we eliminate the second and third regressors from the benchmark import price model (18) to examine the robustness of our empirical findings from Section 2.5 to possible serial correlation between the terms containing the price differential, $\left(\ln D_{kt-1}\right)^{*}$, and the exchange rate, $(\ln e_{kt-1})^*$. We estimate the following unrestricted threshold regression:

$$\begin{aligned}(\ln p_{kt}{}^{i})^* &= \beta_1(\ln MC_{kt-1})^* + \beta_2(\ln e_{kt-1} I(\ln D_{kt-1} \le \gamma))^* \\ &+ \beta_3(\ln e_{kt-1} I(\ln D_{kt-1} > \gamma))^* + \zeta^*_{kt}.\end{aligned} \tag{41}$$

Consequently, the restricted regression implies no structural change in the exchange rate coefficient:

$$(\ln p_{kt}{}^{i})^* = \beta_1(\ln MC_{kt-1})^* + \beta_e(\ln e_{kt-1})^* + \zeta^*_{kt}. \tag{42}$$

The estimation results are presented in Tables 7 and 8 of the Appendix. Comparing the robustness check results to the previous findings reported in Tables 5 and 6 does not reveal substantial differences either in terms of the size of the estimated parameters or their statistical significance. This implies that potential responsiveness of the log-transformed price differential, $(\ln D_{kt-1})^*$, to the shocks affecting the log-transformed exchange rate, $(\ln e_{kt-1})^*$, does not undermine the validity of our statistical inference.

Specifically, Table 5 showed that the only variable that has a statistically significant impact on the import unit-value of Spirits is the exchange rate in the lower regime. We also observed that the threshold estimate was statistically significant at the 99% confidence level. Our robustness check results from Tables 7 and 8 confirm previous findings. Specifically, the estimated coefficient on the exchange rate in the lower regime, β_2 , is positive and statistically significant at the 99% confidence level, although it is slightly larger, than before the regression modification (see β_4 in Table 5). Similarly, the value of the estimated threshold parameter, -0.14, is identical to that reported in Table 6 and has the same level of statistical significance, 0.01.

The robustness of our previous estimation results is also confirmed for Cigarettes. We observed in Table 5 that the only statistically significant determinant of the Cigarettes' import price was the PPI, while the exchange rate exhibited neither linear nor non-linear effect on the import unit-value. Our results from running the modified import price regression (41) are consistent with previous observations. First, the only statistically significant coefficient is the coefficient on the marginal cost, β_1 , whose level of significance is higher than that of the PPI coefficient from the baseline regression (see Table 5). Second, the threshold estimate is not statistically significant, as reported previously in Table 6. Thus, in both cases (Tables 6 and 8) we were unable to support our hypothesis that the ERPT into import prices follows a two-regime process.

The results from estimating the modified unrestricted model (41) for Pigments are as encouraging as previously obtained estimates. The robustness check delivered the same point estimate of the threshold as before, 0.40, at the same level of statistical significance, 5%. Similarly, the point estimates of the upper regime ERPT coefficient and their standard errors are identical across Tables 5 and 7. Interestingly, the modified import price specification (41) enabled us to reveal the statistical significance of the marginal cost coefficient, β_1, at the 10% significance level, while it was previously insignificant. However, since in Table 5 the T-statistic of β_1 lies at the margin between the "no-rejection" region and the rejection at the 90% confidence level, this discrepancy is not essential.

Our results from running the robustness check on Footwear data slightly differ from previous findings (Table 5). On the one hand, while previously the marginal cost coefficient, β_1, was statistically insignificant, our new results suggest that the marginal cost has a significant impact on the import price. On the other hand, the exchange rate coefficient in the upper regime, β_3 in Table 7, lost its statistical significance after we modified the baseline specification (18). However, this disparity is explained by a slight difference between Tables 5 and 7 in terms of coefficient point estimates and standard errors. These differences lead the T-statistic to cross the margin between the rejection and "no-rejection" regions in both directions, whereby those coefficients that are significant at a low confidence level may become statistically insignificant and vice versa. However, the similarity between the unrestricted models (18) and (41) lies in our inability to detect non-linearity in the ERPT. In both situations the estimate of the threshold is statistically insignificant, although the p-value from the baseline case, 0.387, is closer to our theory than the new p-value, 0.510 (Table 8).

The results for Rubber differ slightly from the findings corresponding to the benchmark model of import price (18). Previously we determined that the PPI coefficient, β_1, and the lower-regime ERPT coefficient, β_4, were statistically significant at the 99% confidence level (Table 5). After running the robustness check, we still observe a statistically significant coefficient on the PPI index at the 1% significance level, but the lower-regime coefficient on the exchange rate loses statistical significance. Moreover, the upper regime-coefficient on the exchange rate, β_3 in Table 7, becomes significant at the 95% confidence level, although Table 5 reported that large price differentials were not relevant for the ERPT. However, this discrepancy between the ERPT estimates is not important because both Tables 6 and 8 suggest that the bootstrap p-value of the F_1 - test statistic is insufficiently small to reject the null hypothesis of no structural change. Thus, we should adopt the restricted regressions of the benchmark (26) and modified (42) models of the import price and assume a linear effect of the exchange rate on the import price, β_e. Therefore, since we were able to detect a negative and statistically significant effect of the exchange rate in both regressions, the robustness check results are consistent with our initial findings on the ERPT.

The robustness check findings for Joinery are almost identical to the results from running the baseline regression (27) in terms of the size and statistical significance of the parameter estimates. In both cases, the only significant determinants of the import unit-value are the marginal cost and the lower-regime exchange rate, whereby both variables' coefficients are statistically significant at the 99% confidence level. Our conclusion on the linearity of the ERPT also remains unchanged after transforming the import price model (27) into equation (41). Specifically, both Tables 6 and 8 report a statistically insignificant threshold with a point estimate of -0.10.

The robustness check of the ERPT into the import prices of Cartons is consistent with previous findings. Specifically, both Tables 5 and 7 deliver a statistically significant ERPT coefficient with a point estimate of -0.10. However, we note that the coefficient on the PPI becomes statistically significant, unlike the PPI coefficient estimate from the baseline regression (27). This finding can be explained by the absence of the interaction term, $\left(\ln MC_{kt-1} \ln D_{kt-1}\right)^*$, from the modified regression (41). Specifically, the statistically significant PPI coefficient (Table 7) may partially reflect the marginal cost effect that was previously absorbed by the coefficient on the omitted term $\left(\ln MC_{kt-1} \ln D_{kt-1}\right)^*$. Comparing the PPI coefficient, β_1 (Table 7), to the coefficient on the interactive term, β_3 (Table 5), confirms the plausibility of our hypothesis, i.e. the two coefficients are almost identical in size and have similar standard errors. As far as the threshold parameter is concerned, both baseline (27) and modified (41) regressions argue in favour of a linear ERPT with statistically insignificant threshold estimates.

The results from estimating the modified regression (41) for Tubes suggest that our previous findings on the ERPT are affected by the elimination of the terms containing the log of the price differential, $(\ln D_{kt-1})^*$ and $(\ln MC_{kt-1} \ln D_{kt-1})^*$. Specifically, while the exchange rate coefficients were previously statistically insignificant (Table 5), Table 7 shows a statistically significant exchange rate coefficient with a point estimate of -0.20. We suggest that the coefficient on the exchange rate may have absorbed the effect of the omitted terms, $(\ln D_{kt-1})^*$ and $(\ln MC_{kt-1} \ln D_{kt-1})^*$, which were shown to have a statistically significant impact on the import price (Table 5). Specifically, a depreciation of the US dollar relative to Euro increases the differential between the import price of the European good and the world price for this commodity. Thus, the negative exchange rate coefficient (Table 7) may indicate a negative impact of the log of the price differential, $(\ln D_{kt-1})^*$, on the import price.

The elimination of the regressors containing the price differential from the baseline import price model (27) for Tubes also affected the statistical significance of the threshold estimate. While the threshold parameter was previously insignificant (Table 6), it became statistically significant at the 10% significance level after running the modified regression (41). We argue that this finding on the non-linearity of the ERPT reflects the non-linear effect of the omitted interaction term, $(\ln MC_{kt-1} \ln D_{kt-1})^*$. Specifically, Table 5 confirmed that the log of the price differential has a non-linear effect on the import price through the statistical significance of the coefficient on the interaction term, $(\ln MC_{kt-1} \ln D_{kt-1})^*$. After the elimination of the interaction term, the non-linear effect of the price differential may have been reflected in the statistical significance of the threshold estimate, because the existence of threshold implies that the price differential (i.e. threshold variable) has a non-linear impact on the import unit-value. However, our finding on the positive and statistically significant effect of the PPI on the import price is valid for both baseline (27) and modified (41) models.

Examining the robustness check results for Peripheral units suggests no significant differences from the previous output. Both baseline (27) and modified (41) regressions revealed that the only variable having a statistically significant impact on the import price is the upper-regime exchange rate. In both cases, the upper-regime ERPT is negative with a point estimate of -0.39 and -0.38, respectively. Our previous finding on the linearity of the

ERPT is also robust to the exclusion of the price differential terms. Specifically, both Tables 6 and 8 report a statistically insignificant threshold parameter with a point estimate of -0.25. Thus, possible serial correlation among the baseline model (27) regressors has not affected our statistical inference on the ERPT into the Peripheral units' import price.

Our previous empirical findings for Sailboats are also robust to serial correlation, since we are unable to detect substantial differences between Tables 5 and 7 in terms of the size of the coefficient estimates. Thus, the estimated coefficients on the PPI, lower-regime exchange rate and upper-regime exchange rate equal 3.84, 0.16 and -0.44 for the baseline model (27) and 3.38, 0.16 and -0.46 for the modified regression (41), respectively. The only difference between these two cases lies in the statistical insignificance of the PPI coefficient estimate in Table 7, while previously PPI had a significant impact on the import price. However, in both cases, the PPI coefficient estimate lies at the boundary between the "no-rejection" region and the region of the rejection of the null hypothesis. In particular, the baseline (27) PPI coefficient estimate is significant at the 90% confidence level, while the modified (41) estimate is close to the rejection of the null hypothesis of no significance with a T-statistic of 1.60.

Similarly, the omission of the price differential terms in the modified regression (41) for Sailboats did not impact significantly our statistical inference on the ERPT. Similarly to the baseline (27) case, we obtained a threshold parameter with a point estimate of -1.60. Although the associated p-value is lower than previously (Table 6), both p-values are insufficiently small to reject the null hypothesis of linear ERPT.

The results of the robustness check of the ERPT into the import price of Stockings contrast our previous predictions, because the coefficients of the terms which we omitted in the modified regression (41), $(\ln MC_{kt-1} \ln D_{kt-1})^*$ and $(\ln D_{kt-1})^*$, were statistically significant (Table 5). The first difference between the baseline (27) and modified (41) model outputs lies in the statistical significance of the estimated PPI coefficient (Table 7), while previously it was not significantly different from zero (Table 5). We suggest that the coefficient on the log-transformed marginal cost, $(\ln MC_{kt-1})^*$, in the modified regression (41) may have absorbed the impact of the omitted interaction term, $(\ln MC_{kt-1} \ln D_{kt-1})^*$, because the latter contained the marginal cost and was statistically significant at the 95% confidence level (Table 5). This hypothesis seems plausible when we note that the marginal cost coefficient from Table 7 and the interaction term coefficient from Table 5 are both large and positive. But the most striking difference between the baseline regression (27) output and modified regression (41) results is reflected in the statistical insignificance of both exchange rate coefficients, while the lower-regime exchange rate coefficient was previously significant at the 95% confidence level (Table 5). Thus, the omission of the variables that had a statistically significant impact on the import price, $(\ln MC_{kt-1} \ln D_{kt-1})^{*}$ and $(\ln D_{kt-1})^{*}$, affected the ERPT estimates. However, our previous statistical inference on the linearity of the ERPT (Table 6) has not been impacted. The bootstrap replications of the baseline (27) and modified (41) regressions yielded a positive and statistically insignificant estimate of the threshold parameter, although the baseline model p-value lies closer to the region of the rejection of the null hypothesis of no structural change at the 90% confidence level.

We conclude the robustness check for potential serial correlation among regressors by examining the modified regression (41) results for Catalogues. Similarly to the baseline case (27), the point estimate of the ERPT coefficient is positive and statistically significant at the 99 % confidence level. Moreover, neither the baseline (27) nor modified (41) regression outputs could reject the null hypothesis that the PPI coefficient is insignificantly different from zero. Finally, the exclusion of price differential terms from the baseline regression (27) did not impact the size and statistical significance of the estimated threshold parameter. Both Tables 6 and 8 report a statistically insignificant threshold with a point estimate of 0.70. Thus, our findings suggest that potential serial correlation among regressors of the benchmark model (27) of Catalogues' import prices did not undermine the robustness of ERPT estimates.

This section concluded that, for the majority of product categories considered, potential serial correlation among regressors of the unrestricted import price model (27) does not impact the estimates of structural breaks in the ERPT. In order to enhance the robustness of our predictions on the ERPT, we run an additional robustness check in the next section, which examines the possibility of spurious correlations resulting from omitted variables bias.

2.6.2 Checks for possible bias from omitted variables

In this section we are concerned with potential bias stemming from omitted variables. The import price definition (13a) suggests that the import price of good i is affected by the marginal cost, exchange rate and the price differential between good i and its substitute. However, the import price definition (13a) may have omitted additional determinants of the import price. If these omitted variables are correlated with the included determinants of the import price, the coefficient estimates from the import price regression (27) may be biased and inconsistent. A suitable candidate for an omitted variable is a measure of technological improvement, since it affects both the regressor (marginal cost) and the dependent variable (import price) in the threshold regression (27). On the one hand, a more efficient technology lowers labour costs, as producers can substitute machinery for labour in some chains of the production process. On the other hand, technological advancement may affect the final price of the good by improving its quality.

In order to alleviate omitted variables bias, Hansen (1999) proposes to augment the regression with quadratic and cubic terms of those variables which have a linear effect on the dependent variable. Therefore, we augment our baseline specification (27) of the import price with the powers of the log-transformed marginal cost and price differential:

$$\begin{aligned}&\left(\ln p_{kt}{}^{i}\right)^{*} = \beta_1\left(\ln MC_{kt-1}\right)^{*} + \beta_2\left[\left(\ln MC_{kt-1}\right)^{*}\right]^2 + \beta_3\left[\left(\ln MC_{kt-1}\right)^{*}\right]^3 + \beta_4\left(\ln D_{kt-1}\right)^{*} + \\ &+ \beta_5\left[\left(\ln D_{kt-1}\right)^{*}\right]^2 + \beta_6\left[\left(\ln D_{kt-1}\right)^{*}\right]^3 + \beta_7\left(\ln MC_{kt-1}\ln D_{kt-1}\right)^{*} + \\ &\beta_8\left(\ln e_{kt-1} I\left(\ln D_{kt-1} \le \hat{\gamma}\right)\right)^{*} + \beta_9\left(\ln e_{kt-1} I\left(\ln D_{kt-1} > \hat{\gamma}\right)\right)^{*} + \zeta_{kt}^{*}.\end{aligned} \tag{43}$$

The unrestricted model of the import price (43) allows us to infer non-linearities in the regression relationships. For instance, the statistical significance of the coefficient on the power of the marginal cost, i.e. β_2 or β_3, suggests that the marginal cost has a non-linear influence on the import unit-value.

The restricted regression corresponding to the augmented import price model (43) is represented by

$$\begin{aligned}&\left(\ln p_{kt}{}^{i}\right)^{*} = \beta_1\left(\ln MC_{kt-1}\right)^{*} + \beta_2\left[\left(\ln MC_{kt-1}\right)^{*}\right]^2 + \beta_3\left[\left(\ln MC_{kt-1}\right)^{*}\right]^3 + \beta_4\left(\ln D_{kt-1}\right)^{*} + \\ &+ \beta_5\left[\left(\ln D_{kt-1}\right)^{*}\right]^2 + \beta_6\left[\left(\ln D_{kt-1}\right)^{*}\right]^3 + \beta_7\left(\ln MC_{kt-1}\ln D_{kt-1}\right)^{*} + \\ &\beta_e\left(\ln e_{kt-1}\right)^{*} + \zeta_{kt}^{*}.\end{aligned} \tag{44}$$

Before discussing the results from estimating the unrestricted regression (43), let us determine the expected signs of the coefficients on the additional variables. The expected effect of the square (i.e. the second power) of the log-transformed marginal cost is positive, $\beta_2 > 0$. Specifically, an increase of the squared log of the marginal cost, $\left[(\ln MC_{kt-1})^*\right]^2$, implies that either the negative log of the marginal cost has fallen or the positive log of the marginal cost has risen. However, in our data sample the log of the marginal cost may not be negative, because the marginal cost is measured by PPI whose value is always close to 100. Therefore, squared log of the marginal cost has a positive effect on the import price, because an increase of the marginal cost raises the import price (13a).

Similarly, the coefficient on the cube (i.e. the third power) of the marginal cost, $\left[(\ln MC_{kt-1})^*\right]^3$, unambiguously has a positive sign, since an increase in the cube of the log-transformed marginal cost is caused by a rise in the log-transformed marginal cost. Because the log of the import price increases in the log-transformed marginal cost, coefficient β_3 exceeds zero.

In contrast, the expected sign of the coefficient on the squared log of the price differential, β_5, is ambiguous, since it depends on the sign of the log-transformed price differential. A rise in the second power of the log of the price differential, $\left[(\ln D_{kt-1})^*\right]^2$, suggests that either $(\ln D_{kt-1})^*$ has risen and $(\ln D_{kt-1})^* > 0$ or $(\ln D_{kt-1})^*$ has fallen and $(\ln D_{kt-1})^* < 0$. For positive values of the log of the price differential, the log of the import price will fall in the square of the log-transformed price differential, i.e. $\beta_5 < 0$, because the price differential has a negative impact on the import price (see 14a). In contrast, for negative logs of the price differential, $\beta_5 > 0$ holds because a fall in the price differential raises the import price.

The coefficient on the cube of the log-transformed price differential, $\left[(\ln D_{kt-1})^*\right]^3$, is unambiguously negative. Specifically, whether the log of the price differential is positive or negative, an increase of $\left[(\ln D_{kt-1})^*\right]^3$ implies that $(\ln D_{kt-1})^*$ has risen. Therefore, the log of the import price falls in $\left[\left(\ln D_{kt-1}\right)^{*}\right]^{3}$ due to the negative impact of the price differential on the import price, i.e. $\beta_6 < 0$.

Tables 9A, 9B and 10 in the Appendix report the results from estimating the augmented import price specification (43). They support our previous predictions on the extent of the ERPT into Spirits' import prices and its non-linearity. In both the baseline (27) and augmented (43) regressions of the import price, threshold parameter estimate equals -0.14 and is statistically significant at the 99% confidence level. Moreover, in both cases, the upper-regime ERPT is negative and statistically insignificant, while the lower-regime ERPT is positive and significant at the 99% confidence level. In contrast, the marginal cost coefficient in the augmented regression (43) became statistically significant at the 5% level of significance, while previously it was not significantly different from zero (Table 5). However, the large magnitude of the estimated coefficients on the marginal cost and its powers, as well as substantial standard errors associated with these coefficients, suggest that these estimates may have been affected by the serial correlation among the first three regressors in the specification (43).

The robustness check results for Cigarettes are also consistent with previous empirical findings (Table 5). Specifically, both baseline (27) and augmented (43) regression outputs deliver a linear ERPT with a statistically insignificant threshold estimate of -0.21. Furthermore, in both cases, the ERPT estimate is statistically insignificant in either upper or lower regime. Interestingly, the marginal cost coefficient lost its statistical significance after we augmented the baseline model (27) with non-linear terms. However, this difference from previous output (Table 5) is due to a small reduction of the absolute value of the T-statistic, which led to the statistical insignificance of the coefficient that was previously significant at the 90% confidence level.

The case of Pigments did not generate significant deviations from previous empirical predictions (Tables 5 and 6). Both baseline (27) and augmented (43) regressions yielded a statistically significant structural break in the ERPT with a point estimate of 0.40. Moreover, in both cases, the lower-regime ERPT is negative and statistically insignificant, while the upper-regime ERPT is positive and statistically significant at the 99% confidence level. Similarly to Cigarettes, we observe that previously insignificant estimate of the coefficient on the log-transformed marginal cost (Table 5) became statistically significant in the augmented regression (43). This finding is explained by a small increase in the absolute value of the T-statistic, which caused an insignificant coefficient to become statistically significant at the 10% level of significance.

Our previous conclusion on the linearity of the ERPT into Footwear import prices (Table 6) remains unchallenged. Thus, both baseline (27) and augmented (43) regression outputs report a positive and statistically insignificant estimate of structural break in the ERPT. Similarly, in both cases, the lower-regime ERPT estimate is positive and statistically insignificant. However, the upper-regime ERPT estimate from augmented model (43) became zero and insignificant, while previously it was positive and statistically significant at the 90% confidence level (Table 5). We attribute the significance of the upper-regime ERPT coefficient in the baseline case (27) to spurious correlations associated with omitted variable bias, because the baseline regression excluded the cubed price differential, whose coefficient is statistically significant (Table 9B). It is worth noting that previously insignificant coefficients on the price differential and interaction term became statistically significant (Tables 9A and 9B). However, this finding is not surprising, since the T-statistic values corresponding to these two estimates lie at the border between the “no-rejection” region and the critical region for the 90% confidence level.

The robustness check results for Rubber also suggest that the ERPT estimates from the benchmark import price regression (27) may suffer from omitted variables bias. Specifically, the lower-regime ERPT estimate was statistically significant at the 99% confidence level (Table 5), but it is not significantly different from zero in the augmented regression (43). We argue that the lower-regime ERPT coefficient in the baseline case (27) may have spuriously reflected the non-linear impact of the omitted variable that is correlated with the exchange rate, namely $\left[(\ln D_{kt-1})^*\right]^2$, whose coefficient is statistically significant (Table 9A). We are also surprised by the statistical insignificance of the PPI coefficient, while previously the marginal cost had a significant impact on the import unit-value (Table 5). However, the large point estimates and standard errors of the coefficients on the marginal cost and its powers hint that these estimates may have been affected by the serial correlation among marginal cost terms.

Our previous findings on the linearity of the ERPT into the Rubber import price remained valid after the addition of non-linear terms to the baseline regression (27), as both baseline and augmented (43) regressions delivered insufficiently small p-values that failed to reject the null hypothesis of no structural change. Similarly, in both cases the upper-regime ERPT is not significantly different from zero, as both estimation outputs failed to provide evidence of non-linearities in the ERPT.

Our initial findings on the ERPT of Joinery do not seem to be affected by omitted variables bias, because the parameter estimates from the augmented regression (43) are broadly consistent with the baseline regression (27) results. Thus, in both cases, the threshold parameter is statistically insignificant with a point estimate of -0.10, although both bootstrap p-values are close to the region of the null hypothesis rejection (i.e. $pv < 0.2$). The point estimates of the ERPT are also similar in size and statistical significance to our previous estimation results (Table 5). In both baseline (27) and augmented (43) models, the upper-regime ERPT is negative and insignificant, while the lower-regime ERPT is negative and statistically significant at the 99% confidence level.

Our robustness check findings for Cartons also suggest that the initial ERPT estimates (Tables 5 and 6) are not sensitive to potentially omitted variables. Specifically, in both benchmark (27) and augmented (43) models the point estimate of the threshold parameter equals -0.10, but the large size of the associated bootstrap p-values does not allow us to reject the null hypothesis of the ERPT stability. Moreover, in both cases, the upper-regime estimate of the ERPT coefficient is statistically insignificant and equals 0.04, while the lower-regime ERPT is negative and significant at the 90% confidence level. Finally, in both benchmark (27) and augmented (43) regressions we failed to find evidence of the importance of the marginal cost for the import price, as both PPI coefficients are not significantly different from zero.

Comparing our previous findings for Tubes (Table 5) to the ERPT predictions of the augmented regression (43) suggests that the import price specification (27) may suffer from omitted variables bias. Specifically, while previously the ERPT coefficients were not significantly different from zero, the upper-regime ERPT estimate became statistically significant at the 99% confidence level (Table 9B). Thus, the estimated ERPT coefficients of the baseline (27) regression may be subject to omitted variables bias, because the omitted non-linear terms, $\left[(\ln D_{kt-1})^*\right]^2$ and $\left[(\ln D_{kt-1})^*\right]^3$, are statistically significant in the augmented regression (43). However, both regressions confirmed that the log-transformed marginal cost, log-transformed price differential and their product, $(\ln MC_{kt-1} \ln D_{kt-1})^*$, are significant determinants of the import price, since the estimated coefficients on these three variables are statistically significant. Furthermore, in both cases, the ERPT is proved to be linear, as the two bootstrap p-values are too large to reject the null hypothesis of parameter stability.

Examining the augmented regression (43) results for Peripheral units does not indicate that previous ERPT estimates (Tables 5 and 6) contain omitted variables bias. Specifically, both augmented (43) and baseline (27) regressions suggest that the ERPT follows a one-regime process, as the associated bootstrap p-values exceed the desired level of statistical significance. Moreover, in both cases, the point estimate of the ERPT is negative and statistically significant at the 95% confidence level. In contrast, we are surprised by the negative and statistically significant estimate of the marginal cost coefficient (Table 9A), while previous output (Table 5) suggested that the marginal cost has no impact on the import price. However, we doubt the reliability of this coefficient estimate, because the large size of the estimate and its standard error alludes to the serial correlation among the marginal cost terms in the augmented regression (43).

Our previous conclusion about the linearity of the ERPT into Sailboats' import prices (Table 6) could not be overruled after estimating the augmented regression (43) of the import price. Both baseline (27) and augmented (43) regressions report a negative and statistically insignificant estimate of the threshold parameter. Similarly, our previous empirical finding about the insignificance of the exchange rate coefficients is confirmed (Table 9B). We are disappointed by the statistical insignificance of the estimated coefficient on the marginal cost because previously it was significantly different from zero (Table 5) at the 90% confidence level. However, as its T-statistic exceeded the critical value by as little as 0.04, it is not surprising that the statistical significance of the marginal cost coefficient is not robust to the model specification. We also note that the coefficients on the price differential and the interaction term, $(\ln MC_{kt-1} \ln D_{kt-1})^*$, became statistically significant, while previously they were not significantly different from zero (Table 5). However, given that these two regressors serially correlate with variables which were absent from the baseline regression (27), i.e. $[(\ln D_{kt-1})^*]^2$, $[(\ln D_{kt-1})^*]^3$, $[(\ln MC_{kt-1})^*]^2$ and $[(\ln MC_{kt-1})^*]^3$, the point estimates of β_4 and β_7 may not be reliable.

The estimation results of the augmented ERPT model (43) for Stockings did not conflict with the previous empirical findings (Table 5). Specifically, both baseline (27) and augmented (43) regressions report an estimated threshold parameter of 1.42 and a bootstrap p-value that lies outside the region of the rejection of the null hypothesis of no structural change. Moreover, in both cases the lower-regime ERPT is positive and statistically significant, while the upper-regime ERPT is not significantly different from zero. Similarly, in both baseline (27) and augmented (43) regressions the marginal cost coefficient is statistically insignificant, the price differential coefficient is negative and statistically significant, and the coefficient on the interaction term, $\left(\ln MC_{kt-1} \ln D_{kt-1}\right)^{*}$, is positive and statistically significant.

The results from the augmented regression (43) on data for Catalogues support our previous predictions on the size and statistical significance of the parameter estimates (Tables 5 and 6). Thus, both augmented (43) and benchmark (27) regressions suggest a one-regime ERPT by delivering a statistically insignificant threshold estimate of 0.70. Moreover, in both cases, the lower-regime ERPT is positive and statistically significant, while the upper-regime ERPT is negative and insignificantly different from zero. Furthermore, both augmented (43) and benchmark (27) regressions deliver a statistically insignificant coefficient on the marginal cost and a positive coefficient on the price differential, which is significant at the 95% confidence level. Finally, in both cases, the estimated effect of the interaction term, $\left(\ln MC_{kt-1} \ln D_{kt-1}\right)^{*}$, is negative and statistically significant.

In this section we examined the robustness of our predictions on the degree and stability of the ERPT to potential serial correlation among regressors and omitted variables bias. The former issue was tackled by removing from the import price regression the variables that might be serially correlated with the exchange rate. We dealt with the latter issue by adding the second and third powers of selected regressors to the import price regression. Running threshold regression on the modified specifications of the import price suggests that our initial findings on the size and stability of the ERPT effect are robust to serial correlation and omitted variables bias. For the majority of the products considered, the point estimates of the ERPT parameters and their statistical significance have not been affected by adjustments of the import price specification.

2.7 Conclusion

This Chapter studied structural breaks in the ERPT into the US import prices of selected European goods. First, the study proposed a novel theoretical model that justifies threshold effects in the ERPT by structural breaks in the consumer’s incentive to switch to an alternative brand. Specifically, if the consumer’s switching incentive rises above the threshold, the ERPT falls since the exporter decreases the mark-up of price over the marginal cost to prevent the consumer from switching. Second, we employed the threshold regression and bootstrap simulation methodology by Hansen (1999) to test for threshold effects in the ERPT into the US import prices of twelve European goods in 1995-2011. Our estimation output suggests that, for the majority of traded commodities considered, either the LR test statistic rejects the null hypothesis of no structural change or it lies at the margin between the no-rejection and rejection regions. The point estimates of the threshold parameter are consistent with the proposed theoretic model. Specifically, a higher ERPT is observed in the region where the price advantage of the European exporters over competitors is large. Similarly, a lower ERPT characterizes the regime where the European exporters do not possess a significant price advantage over other suppliers. Finally, we checked that our predictions on the degree and stability of the ERPT are robust to serial correlation among regressors and omitted variables bias.

However, our ERPT model has certain limitations. The most evident limitation relates to its reliance on the cost of switching between substitutes, since the switching cost represents a fundamental mechanism generating non-linearities in the ERPT. Some product categories may have substantial switching costs, while for other commodities such costs would be negligible. For example, it would be costly to switch to alternative model of the sailboat, since it requires an adequate training that would enable the user to operate the new model. However, switching to a substitute brand of cigarettes does not entail such training costs. Therefore, our model may not fit all products equally well.

Another limitation of our framework lies in the absence of data on switching costs. To the best of the author’s knowledge, there is no survey reporting such costs, because the majority of customers do not normally record their switching expenses. Thus, we cannot judge whether threshold estimates represent a plausible estimate of switchings costs in the absence of ballpark figures on the switching cost. We are unable to deduce the role of the switching cost in generating thresholds in the ERPT, because there may be other reasons for non-linear response of the import price to the exchange rate. For example, customer may be loyal to a certain product and hesitate to switch, even if the price of his preferred commodity is higher than that of a substitute. If this price differential is small, he may continue buying from the existing supplier, as his utility from consuming the favourite good outweighs the loss that he incurs by failing to switch to a cheaper substitute. However, if the price differential is sufficiently large, the willingness to save may prevail over loyalty and customer may abandon his preferred supplier.

Similarly to the switching cost, customer's loyalty may generate structural breaks in the ERPT. Suppose that a depreciation of the importer's currency generated an increase in the import price of his favourite commodity. If the price differential between this commodity and its substitute is small, the importer is unlikely to abandon his existing supplier due to the brand loyalty. Therefore, the exporter producing the importer's preferred commodity does not have the incentive to offset the increase in the local currency price of his good by limiting the ERPT, since he is unlikely to lose a loyal buyer. However, if his product becomes substantially expensive relative to the substitute, the importer may switch to a rival firm's product. In order to prevent the customer from leaving, the existing supplier needs to offset the increase in the import price of his product by reducing the ERPT. Therefore, the ERPT is non-linear and follows a two-regime process. In the first regime, pass-through is high because the price differential between the preferred good and its substitute is small. In the second regime, ERPT is low since the price differential becomes sufficiently large to exceed its threshold level.

Thus, using the price differential between substitutes as threshold variable does not allow us to determine whether structural breaks in the ERPT are caused by switching costs or brand loyalty. Although the switching cost represents a plausible theoretic mechanism that explains non-linearities in the ERPT, we are unable to confirm that causality runs from the switching cost to the import price in the absence of data on switching costs. Therefore, in the next Chapter we propose a new theoretic model of non-linear PTM and ERPT, which does not rely on the switching cost to justify structural breaks in the parameters. Instead of concentrating on switching costs, we discuss the role of the cost of "entering the market". This concept was borrowed from Krugman (1986) who suggested that the demand for a product depends on the volatility of its price, since customers need time to choose among all affordable products in the market. For example, if fluctuations of a car price are large, customers may not find it reasonable to visit its showroom, because the price may exceed their budget in the near future. Thus, they may not wish to invest into a costly product analysis, if at the end they may not be able to afford the product. Krugman (1986) argues that customers prefer avoiding the suppliers which fail to maintain a reasonable level of price stability. Therefore, due to the importer's preference for price stability, a rational exporter should attempt to mitigate an increase in the import price of his good following the depreciation of the importer's currency.

Using Krugman's proposition on the importer's preference for price stability (Krugman, 1986), in Chapter 3 we build a partial equilibrium model where the extent of the PTM is unstable, since it responds to the inconstant volatility of the import price. Intuitively, the extent of the PTM should be stronger during periods of high volatility of the import price, because importers are likely to switch to a supplier offering a higher price stability. However, during times of low volatility of the import price, limiting the ERPT into the import price may not be necessary, since the likelihood of losing potential or existing customers is smaller. Thus, the ERPT into import prices is likely to be unstable, since the volatility of the import price is inconstant due to currency fluctuations.

3. Chapter 3: Does Currency Volatility Generate Time Variation in the PTM?

3.1 Introduction

There exists abundant empirical research on the ability of the PTM models to explain the dynamics of export and import prices. Goldberg and Knetter (1997) offer a comprehensive review of empirical evidence on the international price discrimination by exporters and incomplete ERPT. Despite the abundance of empirical studies on the ability of exchange rate movements to explain price dynamics, the time variance of the model parameters has not been studied in depth, although the responsiveness of traded goods' prices to currency movements may increase or decrease over time. For instance, Vigfusson et al. (2007) detect widespread instability in the responsiveness of export prices to exchange rate movements. Furthermore, Campa and Goldberg (2002) conduct tests of parameter stability in the relationship between exchange rates and prices.

However, few attempts have been made to provide a theoretical justification behind the instability in the exchange rate elasticity of prices. Froot and Klemperer (1989) were among the first to point out the instability of the PTM over time. In a two-period setting, they show that the impact of an appreciation of the importer's currency on the import price depends on the exporter's perceptions of the duration of the appreciation. If the appreciation is perceived to be temporary, the exporter will not adjust the import price because the appreciation of the importer's currency increases the value of the exporter's profits in his currency. Thus, the exporter prefers keeping the import price intact in order to enjoy higher profit margins, because the exchange rate is believed to revert to the initial level in the next period and erode these profit margins. However, if the importer's currency appreciation is perceived to be permanent, the exporter will unambiguously decrease the import price, since the value of his costs in the importer's currency falls permanently as a result of a permanent appreciation. Thus, the degree of the ERPT into import prices is lower when the exchange rate changes temporarily, as opposed to a permanent currency movement.

In this chapter, we revisit the benchmark theoretic model of PTM (Gagnon and Knetter, 1995; Knetter, 1995) and adjust it to introduce exchange rate volatility, which undermines the stability of the PTM coefficients[2] due to customers' preference for price stability. Specifically, in a volatile exchange rate environment, firms are expected to strongly reduce their export prices following the importer's currency depreciation, because customers dislike large and frequent fluctuations in the import price (Krugman, 1986). In a stable exchange rate environment, exporters have a weaker incentive to decrease the export price after the importer's currency depreciation, because the import price level is relatively stable.

After introducing our theoretic model of unstable PTM, we test the stability of the PTM into the UK export prices using a selection of model mis-specification tests that are robust to varying degrees of parameter evolution (Rossi, 2006). Our test selection includes models with no adaptivity (fixed parameter models), models with moderate adaptivity (recursive tests, rolling regressions and random walk coefficient time varying parameter (RWCTVP) models with small coefficient evolution) and models with high adaptivity (RWCTVP models with large coefficient evolution). The adaptivity is defined as the robustness of a model to the time variation in its parameters. These tests enable us to detect structural breaks in the PTM parameters by examining the ability of a specification to forecast export prices.

Although we could potentially apply structural break tests to the estimated PTM parameters, Rossi (2006) suggests that in a situation of parameter instability we should test jointly for both the significance of a coefficient and its instability. Thus, we should test a joint null hypothesis that implies both parameter constancy *and* coefficient insignificance. Specifically, the first part of the joint null hypothesis of the PTM test implies that the coefficient on the exchange rate in a regression of the export price equals some constant value, while the second part states that this constant value of the exchange rate coefficient equals zero. Rossi (2006) suggests that out-of-sample forecast test represents a superior methodology for jointly testing the significance and inconstancy of a parameter. Therefore, we conduct four out-of-sample forecasting tests – split, rolling, recursive and RWCTVP regressions.

[2] Pricing-to-market coefficients denote coefficients on exchange rate terms in the regression of the export price.

The novelty of this study is three-fold. First, this Chapter provides theoretical underpinnings for the instability of the PTM by extending the stylized PTM model (Gagnon and Knetter, 1995; Knetter, 1995). We show that the instability in the relationship between export prices and exchange rates may be caused by the volatility of the exchange rate, because currency volatility leads to the import price volatility. The importance of the import price volatility for export price-setting was suggested by Krugman (1986), who argued that consumers prefer credible suppliers that maintain a stable range within which import prices fluctuate. Specifically, since choosing an appropriate product may demand significant time and financial resources, customers need a stable price benchmark in order to determine whether the import price is significantly attractive to engage in a costly market research. Using Krugman’s hypothesis on consumers’ preference for price stability (Krugman, 1986), we adopt a new function of the importer’s demand, which depends negatively on the volatility of the import price. The shape of the demand function represents the main distinction between our model and the stylized PTM framework (Knetter, 1995). The addition of the import price volatility to the arguments of the importer’s demand function introduces instability in the response of the export price to the exchange rate, because import price instability discourages consumers from starting to analyze the firm’s product. During periods of high exchange rate volatility, the exporter facing his currency appreciation may wish to correct large import price fluctuations by sharply cutting the export price. When the exchange rate volatility is low, the exporter may not need to reduce his export price substantially after the appreciation, because the range of fluctuations of the import price is likely to be narrow and insufficient to encourage the importer to avoid this product. Thus, in times of high exchange rate volatility, the increase of the import price following the importer’s currency depreciation is relatively low, since the exporter stabilizes the import price level by performing a relatively large decrease in the export price. In contrast, in the situation of low currency volatility, the increase in the import price following the exporter’s currency appreciation is relatively large due to relatively weak reduction of the export price. Therefore, the extent of the ERPT falls in the volatility of the exchange rate.

Second, we use a recently developed forecast encompassing test (Clark and McCracken, 2001) in order to test the statistical significance of the difference between the mean forecasting errors of two nested models. Specifically, we assess a model’s ability to forecast export prices in order to determine the most appropriate specification of the export price evolution. The forecasting ability of the model is described by the size of its average forecasting error. When faced with two export price specifications, we should choose the model that delivers a lower mean forecasting error than alternative model. In order to determine whether the difference between the mean squared errors of the rival specifications is statistically significant, we employ the ENC-NEW forecast encompassing test by Clark and McCracken (2001). They show that ENC-NEW test is the most powerful out-of-sample forecast statistic for small samples.

It is worth noting that Diebold and Mariano (1995) also developed a methodology for comparing predictive accuracy of competing models, but their methodology is not suitable for nested models. However, our econometric framework involves comparing the forecasting ability of nested models, because in order to test for PTM, we need to test the statistical significance of the exchange rate coefficient using two nested models of export price. The unrestricted specification includes exchange rate regressors and the restricted specification excludes them. If firms conduct the PTM by adjusting their export prices following currency movements, the inclusion of the exchange rate in the export price specification should significantly reduce the mean forecasting error. Thus, we need the forecast encompassing test by Clark and McCracken (2001) in order to determine the statistical significance of the difference between the average forecasting errors of the unrestricted and restricted models.

Third, we attempt to design an econometric framework that has a superior ability to predict export prices. To the best of our knowledge, the recent empirical literature has not focused on assessing the forecasting performance of export price models. Although several studies implement rolling regressions to study time variance in the ERPT (Vigfusson et al., 2007), the significance of a model’s forecasting superiority has not been tested rigorously. We attempt to fill this gap in the empirical literature by running four types of out-of-sample tests, i.e. fixed, rolling, recursive and RWCTVP regressions. Out-of-sample tests enable us to assess the ability of the in-sample estimates of the model parameters to predict one-period-ahead values of the export price. Thus, our estimation methodology simultaneously serves two purposes. First, it enables us to find the predictive content of exchange rates for determining export prices using a time varying parameter model. Second, it allows us to detect the specification that shows a superior ability to forecast export prices. Developing sound tools for predicting export prices will assist policy-makers in forecasting future levels of inflation, because the dynamics of the domestic price level depends on fluctuations of the export prices of imported goods.

This Chapter is organized as follows. Section 3.2 discusses the role of the exchange rate volatility on exporters' pricing policies, since currency volatility represents the driver of the ERPT instability in our model. Specifically, we will present the assumptions that we make about the importer's demand function, since the constancy of the PTM parameters in our framework depends on the shape of the buyer's demand function.

Section 3.3 presents a brief overview of three partial equilibrium models of the ERPT and PTM by imperfectly competitive firms, namely the frameworks by Knetter (1989), Gross and Schmitt (2000) and Benigno and Faia (2010). We discuss these particular theoretic models due to their ability to justify a time varying PTM and ERPT into import prices.

Section 3.4 introduces our theoretical framework, which represents a partial equilibrium model featuring a representative exporting firm. This monopolistically competitive firm exports to a destination country whose consumers dislike the volatility of the import price of its good. Through solving the firm's profit-maximization problem we show that the response of the export price to the exchange rate is unstable over time, since the export price depends on the time varying volatility of the import price.

Section 3.5 presents our econometric framework, which represents a selection of out-of-sample forecasting tests designed to detect the importance of the exchange rate for reducing the mean forecasting error of an export price model. The out-of-sample forecasting tests adopted in this study differ on the robustness to parameter evolution over time (i.e. the degree of the regression parameter evolution), in order to enable us to determine the degree of the instability in the PTM and ERPT.

Section 3.6 describes the dataset used to estimate the forecasting performance of competing models of export price. Specifically, we retrieved data on UK manufactured exports to the EU from the *Monthly Review of External Trade Statistics*, since this database disaggregates export price indices by commodity group and offers a relatively high frequency (i.e. monthly). A higher level of product disaggregation increases the precision of the regression coefficient estimates, since various commodities may be subject to different degrees of the PTM and ERPT (Campa and Goldberg, 2002).

Section 3.7 presents empirical results from running rolling, recursive, fixed and RWCTVP regressions of the UK export price indices on the PPI for the output of manufactured goods and Broad Sterling Effective Exchange Rate Index. We report a Root Mean Squared Forecast Error (RMSFE) for each export price specification in order to determine the model that delivers a superior forecasting performance by offering the smallest forecast error. In addition, we present the values of the forecast encompassing test statistic by Clark and McCracken (2001) in order to infer whether the addition of the exchange rate to the export price model significantly reduces its RMSFE.

Section 3.8 outlines an empirical methodology for checking the robustness of the estimation results to seasonal effects in export price series. First, we transform each variable in the export price regression into annualized inflation in order to remove potential seasonality observed over one year. Second, we repeat the estimation procedure from Section 3.7 by applying out-of-sample forecasting tests to the transformed data, which is represented by the annualized inflations of the UK export prices, PPI and exchange rates. Third, we report the resulting RMSFE and the values of the forecast encompassing test statistic by Clark and McCracken (2001), in order to compare the results from running the export price regression on seasonally adjusted data to the empirical findings presented in Section 3.7.

Finally, Section 3.9 concludes this Chapter by summarizing its main empirical findings. Specifically, we will discuss whether models including exchange rates forecast export prices significantly better than the specifications which restrict the exchange rate coefficients to equal zero. We will also determine whether models that accommodate parameter evolution predict UK export prices better than models with a zero degree of robustness to parameter inconstancy.

3.2 The effect of exchange rate volatility on the PTM

The volatility of the exchange rate affects the exporting firm's price setting policies by influencing international trade flows. For instance, Kenen (2000) suggests that increased exchange rate variability may adversely affect future trade volumes and investment due to the uncertainty generated by foreign currency exposure. In order to understand the risk resulting from an adverse movement of the exchange rate, consider a US firm that exports to the UK a good whose price is set in Great British Pounds. An appreciation of the Pound Sterling raises the US firm's revenue expressed in USD, because the number of US dollars that may be obtained for one Pound increases. Conversely, the depreciation of the Pound Sterling generates a fall in the USD revenue of the US exporter, as the conversion of one Pound into US dollars yields a smaller number of units. Thus, the uncertainty of future exchange rate movements implies the unpredictability of the exporter’s revenues. Therefore, exporting firms should incorporate the risk generated by the volatility of the exchange rate into their price-setting policies. For example, US exporters may wish to maintain in the current period large profit margins by charging sizeable mark-ups of price over the marginal cost, if they believe that in the next period the Pound Sterling will depreciate and erode the exporter’s profits expressed in USD.

Not only does the volatility of the exchange rate affect exporters in the economy, but it may also influence importers’ behaviour. Krugman (1986) suggested that buyers dislike frequent fluctuations in the price of the product that they plan to purchase. He explains the buyer’s preference for price stability by noting that the purchase of foreign differentiated commodities follows a two-stage process. For instance, consider a differentiated good that possesses complex characteristics and demands a commitment to researching various options available in the market. Suppose that a buyer considers acquiring an imported car and has to choose between a BMW and alternative model. In the first stage of the decision-making process, he must visit the venues displaying these cars, test-drive available items and study the terms and conditions of the deal. In the second stage, he may proceed to the actual purchase of the chosen car, after having matched his available budget resources to an affordable variety.

However, since visiting the car showroom involves certain financial and time costs, customers need to decide whether it is beneficial to embark on the product analysis before conducting such visits. Specifically, the expected price should be sufficiently attractive to outweigh the costs of the product analysis, which the buyer incurs. Suppose that the exchange rate between the currencies of the importing and exporting countries is volatile. Let us hypothesize that after a costly marketing research, the buyer decided to import the BMW from Germany, but a sudden depreciation of the national currency with respect to the Euro led to a sharp increase of the BMW import price. Let us assume that the extent of the depreciation led the car’s import price to exceed the importer’s budget. Thus, after having incurred substantial costs associated with the product analysis, the importer was unable to afford the car. Therefore, Krugman (1986) suggests that customers consider the firm’s product only when they expect the exporter to maintain a previously announced price level. If they observe that the BMW price is fluctuating frequently, they would rather refrain from visiting its showrooms, because they may be unable to afford the product at the end of the costly marketing research.

Thus, Krugman (1986) justifies the stickiness of import prices by exporters' efforts to maintain import price stability. He argues that the exporter prevents the fluctuations of the import price of his good from exceeding a stable price range in order to attract customers. If the commodity price is set in the exporter's currency, the price expressed in the importer's currency will fluctuate in response to exchange rate movements. Consequently, a sudden depreciation of the importer's currency raises the import price and undermines the importer's belief that in the future the exporter will keep the import price at a previously announced level. If the firm loses its reputation of a stable price-setter, in the future buyers will probably avoid its products and search for a producer with a more credible pricing policy. Therefore, the exporting firm should build its reputation of a credible supplier by maintaining a stability of the import price, in order to encourage customers to embark on the analysis of its product and attract those importers who find that the import price is sufficiently competitive to compensate them for product research costs.

Thus, the volatility of the exchange may lead to a loss of the existing customers or failure to gain new importers due to fluctuations of the import price. Using Krugman's assumption on the importer's preference for price stability (Krugman, 1986), we build a consumer demand function that depends negatively on the import price volatility, which is induced by exchange rate fluctuations. Since the importer's demand depends on the volatility of the exchange rate, the degree of the PTM is affected by currency volatility. Suppose that a monetary policy shock raised the volatility of the exchange rate between the importing and exporting countries. Since the import price represents a product of the export price and the exchange rate, the policy shock raises the volatility of the import price relative to the volatility of prices of domestically produced varieties. As the importer is likely to switch to products whose prices fluctuate less frequently, the exporter must maintain a stable range of the import price in order to prevent a fall of the demand for its good. Specifically, the exporter should limit an increase in the import price when the importer's currency depreciates. Thus, the exporter should conduct the PTM by adjusting the mark-up of price over the marginal cost, in order to stabilize the import price level and prevent it from deviating substantially from the initially announced level. By limiting the degree of the ERPT into import prices, the exporter encourages potential customers to study the characteristics of its product and prevents the existing importers from switching to alternative supplier.

Moreover, since the importer's demand depends on currency volatility, exporters should vary the response of the export price to exchange rate movements, depending on the level of the exchange rate volatility. Higher exchange rate volatility implies higher volatility of the import price, which lowers the demand for imports, since we assumed a negative relationship between the price volatility and the import demand. Conversely, the decrease in the exchange rate volatility leads to an increase in the importer's demand, since importers will substitute the imported good for products that exhibit relatively high price volatility.

Thus, as the volatility of the import price increases due to currency volatility, the firm should offset a larger fraction of the ERPT, since the increase of the import price as a result of the importer's currency depreciation would further raise the volatility of the import price. A further increase in the import price instability as a result of the ERPT would decrease the demand for imports. In contrast, as exchange rate volatility falls, it may not be necessary to significantly limit the ERPT, because the increase in the import price volatility as a result of the ERPT is offset by the fall of the import price volatility following the decrease in the exchange rate volatility.

Since the exporter limits the ERPT into import prices by conducting the PTM through adjustments of the mark-up of price over the marginal cost, both the ERPT and PTM respond to the volatility of the import price. Consequently, the degree of the ERPT and PTM is expected to be unstable, since the volatility of the exchange rate is not constant, unless the exporting country pegs its currency to the importing country's currency, or vice versa. However, in the literature on the PTM and ERPT we only consider cases where the exchange rate between the importer and exporter fluctuates over time, because a time varying exchange rate is essential for estimating the response of export and import prices to currency movements.

Before we proceed to modelling the instability of the PTM and ERPT using an inconstant volatility of the import price, in the next Section we briefly outline theoretic literature on the instability in the response of export and import prices to exchange rate changes. The next section reviews three partial equilibrium frameworks of the imperfect competition in the international trade, which emphasize the role of three channels for generating an unstable PTM and ERPT: namely, the price elasticity of the demand, the cost of switching to a substitute product and the exporter's market share in the importer's country.

3.3 Modelling a time variance in the PTM and ERPT

In this section we outline three theoretic models that justify a time varying ERPT and PTM by exporters operating in an imperfect competition. The assumption of the imperfect competition is essential for analysing the PTM, because monopolistic competitors set prices as a mark-up over the marginal cost. Thus, the existence of the price mark-up allows the firm to engage in the international price discrimination by conducting the PTM. Essentially, the presence of the mark-up of price over the marginal cost explains the firm's market power to discriminate among importers. For example, consider a British firm which exports its product to both the USA and Canada. Assume that the good's price is fixed in the exporter's currency. Suppose that the US dollar experienced depreciation with respect to the Great British Pound, while the exchange rate between the Pound Sterling and the Canadian dollar remained constant. In order to prevent an increase in the USD price of its good, the British exporter should decrease its export price of sales to the US. If the mark-up of price over the marginal cost was absent, as in perfect competition, the decrease of the export price would not be possible, because the marginal revenue from selling the product should cover the marginal cost of producing it. However, the existence of the price mark-up allows the firm to decrease the export price without causing the price to fall below the marginal cost. Thus, the decrease of the price of British exports to the US generates a price differential between the US and Canada, because the export price of the British good is lower for the US market, compared to Canada. Therefore, it is essential to allow for a mark-up of the export price over the marginal cost in order to explain the PTM, which represents the policy of monopolistically competitive firms to vary their export prices in response to movements in the exchange rate between the importer's and exporter's currencies.

The purpose of a brief introduction to theoretic literature on the inconstancy of the PTM and ERPT is to provide additional motivation for using time varying parameter regressions for estimating export price models. Therefore, unlike Chapter 1 where we solved the agents' optimization problems, this section will not offer a detailed derivation of model equations. However, the model solutions can be easily verified by following the algorithm for the firm's optimization problem, which was followed in Chapter 1 while solving the partial equilibrium models by Krugman (1986) and Campa and Goldberg (2002). First, we must provide the functions for the exporting firm's profits and the importing consumer's demand for its product. Second, we must maximize the exporter's profit function subject to the importer's demand, whereby the profit represents the objective function and the demand is the constraint equation. The solution to the profit-maximization problem of the exporting firm yields the optimal export price. Finally, in order to compute the degree of the PTM, we must differentiate the optimal export price with respect to the exchange rate, since the PTM represents the sensitivity of the export price to fluctuations in the exchange rate between the exporting and importing countries.

Since this Chapter examines potential instability of the PTM degree over time, we present three dynamic multi-period set-ups which justify the time variance of the ERPT. We start by reviewing the seminal model of export price determination by Knetter (1989), because our theoretical framework represents an extension of his model. Therefore, it is beneficial to discuss the baseline model before extending it.

Our interest in the second model (Gross and Schmitt, 2000) is explained by its two-period outlook, where the ERPT into import prices varies across periods due to the cross-period interdependence of price-setting decisions. Specifically, the first-period export price determines the firm's profits in the second period, because a lower price in the first period allows firms to gain new customers. Moreover, some customers gained in the first period will continue importing from the firm in the second period, since importers face a cost of switching to an alternative supplier. Thus, the second-period profit increases as a result of the reduction in the first-period price. Since our model of time varying ERPT represents a multiple time period framework containing more than two periods, it is beneficial to start with a theoretic contribution that justifies ERPT variation across two periods.

The motivation behind the discussion of the third model (Benigno and Faia, 2010) lies in its structure of the mark-up of price over the marginal cost. Specifically, mark-ups vary because the firm's market share fluctuates over time. Intuitively, a variable market share implies an inconstant market power of the firm. Since the mark-up of price over the marginal cost reflects the firm's market power, a variable market share leads to an unstable mark-up. Consequently, the impact of the exchange rate on the import price becomes inconstant as a result of the variability of the price mark-up over the marginal cost.

3.3.1 Benchmark model of the time varying PTM in the imperfect competition

Knetter (1989) was among the first to model the PTM. He considers an imperfectly competitive firm which exports to a number of foreign countries indexed by *i*. The firm's profits are denoted by Π_t and calculated in each period t $(t = 1,2,3,...,T)$ as follows:

$$\Pi_t = \sum_{i=1}^{N} p_{it} q_{it} - C\left(\sum_{i=1}^{N} q_{it}\right)\delta_t , \qquad (1)$$

where p_{it} denotes the price expressed in the exporter's currency and q_{it} stands for the quantity of product demanded by importing country, *i*. *C* defines a function which measures the exporter's costs expressed in his own currency. The firm's costs, *C*, depend positively on the quantity of goods sold, q_{it}. The random variable, δ_t , accounts for shifts in the cost function due to a number of unmeasured factors. For example, a positive shock to input prices, such as an oil price shock, will shift the cost function upwards .

The optimal export price charged in each market is determined through maximizing the exporter's profit function (1) subject to the importer's demand

$$q_{it} = \Phi_i\left(s_{it} p_{it}\right)v_{it} . \qquad (2)$$

The quantity demanded by market i at time t, q_{it}, is a function of the export price, p_{it}, and the exchange rate, s_{it}, defined as the number of units of the importer's currency required to purchase one unit of the exporter's currency. A random variable, v_{it}, is included to accommodate for unmeasured shifts in the demand function. For example, a shift of consumer tastes in favour of the imported product generates an upward shift of the demand function.

Substituting the demand function (2) into the firm's profit function (1) and differentiating profits with respect to the period-specific export price, p_{it}, yields the following rule for determining the optimal export price:

$$p_{it} = c_t\left(\frac{\varepsilon_{it}}{\varepsilon_{it} - 1}\right), \qquad (3)$$

where c_t denotes the marginal cost of production incurred at time t. Note that the marginal cost of producing an additional unit of output does not depend on the export destination. Specifically, Knetter (1989) assumes that the firm's good sold to one importing country is identical to its good exported to another country. Therefore, the marginal costs of producing an additional unit of the good are equalized across export destinations. ε_{it} stands for the country-specific elasticity of demand with respect to the import price. Unlike the marginal cost, the price elasticity of demand is specific to the importer, whereby the demand in one importing country may be more sensitive to a 1% increase in the import price than the demand of another country.

Thus, similarly to the model by Krugman (1986) reviewed in Chapter 1, the export price (3) is set as mark-up over the marginal cost, where the mark-up, $\left(\frac{\varepsilon_{it}}{\varepsilon_{it}-1}\right)$, is a function of the price elasticity of the demand. The optimal export price (3) reflects the international price discrimination, since export prices vary across importers due to the destination-specific nature of the demand elasticity, ε_{it}, even though the marginal cost of production is common across destinations.

The effect of the exchange rate on the export price is introduced through the dependence of the demand function, Φ_i (2), on the import price, $s_{it} p_{it}$. Since the import price is sensitive to the exchange rate, the importer's demand is also affected by currency fluctuations, because a depreciation of the importer's currency raises the import price, while its appreciation generates a decrease of the import price. Since the importer's demand fluctuates with currency movements, the elasticity of the demand with respect to the import price also responds to changes in the exchange rate. The response of the demand elasticity to currency fluctuations depends on the assumptions that we make about the demand schedule. If the importer's demand becomes more elastic when the import price increases, the depreciation of the importer's currency leads to a rise in the demand elasticity. In contrast, if the importer's demand elasticity falls in the import price, the depreciation of the importer's currency decreases the demand elasticity, ε_{it}.

By affecting the elasticity of demand with respect to the import price, a change in the exchange rate impacts the mark-up of the export price over the marginal cost. Specifically, let us assume that the elasticity of the importer's demand increases in the import price.

Therefore, a depreciation of the importer's currency, i.e. a rise in s_{it}, raises the value of the demand elasticity, ε_{it}, by increasing the import price. From the optimal export price definition (3) it is obvious that the export price, p_{it}, falls in response to the importer's currency depreciation due to a decrease of the price mark-up over the marginal cost. Since the degree of the PTM represents the response of the export price to currency movements, the extent of the PTM is negative in the case when the elasticity of the importer's demand rises in the import price.

Thus, in this model the PTM arises from the link between the exchange rate and the price elasticity of demand, which represents an argument of the optimal export price function (3). If the demand elasticity is constant and unresponsive to the import price, the magnitude of the PTM will be zero, because exchange rate movements will not impact the optimal mark-up of the export price over the marginal cost.

As far as the extent of the ERPT is concerned, it also depends on the firm's perceptions of the response of the importer's demand elasticity to an increase in the import price. With a constant elasticity of the demand with respect to the import price, a depreciation of the importer's currency by 1% leads to an increase of the import price by 1%, because the mark-up of the export price over the marginal cost is unresponsive to currency fluctuations. If the demand elasticity increases in the import price, a 1% depreciation of the importer's currency raises the import price by less than 1%, because the mark-up of the export price (3) over the marginal cost falls in the demand elasticity. Finally, a negative relationship between the import price and the price elasticity of the importer's demand implies that a 1% depreciation of the importer's currency raises the import price by more than 1%, because the price mark-up over the marginal cost increases following a fall in the demand elasticity.

Knetter's model shows that the degree of the PTM and ERPT varies over time if the elasticity of the importer's demand with respect to the import price is inconstant. Specifically, the size of the PTM and ERPT depends on the response of the mark-up of the export price over the marginal cost to the exchange rate. Since the mark-up of the export price (3) represents a function of the price elasticity of demand, the instability of the demand elasticity leads to a time variance of the PTM and ERPT. While this model successfully justifies the instability of the PTM and ERPT by the inconstancy of the price elasticity of the importer's demand, it does not explain the causes of unstable demand elasticity. The export price-setting framework by Gross and Schmitt (2000) suggests that the sensitivity of the demand to prices may vary across periods due to the existence of consumers' costs of switching to a substitute good.

3.3.2 Time varying PTM in dynamic oligopolistic competition with switching costs

One of the limitations of the model by Knetter (1989) lies in the absence of the competition between alternative producers of the same good. However, the exporter cannot ignore the existence of the competitors which sell a close substitute for his good, because importers may switch to a producer offering a more attractive price. Specifically, a decrease of the export price set by a competitor may cause a fall in the exporter's market share in the importing country. Therefore, the exporter's price-setting behaviour depends on rivals' pricing strategy due to the risk of losing the market share in the face of competition.

Gross and Schmitt (2000) address the importance of pricing interactions among competitors for the ERPT relationship. They build a two-period model featuring two foreign producers denoted by A and B. Customers who wish to switch to a substitute good must incur a cost of switching. The model assumes that foreign producers sell to a market where local production is absent. The discounted profits for producer k $\left(k = A, B\right)$ are modelled as follows:

$$V^k = e_1^k \Pi_1^k \left[p_1^A, p_1^B, X_1^k\right] + \lambda^k e_2^k \Pi_2^k \left[s^k\left(p_1^A, p_1^B\right), p_2^A, p_2^B, X_2^k\right] . \qquad (4)$$

Thus, the exporter's discounted profits represent a sum of the profits earned in the first period and the second-period profits discounted using a discount factor, λ^k. e_t^k $\left(t = 1,2\right)$ denotes the exchange rate in period t, which is expressed as the number of units of exporter $k's$ currency per unit of the importer's currency. The discounted profit function (4) hints cross-period interdependence of price-setting decisions. Specifically, note that the import prices charged in the first period by the two rivals, p_1^A and p_1^B, affect their current and future profits, Π_1^k and Π_2^k. The relationship between the first-period prices and the second-period profits is due to the effect of the initial price levels on the firms' market shares, s^k.[3] A reduction in the import price of the first period allows the firm to increase its market share by attracting new customers and boost its

[3] Note that all prices are expressed in the importer's currency, as opposed to Knetter's set-up (Knetter, 1989).

future profits. X_t^k denotes a vector of exogenous variables which determine contemporaneous profits for each supplier, e.g. costs of production and exchange rates.

The algorithm for determining the optimal import prices set in the first and second periods is performed in two steps. First, we find the second-period import price by maximizing the second-period profits, Π_2^k, with respect to the second-period price, p_2^k, conditional on the import price which was observed in the first period, p_1^k. Second, the firm's total profits (4) are maximized with respect to the first-period import price, p_1^k, in order to determine the optimal import price for the first period. The functional forms of the optimal import prices for each period and supplier are defined as follows:

$$\hat{p}_2^A = f_2\left(p_1^A, p_1^B, X_2^A, X_2^B\right), \tag{5a}$$

$$\hat{p}_2^B = g_2\left(p_1^A, p_1^B, X_2^A, X_2^B\right), \tag{5b}$$

$$\hat{p}_1^A = f_1\left(X_1^A, X_1^B, X_2^A, X_2^B\right), \tag{5c}$$

$$\hat{p}_1^B = g_1\left(X_1^A, X_1^B, X_2^A, X_2^B\right). \tag{5d}$$

Thus, the first-period import price set optimally by firm *A* (5c) is determined by the exchange rates and costs of production faced by the two exporters in the first and second periods. The optimal import price charged by firm *B* in the first period (5d) is determined by the same set of variables as the optimal price of firm *A* in the first period. Similarly, the optimal import prices set by the two competitors in the second period (5a and 5b) are determined by a common set of variables. This variable set is composed of the first-period import prices charged by the two firms and the second-period vectors of exogenous variables faced by the two competitors.

Since prices are expressed in the importer's currency, differentiating the price with respect to the exchange rate yields the degree of the ERPT. If prices were expressed in the exporter's currency, the derivative of the price with respect to the exchange rate would give the degree of the PTM. However, the degree of the ERPT provides an insight into both ERPT and PTM, since these two phenomena operate in opposite directions. Specifically, an incomplete pass-through may be explained by the PTM, whereby the exporter lets his profit margin absorb the exchange rate movement and limits the increase in the import price following the importer's currency depreciation by a downward mark-up adjustment (Knetter, 1989).

Consider a movement in firm $A's$ first-period exchange rate, e_1^A, which is one of the elements comprised by the vector of exogenous variables, X_1^A. The movement in firm A's first-period exchange rate affects the current and future import prices set by the two competitors, p_1^k and p_2^k. Specifically, current exchange rate determines future import prices, because p_2^k is affected by the previous import price, p_1^k, which is sensitive to e_1^A. In order to determine the response of the first-period import price to the contemporaneous exchange rate, the exporter's profit function (4) must be totally differentiated.[4] The solution to this total differentiation problem yields the following set of comparative static equations which provide an insight into the ERPT of firm A's exchange rate into the first-period import prices set by producers A and B:

$$\frac{dp_1^A}{de_1^A} = -\frac{D_1^A}{V}(1-\varepsilon_1^A)V_{BB}^B \text{ and } \frac{dp_1^B}{de_1^A} = \frac{D_1^A}{V}(1-\varepsilon_1^A)V_{BA}^B, \tag{6}$$

where

$$V_{kk}^k = \frac{\partial V_k^k}{\partial p_1^k},\ V_k^k = \frac{\partial V^k}{\partial p_1^k},\ V = V_{AA}^A V_{BB}^B - V_{AB}^A V_{BA}^B, \text{ and } \varepsilon_t^A = -\frac{\partial D_1^A}{\partial p_1^A}\frac{p_1^A}{D_1^A}. \tag{6a}$$

D_t^k denotes the importer's demand faced by firm k in period t, ε_t^k is the elasticity of demand for imports from firm k at time t with respect to the current import price. Gross and Schmitt (2000) prove that the sign of the ERPT (6) into both import prices depends on the price elasticity of demand, ε_t^k. If demand is inelastic $\left(\left|\varepsilon_t^k\right| < 1\right)$, the ERPT into the import prices of both producers is positive. In contrast, an elastic demand $\left(\left|\varepsilon_t^k\right| > 1\right)$ would yield a negative ERPT of firm A's first-period exchange rate into the import prices set by producers A and B in the initial period.

The intuition behind the importance of the price elasticity of demand for the extent of the ERPT is straightforward, since the demand elasticity measures a proportionate reduction of sales as a result of the import price increase. An appreciation of firm A's currency suggests that e_1^A decreases. Consequently, the exporter's production costs expressed in the importer's currency, $\frac{c^A}{e_1^A}$, increase, where c^A denotes firm $A's$ constant marginal cost of production expressed in its own currency. Therefore, the producer should increase the import price, p_1^A, in order to offset the loss of his first-period profits,

[4] For a full exposition of the total differentiation of the discounted profits, refer to Gross and Schmitt (2000).

i.e. $\Pi_1^A = (p_1^A - \frac{c^A}{e_1^A})D_1^A$, which he suffers due to an increase of production costs. As a result of the cost effect, the first-period import price of firm *A* increases following the exporter's currency appreciation. Consequently, the derivative of the first-period import price with respect to the contemporaneous exchange rate, $\frac{dp_1^A}{de_1^A} < 0$, is negative.

Following an increase in p_1^A, firm *B*'s import price, p_1^B, also rises since the two pricing strategies are strategic complements by assumption. In game theory, strategic complements imply that a player prefers to be more aggressive, when the other player acts more aggressively (Bulow et al., 1985). Price increase represents an example of aggressive price strategy. Thus, when firm *A* plays aggressively by raising its import price, firm *B* mimics this aggressive move by increasing its own price.

However, apart from affecting the exporter's first-period profits, p_1^A also influences his second-period profits due to the presence of consumer costs of switching to a substitute good. Switching costs imply that some of the customers of firm *A* are locked within their first-period consumption pattern and unable to switch to alternative supplier. The existence of the "locked-in customers" suggests that the demand for firm *A*'s product is inelastic with respect to the import price. Firms may exploit this type of consumers and attract them in the first period by a decrease in the import price despite the increase in production costs expressed in the importer's currency as a result of the appreciation of the exporter's currency, i.e. $\frac{dp_1^A}{de_1^A} > 0$. Due to a lower first-period import price, firm *A* will lose in the short-run by suffering smaller first-period profits. However, in the long run, firm A will gain additional revenues from those consumers who started purchasing its product in the first period because of its price reduction and remained attached to the current supplier in the second period as a result of substantial switching costs. Therefore, the reduction in the first-period import price is essentially firm *A*'s investment in its second-period profits, because the market share gained in the first period increases the next period's profits thanks to the existence of "locked-in customers" (Klemperer, 1987).

Since the first-period import price affects the exporter's profits in both periods, a change in the first-period exchange rate, e_1^A, affects the import price set by firm *A* in both first and second periods. Moreover, firm *A*'s first-period exchange rate also affects the second-period import price set by firm *B* through the effect of e_1^A on firm *A*'s second-period price, because each producer mimics the pricing strategy of its competitor. Specifically, each firm responds to a price reduction (increase) of the competitor by reducing (raising) its own price. A non-zero effect of the current exchange rate on the future import prices can be confirmed by differentiating the second-period prices (5a and 5b) with respect to e_1^A:

$$\frac{dp_2^A}{de_1^A} = \frac{\partial f_2}{\partial p_1^A}\frac{\partial p_1^A}{\partial e_1^A} + \frac{\partial f_2}{\partial p_1^B}\frac{\partial p_1^B}{\partial e_1^A} \text{ and } \frac{dp_2^B}{de_1^A} = \frac{\partial g_2}{\partial p_1^A}\frac{\partial p_1^A}{\partial e_1^A} + \frac{\partial g_2}{\partial p_1^B}\frac{\partial p_1^B}{\partial e_1^A}. \tag{7}$$

Thus, the reaction of firm *A*'s import price to a change in the past exchange rate, e_1^A, is the sum of two effects: an own price effect and a strategic effect. The own price effect implies that the past exchange rate, e_1^A, affects the current import price of firm *A* by influencing the firm's import price in the first period. The strategic effect suggests that the past exchange rate, e_1^A, is relevant to the second-period import price set by producer *A* by affecting the competitor's past price. The derivative of the second-period import price of firm *B* with respect to the past exchange rate of firm *A* also represents the sum of an own price effect and a strategic effect. However, the sign of the second-period ERPT (7) is ambiguous because the own price and strategic effects have opposite signs (see proof in Gross and Schmitt, 2000). Thus, the direction of the exchange rate effect on future import prices cannot be predicted with certainty.

The model by Gross and Schmitt (2000) delivers a dynamic ERPT relationship, because the assumption of the cost of switching between substitute goods allows them to justify a time variation in the relationship between the exchange rate and the import price. Specifically, the first-period ERPT is different from that of the second period, because the first-period import price only responds to contemporaneous exchange rate, while the second-period price absorbs the effects of both current and past exchange rates. Moreover, the firm's import price is also affected by the exchange rate between the currencies of the importer and the competitor. Since the firm's import price absorbs fluctuations of multiple exchange rates, unambiguous predictions on the degree of the ERPT cannot be delivered.

Another limitation of this model lies in the constancy of the firm's market share, which is fixed at the first-period level and determined by the current import prices set by the two competitors. Benigno and Faia (2010) offer a more realistic price-setting scenario, where firms' market shares evolve over time and induce an instability in the response of the import price to currency fluctuations.

3.3.3 Time variance of the ERPT in the context of unstable market shares

Benigno and Faia (2010) remove the assumption of a sticky market share adopted in Gross and Schmitt (2000) and analyze the effect of a dynamic market share on the optimal import price. The globalization of the international trade leads to a continuous change in the number of suppliers in the market. Therefore, the market share of any producer is likely to evolve over time. Since the firm's market share affects its profits, swings in the market share affect its optimal import price. Thus, Benigno and Faia (2010) explain time variation in the ERPT into import prices by fluctuations in market shares.

Benigno and Faia (2010) build a two-country model with multiple production sectors. There exists a total of N differentiated goods available in the domestic market, of which N_f are supplied by foreign producers and N_h are produced by home firms. In all subsequent relationships, subscript f denotes foreign suppliers from Country F and subscript h refers to domestic firms from Country H. The optimal demand of the home country for good i produced in sector k is defined as:

$$Y_i = \left(\frac{P_i}{P_k}\right)^{-\sigma}\left(\frac{P_k}{P}\right)^{-\theta} Y\,, \tag{8}$$

where σ defines the elasticity of substitution among the differentiated goods which belong to sector k and θ stands for the elasticity of substitution across production sectors. P_i denotes the price of good i, P_k defines the aggregate price for sector k, P refers to the aggregate price index for the entire economy and Y stands for the economy-wide demand.

Similarly to the ERPT framework by Gross and Schmitt (2000), this study incorporates the exporter's market share, ξ_i, into the firm's profit maximization problem. The effect of the market share on the optimal import price is modelled via the elasticity of demand for good Y_i with respect to its price, P_i:

$$\tilde{\sigma}_i = \frac{\partial Y_i}{\partial P_i}\frac{P_i}{Y_i} = \frac{\partial \ln Y_i}{\partial \ln P_i} = -\sigma + \sigma \frac{P_i}{P_k}\frac{\partial P_k}{\partial P_i} - \theta \frac{P_i}{P_k}\frac{\partial P_k}{\partial P_i}\,, \tag{9}$$

where the demand definition (8) was substituted for Y_i. The absolute value of the price elasticity of demand (9) can be expressed as follows:

$$|\tilde{\sigma}_i| = \sigma - (\sigma - \theta)\xi_i, \tag{10}$$

where ξ_i denotes the market share gained by firm i in sector k:

$$\xi_i = \frac{P_i}{P_k}\frac{\partial P_k}{\partial P_i} \tag{10a}$$

Let us assume that the cross-variety demand elasticity exceeds its cross-sector elasticity in absolute terms, i.e. $|\sigma| > |\theta|$. Thus, a greater market share, ξ_i, leads to a lower $|\tilde{\sigma}_i|$, which denotes the responsiveness of the demand for a good to a change in its price. Intuitively, when the firm has a large market share, there are few substitutes available to consumers who wish to switch. Therefore, an increase in the firm's price would not lead to a significant reduction in the demand for its product, because customers do not have many alternative suppliers.

Since the size of the market share determines the price elasticity of demand (10), it is crucial for the degree of the PTM and ERPT. Intuitively, a higher market share gives the firm a monopoly power and enables it to vary export prices in response to exchange rate shocks. In order to observe the implications of the market share for the extent of the ERPT, the optimal export price for good i must be determined. Similarly to Knetter's set-up (Knetter, 1989), a domestic firm in country H chooses the optimal price which maximizes its profits subject to the demand for its product (8). The solution to the firm's profit maximization problem yields a price expression which is analogous to the price definition (2):

$$P_{h,t} = \frac{\tilde{\sigma}_{h,t}}{\tilde{\sigma}_{h,t} - 1}\frac{W_t}{A_t}, \tag{11}$$

where W_t stands for nominal wage in country H's labour market and $\tilde{\sigma}_{h,t}$ denotes the price elasticity of the demand for domestic good. A_t denotes shifts in the productivity level of the economy and was absent from the optimal price definition (2).

Firm in country F, which supplies the good market of country H, solves an analogous profit maximization problem, although the latter is affected by the nominal exchange rate, S_t, between the currencies of countries F and H. The optimal import price set by the foreign firm is defined as follows:

$$P_{f,t} = \frac{\tilde{\sigma}_{f,t}}{\tilde{\sigma}_{f,t} - 1}\frac{S_t W_t^*}{A_t^*}. \tag{12}$$

The nominal exchange rate, S_t, is defined as the number of units of country *H*'s currency per unit of country *F*'s currency. W_t^* stands for the nominal wage determined in country F's labour market. A_t^* represents a productivity shifter for the economy of country *F*. $\tilde{\sigma}_{f,t}$ denotes the price elasticity of the demand for foreign good.

Thus, the optimal prices set by firms in countries *F* (12) and *H* (11) represent a time varying mark-up over the marginal cost expressed in the buyer's currency, where the mark-up is a function of the elasticity of the demand for the firm's good with respect to its price. The existence of the mark-up enables the firm to vary the export price in response to shocks to the exchange rate, S_t.

In order to understand the sign of the exchange rate effect on the optimal import price (12), Benigno and Faia (2010) conduct a log-linear approximation of (12) using the following definition of the market share:

$$\xi_h = \frac{P_h Y_h}{N_h P_h Y_h + N_f P_f Y_f}, \tag{10b}$$

where Y_h and Y_f represent outputs of home and foreign firms, respectively. The log deviation of the import price (12) from its steady-state level is defined as follows:[5]

$$\hat{P}_{f,t} = ks_h\left(\hat{P}_{h,t} - \hat{P}_{f,t}\right) + \hat{W}_t^* + \hat{S}_t - \hat{A}_t^*, \tag{13}$$

where $k = \frac{\sigma - 1}{\overline{\sigma} - 1}\frac{\sigma - \theta}{\overline{\sigma}}\frac{1}{N}, \overline{\sigma} = \sigma - \frac{\sigma - \theta}{N}, s_h = \frac{N_h}{N}$ and $s_f = \frac{N_f}{N}$.

Thus, the import price of the foreign good is affected positively by the nominal exchange rate, the foreign nominal wage and the price differential between the domestic good and its foreign substitute. The import price is impacted negatively by the foreign shifter of the productivity level, since an increase in the productivity reduces production costs.

The extent of the ERPT into the import price (13) is determined by the derivative of the price, $\hat{P}_{f,t}$, with respect to the nominal exchange rate, $\frac{\partial \hat{P}_{f,t}}{\partial \hat{S}_t}$. The degree of the ERPT depends crucially on the level of the domestic firm's market share. If the home firm's market share is zero $(s_h = 0)$, foreign firms fully dominate the domestic market, which

[5] The symbol "^" denotes the log-deviation of a variable from its steady-state level.

enables them to fully pass-through exchange rate changes into the import price without losing their market share. Therefore, foreign firms can afford a complete ERPT into the import price, i.e. $\frac{\partial \hat{P}_{f,t}}{\partial \hat{S}_t} = 1$.

However, the case of a full dominance of the home market by foreign suppliers is not plausible. For most goods and markets, the home market is divided between domestic and foreign producers. Thus, the market shares of the firms from Countries *H* and *F*, s_h and s_f, exceed zero. Consequently, the degree of the ERPT into the import price is different from one. Consider the effect of the appreciation of Country *F*'s currency, i.e. an increase in S_t. A large increase in the import price, $\hat{P}_{f,t}$, generated by the appreciation of the exporter's currency might lead to a loss of the market share by the foreign firm, since the market share (10a) depends on the good's price. A fall in the firm's market share increases the price elasticity of demand (10) and lowers the mark-up of the import price (12) over the marginal cost. Consequently, a fall in the price mark-up generates an incomplete ERPT into the import price, which fails to increase by 1% in response to a 1% appreciation of the exporter's currency. The incomplete ERPT is caused by the PTM reflected in a downward adjustment of the price mark-up over the marginal cost as a result of the fall of the exporter's market share.

The response of the import price to exchange rate shocks is also affected by the price differential between the domestic and foreign varieties. The appreciation of the foreign exporter's currency increases the import price of his product (12) and lowers the price gap, $\left(\hat{P}_{h,t} - \hat{P}_{f,t}\right)$. Since the decrease of the price differential has a negative impact on the import price (13), the responsiveness of the price differential to currency fluctuations prevents the import price from moving one-to-one with the exchange rate, i.e. $\frac{\partial \hat{P}_{f,t}}{\partial \hat{S}_t} < 1$. Intuitively, the appreciation of the foreign country's currency makes the imported goods expensive relative to the domestically produced output. Thus, the appreciation provides the importer with an incentive to switch to a domestic supplier, which depresses the exporter's market share. Since a fall in the market share increases the price elasticity of demand (10) and reduces the mark-up of the import price (12) over the marginal cost, the degree of the ERPT falls in the price differential between the domestic and foreign goods, $\left(\hat{P}_{h,t} - \hat{P}_{f,t}\right)$.

Moreover, the effect of the price differential increases in the market share of the domestic firms, s_h, because a higher share of domestic suppliers implies a lower market share of foreign firms.

The definition of the optimal import price (12) suggests that the degree of the PTM and ERPT is time varying due to fluctuations in the price mark-up over the marginal cost. Specifically, Benigno and Faia (2010) suggest that the extent of the pass-through varies following a shift in the fraction of foreign varieties in the market. Given the increasing globalization of the world economy and the geographic disintegration of production processes, it is reasonable to expect a continuous variation in the number of foreign firms supplying the market. For instance, a continuous outsourcing of the domestic production to countries which offer lower labour costs leads to a stable increase in the number of varieties that are imported from abroad. The resulting instability of the market shares of domestic producers undermines the constancy of the relationship between the exchange rate and the price of exports and imports. The inconstancy of the PTM and ERPT in Benigno and Faia (2010) provides an additional justification for using the out-of-sample forecasting tests adopted in this study, since these tests account for instability in regression coefficients by estimating the export price equation recursively over time.

In this section we reviewed three partial equilibrium set-ups which explain structural breaks in the response of export and import prices to fluctuations in the exchange rate between the exporter's and importer's currencies. The model of price-setting by imperfectly competitive exporters (Knetter, 1989) explained variations in the PTM over time by an inconstant elasticity of the importer's demand for the foreign firm's product with respect to its import price. The set-up of the dynamic oligopolistic competition with switching costs (Gross and Schmitt, 2000) argued that the value of the ERPT into import prices may vary across time periods because firms may invest in their future market shares by offering a lower import price in the initial period. The framework of monopolistic competition with variable market shares (Benigno and Faia, 2010) suggests that the extent of the ERPT into the optimal import price is unstable because of the inconstancy of the market shares of foreign suppliers.

The next section builds a new partial equilibrium set-up that justifies time variance in the response of the export price to currency movements. The difference between our framework and the three partial equilibrium models reviewed in this section lies in the channel which induces instability into the PTM. Specifically, we argue that the response of the export price to currency fluctuations depends on the volatility of the exchange rate, which is usually inconstant, if we discard the cases of pegged currency regimes. Thus, the instability of the exchange rate volatility undermines the stability of the relationship between the export price and currency movements.

3.4 Model

The following model of the PTM builds on the stylized model of export pricing (see Gagnon and Knetter, 1995 and Knetter, 1995). We extend the conventional approach to the incomplete ERPT by exploiting the link between consumer demand and import price volatility, which is driven by the exchange rate volatility. We will show that shifts in the volatility of the nominal exchange rate between the currencies of the exporter and importer contribute to the response of the optimal export price to a depreciation of the importer's currency. This section is structured as follows. First, we describe the two building blocks of the firm's optimization problem: namely, the exporter's profit function, which represents the objective function, and the importer's demand function, i.e. the constraint subject to which the profit should be maximized. Second, we solve the firm's optimization problem by choosing the profit-maximizing level of the export price. Finally, we differentiate the optimal export price with respect to the nominal exchange rate and trace the role of the exchange rate volatility in determining the degree of the PTM.

3.4.1 Producers

Consider an exporting firm that produces a differentiated product and uses both domestic and foreign inputs. Foreign inputs are purchased from the country that imports the firm's final good. The exporter's profits can be expressed by the following equation:

$$\Pi_t = p_t q_t - MC_t(e_t)q_t, \tag{14}$$

where p_t denotes price at time t, which is expressed in the exporter's currency. q_t represents the period-specific quantity of sales and MC_t is the marginal cost of producing the exported good at time t. MC_t is assumed to vary in response to the contemporaneous exchange rate, e_t, since the firm is using foreign inputs whose prices expressed in the exporter's currency fluctuate with the exchange rate. For example, if the price of an imported input is fixed in the seller's currency, the depreciation of the firm's currency causes an increase in the marginal cost.[6] Nominal exchange rate, e_t, is defined as the number of units of the importer's currency, which is required to purchase one unit of the exporter's currency. An increase in e_t indicates an appreciation of the exporter's currency. The profit function (14) represents the objective function that must be maximized subject to the constraint which is defined in the next section.

3.4.2 Consumers

The exporting firm faces a demand from the foreign country, which is represented by the following equation:

$$q_t = Q\left(p_t^r, \sigma_p\left(p_t^r, p_{t-1}^r, p_{t-2}^r, ..., p_{t-12}^r\right)\right), \tag{15}$$

where $p_t^r = \dfrac{p_t e_t}{P_t^d}$. The quantity demanded, q_t, depends on the relative import price of the firm's good, p_t^r, which represents the ratio of the import price of the product, $p_t e_t$, to the aggregate price level for this commodity in the importing country, P_t^d. P_t^d is affected by prices charged by the firms which produce close substitutes for the exporter's good.

In addition, the importer's demand (15) is a function of σ_p which denotes the annual average volatility of the exporter's relative import price. For computational simplicity, we assume that the importer's demand, *Q*, is a linear function of the annual average volatility of the import price, σ_p. Adopting a more sophisticated functional form for the importer's demand will not affect this section's main finding, i.e. the destabilizing impact of the volatility of the import price on the degree of the PTM. Similarly, the choice of the time span does not affect the main result of this section. Specifically, replacing the annual volatility with a quarterly or monthly volatility still yields an unstable value of the PTM. However, the annual volatility has the advantage of a greater time span in econometric estimation. Denote the relative import price in the first month of the second year in the sample by p_{13}^r. Then σ_p can be interpreted as the annual average volatility of the relative import price over the period spanning $t = 1$ through $t = 13$.

---

[6] The output level, q_t, is absent from the marginal cost function, *MC*, for computational simplicity. Thus, the marginal cost is assumed to remain constant as the level of production grows. The constancy of the marginal cost with respect to the output is a conventional assumption in the PTM models (see Gross and Schmitt, 2000). Rowntree (1941) provides a rigorous discussion of the validity of the assumption of a constant marginal cost.

In addition to the current relative import price, the price volatility, σ_p, depends on historic realizations of the relative import price, because the importer cares about past observations on the exporter's price-setting behaviour. If the exporter failed to maintain a stable range of the import price over the past year, the resulting high volatility of the relative import price, σ_p, undermines the firm's reputation and the importer's trust in the exporter's intention to maintain price stability. A rise in σ_p strengthens the importer's incentives to switch to a substitute good and causes a fall in the quantity demanded, q_t.

Note that the demand (15) is different from the demand functions which are employed in stylized PTM models, which do not accommodate the role of the price instability (Knetter, 1989). We include a measure of the price volatility into the demand function, in order to reflect Krugman's assumption on the importer's preference for price stability (Krugman, 1986). Since we follow Krugman (1986) by assuming that the importer's demand is negatively affected by the volatility of the import price, the function (15) appears to be a more accurate analytical description of the importer's demand. Due to a negative relationship between the price volatility and the importer's demand, the volatility of the import price determines the optimal export price, which is described in the next section.

3.4.3 Optimal export price determination

The exporter maximizes the profits (14) subject to the demand (15) that it faces in the importer's market. Let us substitute the constraint (15) into the objective function (14), differentiate (14) with respect to the export price, p_t, and set the derivative to zero. In describing the firm's optimization problem, we dropped the arguments of the functions for expositional convenience. Thus, the first order condition associated with the exporter's problem of profit maximization can be represented as follows:

$$\frac{\partial \Pi_t}{\partial p_t} = \frac{\partial \{Q(p_t - MC_t)\}}{\partial p_t} = 0. \tag{16}$$

Using the chain rule of the differentiation yields the following first order condition:

$$\frac{\partial \{Q(p_t - MC_t)\}}{\partial p_t} = \left(\frac{\partial Q}{\partial p_t^r} \frac{e_t}{P_t^d} + \frac{\partial Q}{\partial \sigma_p} \frac{\partial \sigma_p}{\partial p_t^r} \frac{e_t}{P_t^d} \right)(p_t - MC_t) + Q = 0. \tag{16a}$$

Solving the first order condition (16a) for the export price, p_t, yields the following profit-maximizing level of the export price:

$$p_t = MC_t(e_t) - \frac{P_t^d Q\left(p_t^r, \sigma_p\left(p_t^r, p_{t-1}^r, p_{t-2}^r, ..., p_{t-12}^r\right)\right)}{e_t\left(\frac{\partial Q}{\partial \sigma_p}\frac{\partial \sigma_p}{\partial p_t^r} + \frac{\partial Q}{\partial p_t^r}\right)}. \tag{16b}$$

Thus, the optimal export price (16b) increases in the marginal cost. Intuitively, an increase in the marginal cost leads the exporter to raise the export price in order to cover the cost of production and protect his profit margin. In addition to the marginal cost, the optimal export price is affected by the nominal exchange rate through three channels. First, an appreciation of the exporter's currency leads to a fall in his marginal cost, since the imported inputs become relatively cheap when converted to his currency. As a result of the appreciation, the export price falls due to a lower cost of production. Second, the appreciation of the exporter's currency means the depreciation of the importer's currency (i.e. an increase in e_t) , which increases the import price of the good and depresses the level of the import demand (15). The optimal export price must be adjusted downwards in order to prevent this fall in the importer's demand. Third, the depreciation or appreciation of the importer's currency increases the volatility of the exchange rate, which negatively affects the import demand (15). The exporter must impede potential decrease in the importer's demand by decreasing the export price. Let us label these three channels of the exchange rate effect by the cost channel, price channel and volatility channel, respectively.

The overall response of the export price to the nominal exchange rate is determined jointly by the cost, price and volatility channels. The effect of the exchange rate on the export price is given by the derivative of the optimal export price (16b) with respect to the exchange rate, $\frac{\partial p_t}{\partial e_t}$. Dropping time subscripts and the implicit definitions of functions for the clarity of exposition yields the response of the export price to currency movements[7]:

$$\frac{\partial p}{\partial e} = \frac{\partial MC}{\partial e} - \left(\frac{P^d\left(\frac{\partial Q}{\partial \sigma_p}\frac{\partial \sigma_p}{\partial p^r}\frac{p}{P^d} + \frac{\partial Q}{\partial p^r}\frac{p}{P^d}\right)}{e\left(\frac{\partial Q}{\partial \sigma_p}\frac{\partial \sigma_p}{\partial p^r} + \frac{\partial Q}{\partial p^r}\right)} - \frac{P^d Q\left\{\left(\frac{\partial Q}{\partial \sigma_p}\frac{\partial \sigma_p}{\partial p^r} + \frac{\partial Q}{\partial p^r}\right) + e\frac{P^d}{p}\frac{\partial^2 Q}{\partial^2 e}\right\}}{e^2\left(\frac{\partial Q}{\partial \sigma_p}\frac{\partial \sigma_p}{\partial p^r} + \frac{\partial Q}{\partial p^r}\right)^2} \right)$$

(17)

[7] Since $\frac{\partial Q}{\partial e} = \frac{\partial Q}{\partial \sigma_p}\frac{\partial \sigma_p}{\partial p^r}\frac{p}{P^d} + \frac{\partial Q}{\partial p^r}\frac{p}{P^d}$, the term $\frac{\partial Q}{\partial \sigma_p}\frac{\partial \sigma_p}{\partial p^r} + \frac{\partial Q}{\partial p^r}$ can be rewritten as $\frac{\partial Q}{\partial e}\frac{P^d}{p}$ and differentiated with respect to the exchange rate, e .

Dividing the numerator and denominator of the second term on the right hand side of the derivative (17) by $\frac{\partial Q}{\partial \sigma_p}\frac{\partial \sigma_p}{\partial p^r}+\frac{\partial Q}{\partial p^r}$ gives:

$$\frac{\partial p}{\partial e}=\frac{\partial MC}{\partial e}-\left(\frac{p}{e}-\frac{P^d Q\left\{\left(\frac{\partial Q}{\partial \sigma_p}\frac{\partial \sigma_p}{\partial p^r}+\frac{\partial Q}{\partial p^r}\right)+e\frac{P^d}{p}\frac{\partial^2 Q}{\partial^2 e}\right\}}{e^2\left(\frac{\partial Q}{\partial \sigma_p}\frac{\partial \sigma_p}{\partial p^r}+\frac{\partial Q}{\partial p^r}\right)^2}\right). \quad (18)$$

The first term on the right hand side of the derivative (18) defines the cost channel of the exchange rate effect, i.e. the response of the marginal cost, *MC*, to currency movements. The second and third terms on the right hand side of the equation (18) define the extent of the PTM, because they represent an exchange rate effect which cannot be explained by the change of the marginal cost. Consequently, an export price adjustment which is described by the second and third terms must be due to the PTM, since the latter is associated with the adjustment of the mark-up over the marginal cost.

For computational simplicity, let us describe the importer's demand by a mathematical function which yields a zero value when differentiated twice with respect to the nominal exchange rate, i.e. $\frac{\partial(\partial Q/\partial e)}{\partial e}=0$. Using this assumption, the derivative of the export price with respect to the exchange rate (18) is reduced to

$$\frac{\partial p}{\partial e}=\frac{\partial MC}{\partial e}-\left(\frac{p}{e}-\frac{P^d Q}{e^2\left(\frac{\partial Q}{\partial \sigma_p}\frac{\partial \sigma_p}{\partial p^r}+\frac{\partial Q}{\partial p^r}\right)}\right). \quad (19)$$

Finally, let us substitute the definition of the optimal export price (16b) for p_t and restore time subscripts and the implicit definitions of functions. The response of the export price to the nominal exchange rate is given by

$$\frac{\partial p_t}{\partial e_t}=\frac{\partial MC_t}{\partial e_t}+\left(\frac{P_t^d Q\left(p_t^{\,r},\sigma_p\left(p_t^{\,r},p_{t-1}^r,\ldots,p_{t-12}^r\right)\right)}{e_t^{\,2}\left(\frac{\partial Q}{\partial \sigma_p}\frac{\partial \sigma_p}{\partial p_t^{\,r}}+\frac{\partial Q}{\partial p_t^{\,r}}\right)}\right)-\frac{1}{e_t}\left\{MC(e_t)-\frac{P_t^d Q\left(p_t^{\,r},\sigma_p\left(p_t^{\,r},\ldots,p_{t-12}^r\right)\right)}{e_t\left(\frac{\partial Q}{\partial \sigma_p}\frac{\partial \sigma_p}{\partial p_t^{\,r}}+\frac{\partial Q}{\partial p_t^{\,r}}\right)}\right\}. \quad (19a)$$

Finally, grouping the terms that have a common factor in the equation (19a) yields the following derivative:

$$\frac{\partial p_t}{\partial e_t} = \frac{\partial MC_t}{\partial e_t} - \frac{MC(e_t)}{e_t} + 2\left\{ \frac{P_t^{\,d} Q\left(p_t^{\,r}, \sigma_p\left(p_t^{\,r}, \ldots, p_{t-12}^{r}\right)\right)}{e_t^2 \left(\frac{\partial Q}{\partial \sigma_p} \frac{\partial \sigma_p}{\partial p_t^{\,r}} + \frac{\partial Q}{\partial p_t^{\,r}} \right)} \right\}. \tag{20}$$

The sign of the derivative of the export price with respect to the nominal exchange rate, which is jointly determined by three ratios on the right hand side of the equation (20), is unambiguously negative. The first ratio represents the response of the marginal cost to the appreciation of the exporter's currency. The sign of this derivative is negative, since the appreciation of the exporter's currency implies that fewer units of the own currency are required to purchase the inputs whose prices are fixed in the foreign currency, i.e. $\frac{\partial MC_t}{\partial e_t} < 0$. The sign of the second term on the right hand side of the equation (20) is also negative, since both marginal cost and nominal exchange rate are positive values. The last term of the derivative (20) is also unambiguously negative. The numerator of this term is positive, as the aggregate price level and the importer's demand are both positive values. The denominator of this term is negative, because higher volatility of the import price leads to a lower import demand $\left(\frac{\partial Q}{\partial \sigma_p} < 0 \right)$, higher relative import price generates a larger volatility of the import price $\left(\frac{\partial \sigma_p}{\partial p_t^r} > 0 \right)$, and the importer's demand falls in the relative import price $\left(\frac{\partial Q}{\partial p_t^r} < 0 \right)$. Thus, the export price is reduced as a result of the depreciation of the importer's currency.

Thus, the extent of the export price adjustment following currency movements depends on the effect of the nominal exchange rate on the marginal cost, MC_t, and the sensitivity of the importer's demand to $p_t^{\,r}$ and σ_p, which denote the relative import price and the volatility of the import price, respectively. This conclusion is conditional upon two important assumptions that we make about the schedule of the importer's demand. First, the importer switches to a substitute good when the relative import price of the foreign good increases. Second, the importer switches to alternative supplier when the volatility of the import price rises.

Since the response of the export price to the nominal exchange rate (20) depends on the link between the volatility of the import price and the importer's demand, we can deduce that shifts in the volatility of the exchange rate induce instability in the PTM. Specifically, since the relative import price, ${p_t}^r$, is a function of the product of the export price and the exchange rate, $p_t e_t$, an instable exchange rate implies a volatile relative import price. When the import price is volatile, the importer is more likely to switch to a substitute good with a more stable range of price fluctuations. Therefore, the exporter needs to adjust his export price more vigorously during times of a volatile exchange rate in order to protect his market share in the importer's country. The next section examines the sources of potential instability in the PTM.

3.4.4 Instability of the degree of PTM

The volatility of the relative import price, σ_p, is determined by the nature of the exchange rate regime, since the latter influences the exchange rate volatility (Levy-Yeyati and Sturzenegger, 2003). Intuitively, a higher degree of flexibility of the exchange rate regime causes a higher volatility of the exchange rate, which increases the variability of the relative import price, p_t^r. Suppose that either the exporting or the importing country implemented a new exchange rate regime, which increased both the volatility of the exchange rate and the volatility of the relative import price, σ_p.[8] In order to find whether a change in σ_p affects the response of the export price to currency movements, the derivative (20) should be differentiated with respect to the price volatility, σ_p.

First, let us transform the derivative (20) into

$$\frac{\partial p_t}{\partial e_t} = \frac{\partial MC_t}{\partial e_t} - \frac{MC(e_t)}{e_t} + 2\left\{ \frac{Q\left({p_t}^r, \sigma_p\left({p_t}^r\right)\right)}{\left(\frac{\partial Q}{\partial p_t}\right)e_t} \right\}, \tag{21}$$

[8] One may argue that a change of the exchange rate regime is not the only factor that affects the volatility of the relative import price. The diversity of the causes of the import price volatility remains beyond the scope of our study. The purpose of this chapter is to show that the volatility of the import price represents one of the reasons of the PTM instability. We leave the discussion of other causes of the import price volatility for subsequent research.

since $\frac{\partial Q}{\partial p_t} = \frac{\partial Q}{\partial p_t^r}\frac{e_t}{P_t^d} + \frac{\partial Q}{\partial \sigma_p}\frac{\partial \sigma_p}{\partial p_t^r}\frac{e_t}{P_t^d} = \frac{e_t}{P_t^d}\left(\frac{\partial Q}{\partial p_t^r} + \frac{\partial Q}{\partial \sigma_p}\frac{\partial \sigma_p}{\partial p_t^r}\right)$. The derivative (21) can be differentiated with respect to the volatility of the import price as follows:

$$\frac{\partial p_t}{\partial e_t \partial \sigma_p} = \frac{2}{e_t}\left\{\frac{\frac{\partial Q}{\partial \sigma_p}}{\frac{\partial Q}{\partial p_t}} - \frac{Q\left(p_t^r, \sigma_p\left(p_t^r, ..., p_{t-12}^r\right)\right)}{\left(\frac{\partial Q}{\partial p_t}\right)^2}\frac{\partial^2 Q}{\partial p_t \partial \sigma_p}\right\}. \qquad (22)$$

Equation (22) gives the effect of a change in the volatility of the import price on the response of the export price to a movement of the exchange rate. If the volatility of the import price had no effect on the importer's demand, i.e. $\frac{\partial Q}{\partial \sigma_p} = 0$, the response of the export price to the exchange rate would be insensitive to the price volatility, i.e. $\frac{\partial p_t}{\partial e_t \partial \sigma_p} = 0$. However, since we assume the sensitivity of the importer's demand with respect to the variability of the import price, the derivative (22) is not equal to zero. Consequently, a shift in the price volatility, σ_p, leads to a change in the relationship between currency movements and the export price, $\frac{\partial p_t}{\partial e_t}$. Note that the volatility of the import price, σ_p, is unstable due to the inconstancy of the exchange rate volatility, unless the exporter pegs its currency to the importer's currency or vice versa. Thus, our model generates instabilities in the link between the exchange rate and the export price thanks to the destabilizing role of the import price volatility.

In this section we determined that the export price unambiguously falls following the appreciation of the exporter's currency, $\frac{\partial p_t}{\partial e_t} < 0$. First, the appreciation of the exporter's currency leads to a decrease in the export price due to a fall in the cost of imported inputs. However, a negative effect of the import price volatility on the importer's demand leads to a further fall of the export price. Intuitively, the exporter wishes to protect his market share in the importer's country and prevent him from switching to a substitute good, since the consumer dislikes price instability generated by currency movements. Therefore, the firm decreases the export price following the depreciation of the importer's currency in order to offset at least a portion of the increase of the import price, which was induced by currency change.

We also showed that the extent of the PTM is unstable, because it depends on the inconstant volatility of the import price. Since the response of the export price to the exchange rate is indicated by the coefficient on the exchange rate in the regression of the export price, we must adopt an econometric framework which embeds potential instability of the regression parameters. Thus, our partial equilibrium model of the export price justifies the use of the out-of-sample forecasting methodology which focuses on the instability of the regression coefficients over time. The next section describes the out-of-sample forecasting tests which we employ in order to answer two empirical questions. In the first question, we test whether goods exported from the UK to other EU countries are subject to the PTM. The answer to the second question will determine the stability of the response of the UK export price to the exchange rate between the Pound Sterling and the currencies of the UK's trade partners.

3.5 Econometric Methodology

This section discusses the out-of-sample forecasting framework that we design in order to test the significance of the exchange rate for determining the export price and the instability of the link between the export price and the exchange rate. First, we define two nested models, whose ability to forecast export prices must be compared in order to choose the specification that best fits the UK data. Second, we describe four tests of out-of-sample forecasting, namely split, rolling, recursive and RWCTVP regressions. The purpose of these tests is to examine the ability of the coefficient estimates to predict the one-step-ahead values of the export price, whereby the predictive ability is reflected in the average forecasting error. Finally, we outline the computation of the ENC-NEW forecast encompassing test by Clark and McCracken (2001), which enables us to determine whether the inclusion of the exchange rate significantly reduces the forecasting error of the export price model. If the addition of the exchange rate leads to a significant improvement in the forecasting ability of the model, we interpret this finding as evidence of the PTM by exporters. Likewise, if the regressions allowing the exchange rate coefficient to evolve over time predict export prices better than the models that imply a constant link between the export price and the exchange rate, we conclude that the degree of the PTM is unstable over time.

3.5.1 Estimation framework

This section outlines the logarithmic specification of the export price, which we designed in order to estimate the size and the stability of the impact that the exchange rate has on the export price. We start the discussion by describing the set of independent variables that we include into the regression of the export price. In particular, we explain the similarities and differences between our econometric model of the export price and the theoretic definition of the optimal export price (16b).

After defining the baseline regression of the export price, we describe the procedure for testing the presence of the PTM by the UK exporters. Within an out-of-sample forecasting framework, the test of PTM consists of searching for the predictive power of the exchange rate for the export price. Specifically, for goods that are subject to PTM, the exchange rate should significantly improve the ability of the model to predict the export price, because the PTM implies that the export price is adjusted in response to the depreciation or appreciation of the importer's currency (see 21). We test the predictive power of the exchange rate by estimating a regression of the export price where coefficients on the exchange rate terms are restricted to equal zero. Evidence of the PTM is provided by rejecting the null hypothesis that the coefficient on the exchange rate equals zero.

Finally, we describe the algorithm for testing the stability of the link between the exchange rate and the export price. We follow the methodology of Stock and Watson (1994) who propose to compare the forecasting performance of models which vary in their robustness to the evolution of the regression parameters over time. They suggest that the forecasting superiority of adaptive models serves as evidence of the parameter instability, where adaptivity implies the robustness to parameter instability. Thus, we will compare the average prediction errors delivered by four forecasting tests - split, rolling, recursive and RWCTVP models. If relatively adaptive models of the export price deliver significantly lower average forecasting errors, we may conclude that the degree of the PTM is unstable over time.

3.5.2 Baseline regression of the export price

We propose to test for the presence of PTM by running the regression of the following logarithmic specification:

$$\ln p_t = \delta_t + \beta_{1t} \ln p_{t-1} + \beta_{2t} \ln p_{t-2} + \beta_{3t} \ln MC_{t-1} + \\ + \beta_{4t} \ln MC_{t-2} + \beta_{5t} \ln e_{t-1} + \beta_{6t} \ln e_{t-2} + \mu_t, \tag{23a}$$

which defines the export price as a function of the marginal cost and the exchange rate.[9] μ_t denotes the regression error term. In order to apply a recently developed framework for testing the forecasting performance of a model and the instability of its parameters (see Clark and McCracken, 2001; Rossi, 2006; Stock and Watson, 1994), we adopt a second-order autoregression of the export price, which is augmented with four lagged exogenous regressors. Specifically, the export price is regressed on the past realizations of the export price, lagged values of the marginal cost and previous values of the exchange rate.

The tendency in the forecasting literature (Rossi, 2006; Stock and Watson, 1994) to explain the behaviour of the dependent variable with a number of its lags and past values of exogenous explanatory variables is not the only reason behind choosing a second-order autoregression with lagged exogenous regressors. Most importantly, the regression (23a) takes into account the price stickiness which underpins the modern open macroeconomic theory (Benigno and Faia, 2010) and implies that some firms in the industry are unable to exercise an instantaneous adjustment of their price. As a result of price stickiness, the current price level of the industry is affected by prices that were set in previous periods by those firms, who were not able to re-set their prices in the current period. Therefore, we include the lagged values of the export price, p_{t-1} and p_{t-2}, into the regression (23a) in order to highlight the dependence of the current export price on past realizations of the price.

Moreover, instead of including contemporaneous values of the marginal cost and the exchange rate, MC_t and e_t, the model (23a) controls for the lagged values of these regressors due to the aforementioned delay in the adjustment of the export price. Specifically, since the industry level of the export price is determined by the past values of the export price, the current price level is largely determined by past marginal costs and exchange rates. Thus, the current level of the export price is a function of the past export price, which represents a function of the past realizations of the marginal cost and exchange rate. The gradual adjustment of export and import prices to the exchange rate and marginal cost has already been highlighted in the empirical literature. For example, Campa

[9] Note that the PTM coefficients, β_{5t} and β_{6t}, have an additional subscript t, which indicates that the response of the export price to the exchange rate may vary over time.

and Goldberg (2002) estimate the degree of the ERPT into import prices by augmenting the regression of the import price with lagged exchange rates and costs of production.

The specification (23a) is slightly different from the theoretic definition of the export price (16b), since the aggregate price level of the destination market, P_t^d , has not been included. Section 3.6 of this Chapter explains the alternative way in which we controlled for the effect of this variable. Note that the primary role of the aggregate price level, P_t^d , is to measure the relative import price of the UK good, $\frac{p_t e_t}{P_t^d}$. However, we control for fluctuations in the relative price of the UK exports by adopting the *Broad Sterling Effective Exchange Rate Index,* which measures the price competitiveness of the UK goods in the importer's market. Including both the *Broad Sterling Effective Exchange Rate Index* and the aggregate price level may induce an unnecessary multicollinearity into the regression (23a).

Another distinction between the theoretic model of the export price (16b) and its econometric counterpart (23a) is reflected in the absence of a proxy for the volatility of the import price, σ_p . The derivative (22) shows that the impact of the price volatility, σ_p , is represented by a structural break in the relationship between the exchange rate and the export price. Therefore, fluctuations in the volatility of the import price shift the coefficients on the exchange rate terms, β_{5t} and β_{6t} . Since the instability in the regression coefficients is induced by a shift in the volatility, σ_p , the test of parameter instability will allow us to detect the effect of the price volatility without explicitly including σ_p into the equation. Moreover, the inclusion of the volatility of the import price into the regression (23a) is not desirable due to multicollinearity issues. Since σ_p represents a function of the past values of the export price, p_{t-1} and p_{t-2} , we will introduce multicollinearity into the model (23a) through the correlation among three regressors, namely $\ln p_{t-1}$, $\ln p_{t-2}$ and $\ln \sigma_p$.

Furthermore, the exclusion of the volatility of the import price from the regression (23a) should not impact the results of our test of PTM, because the presence of the PTM is indicated by the effect of the exchange rate on the forecasting performance of a model of the export price. Specifically, for the goods that are subject to PTM, a model which contains the exchange rate (i.e. the unrestricted model) must forecast the export price significantly better than a model which excludes it (i.e. the restricted model). Thus, in the case of PTM, the average forecasting error of the unrestricted model of the export price must be significantly lower than the average prediction error of the restricted model. If we add a measure of the import price volatility to the model, both the restricted and the unrestricted (23a) models of the export price must be augmented with the regressor $\ln \sigma_p$. An additional regressor will change the size of each model's forecasting error, but it should not affect the difference between these two errors. Since we test for the presence of PTM by examining the size and the significance of the difference between the average forecasting error of the unrestricted model and the mean prediction error of the restricted model of the export price, the addition of the import price volatility to the regression (23a) should not impact the test of PTM.

Having described the intuition behind our approach to the estimation of the PTM by the UK exporters, we outline the formal algorithm for testing the predictive power of the exchange rate in the next section.

3.5.3 Testing for the presence of PTM

The presence of PTM essentially implies the importance of changes in the exchange rate for explaining the export price. The intuition behind the PTM lies in the exporter's desire to prevent the import price from significantly fluctuating in response to a change of the exchange rate. For example, if the importer's currency depreciates, the firm should adjust the export price downwards in order to offset at least a portion of the import price increase resulting from the depreciation (see 20). The firm's failure to protect the import price from increasing substantially may result in a loss of its market share, since the importer may locate a cheaper substitute for the exporter's good. Therefore, under the PTM hypothesis, fluctuations of the exchange rate should have a significant effect on the export price. Using the terminology that is employed in the forecasting literature, the exchange rate should have predictive power for the export price.

In order to determine the importance of a variable X_t for explaining the variable of interest using an out-of-sample forecasting technique, we need to compare the out-of-sample forecasts of the dependent variable, which are delivered by two rival models. In the unrestricted model, the set of regressors is augmented with the variable X_t which has a putative predictive content, while the restricted model excludes X_t. Therefore, the out-of-sample forecasting test of PTM is performed in three steps. First, we should obtain two series of forecasts of the export price using the unrestricted and restricted models. Second, we should compute forecasting errors delivered by two nested models of the export price. Finally, we should compare the forecasting abilities of the restricted and unrestricted models using either a test of equal forecast accuracy or a forecast encompassing test.

In this chapter, we use the forecast encompassing test by Clark and McCracken (2001), because they prove that their ENC-NEW test (i.e. New Encompassing Test) is the most powerful out-of-sample forecast statistics for small samples. ENC-NEW test statistic enables us to test the null hypothesis of no predictive power of the exchange rate using asymptotic critical values generated numerically.

In order to test for the presence of PTM, the forecasting ability of the unrestricted model of the export price (23a) must be compared to the predictive power of its restricted version:

$$\ln p_t = \delta_t + \beta_{1t} \ln p_{t-1} + \beta_{2t} \ln p_{t-2} + \beta_{3t} \ln MC_{t-1} + \beta_{4t} \ln MC_{t-2} + \mu_t \,. \qquad 23(b)$$

The model (23b) is labelled as the restricted model nested within the unrestricted specification (23a), because we impose the restriction that the coefficients on the exchange rate terms, β_{5t} and β_{6t}, equal zero in the set-up (23a). Thus, the null hypothesis suggests that the unrestricted model (23a) includes two excess parameters, β_{5t} and β_{6t}, while the alternative hypothesis implies that the exchange rate coefficients are statistically different from zero:

$$H^o : \beta_{5t} = 0 \text{ and } \beta_{6t} = 0 \text{ (no PTM)}$$

$$H^a : \beta_{5t} \neq 0 \text{ and } \beta_{6t} \neq 0 \text{ (PTM).} \qquad (24)$$

Under the null hypothesis, the restrictions on the coefficients of the exchange rates are true and the correct specification of the export price is (23b). In contrast, the alternative hypothesis suggests that the parameter restrictions implied by the null hypothesis are false and the behaviour of the export price should be modelled according to the unrestricted equation (23a).

The restricted model (21b) corresponds to the hypothesis of a complete ERPT and zero PTM. If the exporter does not undertake the PTM by decreasing the log-transformed export price, $\ln p_t$, following the depreciation of the importer's currency (a rise in $\ln e_{t-1}$ or $\ln e_{t-2}$), the export price should be insensitive to currency fluctuations, i.e. $\beta_{5t} = \beta_{6t} = 0$. Consequently, a 1% depreciation of the importer's currency leads to a 1% increase of the import price, since the exporter does not limit the ERPT by a downward adjustment of the export price.

In contrast, the unrestricted model (23a) is associated with the hypothesis of PTM. The statistical significance of the coefficients on the previous values of the exchange rate suggests that the exporter undertakes PTM by adjusting the export price following fluctuations of the exchange rate. Consider a depreciation of the importer's currency, which raises the import price of the good whose price is denominated in the exporter's currency. If the firm conducts PTM by decreasing the export price in order to protect the importer from a large increase of the import price, the degree of the ERPT into the import price is limited. In particular, a 1% depreciation of the importer's currency does not cause a 1% increase of the import price.

Although in our theoretical model the derivative of the export price with respect to the nominal exchange rate (20) is unambiguously negative, the export price may also rise following the depreciation of the importer's currency. For example, Knetter's model reviewed in Section 3.3.1 (Knetter, 1989) suggests that the exporter raises the export price (3) in response to the depreciation of the importer's currency, if he believes that the importer's demand becomes less elastic as the import price increases. Since empirical literature reports both positive and negative effects of the importer's currency depreciation on the export price (Knetter, 1989), we do not impose restrictions on the sign of the coefficients on the past realizations of the exchange rate.

In order to prove the existence of the PTM among the UK exporters, we must provide evidence that the forecasting accuracy of the unrestricted model (23a) outperforms that of the restricted equation (23b). The forecasting superiority of the unrestricted model (23a) would imply that the model (23a) represents a more accurate description of the dynamics of the UK export prices, as opposed to the specification (23b). In order to show the forecasting dominance of the unrestricted model (23a), we must prove that the value of the ENC-NEW test statistic of forecast encompassing by Clark and McCracken (2001) is sufficiently large to reject the null hypothesis of no difference between the mean forecasting errors of the models (23a) and (23b).

Since the degree of PTM is unstable in our theoretic model (22), we assess the predictive ability of an export price model by methods which re-estimate the regression coefficients over time. We believe that a recursive estimation of coefficients is the most appropriate econometric tool for studying the PTM in the situation of coefficient instability, because a researcher is less likely to reject the model implying the significance of the coefficient on the variable of interest if the parameter instability is accommodated (Rossi, 2006). Thus, by modelling the instability of the regression parameters, we hope to increase the likelihood of the rejection of the null hypothesis that the exchange rate has a zero effect on the export price. Specifically, since a re-estimation of the regression parameters using the out-of-sample forecasting tests ensures the robustness of the estimation methodology to the parameter instability, our estimation technique may detect the PTM in situations where non-robust empirical models fail to detect it.

An additional motivation for the use of out-of-sample forecasting tests for analyzing the relationship between the exchange rate and the export price originates from Stock and Watson (1994). They suggest that a regression applied to a full sample may fail to deliver statistically significant estimates of coefficients if the regression parameters are unstable over time. However, if we apply the regression to a subsample drawn from the full sample, we may find a robust link between the dependent variable and the independent variable of interest. Using the terminology adopted in the forecasting literature, the relation between two variables might have a predictive content in at least one subsample in the situation of the parameter instability, even if we fail to find the predictive content of the forecasting relation over the full sample. Therefore, if we fail to confirm the statistical significance of the exchange rate coefficients by running the unrestricted regression (23a) over the full sample, we may still prove the presence of PTM by confirming the predictive power of the exchange rate over a subsample.

Since models exploiting the parameter instability use subsamples of the full sample for re-estimating regression coefficients over time, these models are able to detect those forecasting relations that are not evident from running fixed parameter models. Thus, by re-estimating the regression parameters of the unrestricted (23a) and restricted (23b) models, we hope to increase the number of goods for which there is statistically significant evidence of the PTM by the UK exporters.

A recursive estimation of the regression coefficients is conducted through running a selection of out-of-sample forecasting tests, which represent an effective method to decide between two nested models when the constancy of the regression parameters is uncertain. The recursive estimation of the coefficients over time ensures the robustness of a model to the instability of its parameters, because the estimates of the regression parameters are updated with the availability of new data.

The out-of-sample forecasting tests are conducted in two steps. First, the model coefficients are estimated on a portion of sample. Second, the obtained estimates are used in constructing one-period-ahead forecasts of the dependent variable. In this chapter, we will run four types of the out-of-sample forecasting tests, which vary in the method for updating the regression coefficients:

(1) In ***Split*** tests, the estimates that were obtained from running the unrestricted model (23a) on a portion of sample are used for forecasting the export price at all subsequent time periods. Thus, the estimates of the regression parameters are not updated as new data becomes available;

(2) In ***Recursive*** tests, the sample that is used for estimating the regression parameters is augmented with new data as the forecasting advances through time. Therefore, the estimates of the regression coefficients are updated each time when we enlarge the sample employed for the coefficient estimation;

(3) In ***Rolling*** tests, we use a rolling window of R most recent observations on the regressors for obtaining the estimates of the regression coefficients, which are employed in subsequent forecasting. Similarly to the recursive tests, the estimates of the coefficients are adjusted as the R-observation window advances through time;

(4) In ***Random Walk Coefficient Time Varying Parameter (RWCTVP)*** tests, the regression parameters are estimated by recursive least squares and follow a random walk process with zero drift. Using the first-step estimates of the regression coefficients, Kalman filter recursions are conducted in order to obtain one-period predictions of the export price.

The out-of-sample test of PTM is performed in four stages. First, we recursively estimate the regression coefficients of the unrestricted (23a) and restricted (23b) models of the export price using fixed, rolling, recursive and RWCTVP regressions. Second, using the estimated coefficients, we compute one-step-ahead forecasts of the export price. Third, we construct the out-of-sample Root Mean Squared Forecast Errors (RMSFE) of the unrestricted (23a) and restricted (23b) models. RMSFE represent a function of the difference between the predicted values of the export price and its actual values. Finally, we plug the RMSFE values corresponding to the unrestricted (23a) and restricted (23b) equations of the export price into the formula for the ENC-NEW test statistic of forecast encompassing by Clark and McCracken (2001).

Although the predictive ability of a forecasting model is indicated by the size of its mean forecasting error, we need a formal test that proves the statistical significance of the forecasting superiority of the model. Therefore, finding the model that delivers the lowest average forecasting error is not sufficient for determining the correct specification of the export price. Even when the unrestricted model of the export price (23a) delivers a lower RMSFE than the restricted model (23b), we need to prove that the difference between the two RMSFE is statistically significant. The ENC-NEW test of forecast encompassing by Clark and McCracken (2001) allows us to reject the null hypothesis that the difference between the out-of-sample RMSFE of the unrestricted (23a) and restricted (23b) models of the export price is zero. The rejection of the null hypothesis suggests that the forecasting performance of the model containing the exchange rate (23a) dominates the predictive ability of the restricted model (23b) by delivering a significantly lower RMSFE.

Therefore, the existence of PTM is confirmed by rejecting the null hypothesis of the ENC-NEW test of forecast encompassing by Clark and McCracken (2001). The size of a model's out-of-sample mean forecasting error also serves as the primary tool for analyzing the stability of the extent of PTM. The next section explains the algorithm for using the RMSFE series to test for structural breaks in the size of PTM.

3.5.4 Testing for structural breaks in the PTM coefficients

After testing the power of the specification (23a) to predict the UK export prices, we examine the stability of the coefficients on the past exchange rates, since our theoretic model suggests an unstable degree of the PTM (22). Stock and Watson (1994) propose the following algorithm for detecting instability in the regression parameters. They classify all forecasting models into three groups according to their adaptivity, where the adaptivity implies the robustness of a model to the evolution of its parameters over time:

(1) Models with no adaptivity (e.g. fixed parameter models);
(2) Models with moderate adaptivity (e.g. recursive and rolling regressions, RWCTVP models with small coefficient evolution);

(3) Models with high adaptivity (e.g. RWCTVP models with large coefficient evolution.

Stock and Watson (1994) suggest estimating the model using a selection of out-of-sample forecasting tests which vary in their degree of parameter adaptivity. After obtaining the in-sample estimates of the regression parameters, the researcher should compare the forecasting ability of the fixed, rolling, recursive and RWCTVP models by examining their out-of-sample RMSFE. The forecasting superiority of adaptive models over models whose parameters are fixed may be interpreted as the indication of parameter instability. Note that a superior forecasting model should deliver the smallest value of the out-of-sample RMSFE. In contrast, the dominant forecasting performance of fixed parameter models implies parameter constancy.

Following the algorithm by Stock and Watson (1994), we increase the degree of parameter evolution in each round of the estimation of the unrestricted model (23a) of the export price. We start with the split test, a.k.a. fixed parameter regression, which does not accommodate any adaptivity in the regression parameters. After running the fixed parameter test, we estimate the regression coefficients using models with moderate degree of parameter adaptivity, namely rolling and recursive regressions. Finally, we apply set-ups with high degree of parameter evolution, i.e. RWCTVP models.

The test of PTM stability consists of comparing the RMSFE series delivered by the fixed, rolling, recursive and RWCTVP regressions of the unrestricted model (23a) of the export price. The empirical finding, which confirms that adaptive models forecast the export price with a lower out-of-sample RMSFE than fixed parameter regressions, is consistent with our theoretical model of unstable PTM (22). In contrast, the forecasting dominance of fixed parameter models serves as evidence of the stability of the PTM coefficients, β_{5t} and β_{6t}.

3.5.5 Testing the hypotheses on the parameter vector in the situation of parameter instability

In order to illustrate the poor forecasting performance of non-adaptive models, the empirical output of this chapter reports the results from running fixed parameter regressions of the export price. However, Rossi (2006) shows that split regressions are not appropriate for testing the null hypothesis on an unstable parameter. In particular, the parameter instability underpinning data relationships leads to fundamental changes in the null hypothesis that compares two nested models.

Consider the following two autoregressions of the dependent variable, $ln\ y_t$, on the log of the past exchange rate, $ln\ e_{t-1}$:

$$\ln y_t = \delta + \beta_1 \ln y_{t-1} + \beta_2 \ln e_{t-1} + \mu_t , \tag{25}$$

$$\ln y_t = \delta + \beta_{1t} \ln y_{t-1} + \beta_{2t} \ln e_{t-1} + \mu_t , \tag{25a}$$

where μ_t denotes the regression error term. The model (25) corresponds to the case of parameter stability, since the coefficient on the previous exchange rate, β_2, remains constant over the full sample. In contrast, the parameters of the model (25a) evolve over time, since the regression coefficients, β_{1t} and β_{2t}, contain the time subscript, t. Thus, the response of the dependent variable to the past exchange rate varies across time periods.

The fixed parameter model (25) and its time varying parameter version (25a) generate different null hypotheses on the coefficient of the previous exchange rate, H_o:

H_o (25): $\beta_2 = 0$,

$$H_o \text{(25a): } \beta_{2t} = \beta^c \text{ and } \beta^c = 0 . \tag{25b}$$

In the fixed parameter model (25), the researcher tests the restriction that the coefficient on the previous exchange rate equals zero. In contrast, the time varying parameter model (25a) suggests testing a joint null hypothesis on the exchange rate coefficient. The first part of this null hypothesis implies that the PTM coefficient, β_{2t}, is stable and equals a constant value, β^c. The second part of the null hypothesis sets the constant value of the coefficient on the past exchange rate, β^c, to zero.

Since the instability of the model parameters dramatically modifies the null hypothesis on the parameter vector, the results delivered by the Likelihood Ratio (LR) test, which is only applicable to fixed parameter models, are not valid in the presence of the inconstancy of regression coefficients (Rossi, 2006).[10] In contrast, out-of-sample forecasting tests are appropriate for discriminating between the joint null hypothesis on β_{2t} (25b) and the

[10] The LR test is the conventional test for model misspecification, which is employed in the empirical literature in order to compare nested models (Rossi, 2006).

alternative hypothesis suggesting that the exchange rate coefficient is significantly different from zero and unstable (Rossi, 2006).

The additional advantage of out-of-sample forecasting tests lies in their ability to detect a misspecification of a model. Specifically, they enable us to choose between the restricted (23b) and unrestricted (23a) models of the export price by producing the average squared forecast errors. Thus, in order to determine whether the unrestricted model (23a) represents an accurate specification of the export price, we must check that it delivers a significantly lower RMSFE than the restricted version (23b). Unlike the LR test, which is frequently used to test the misspecification of a model, the results delivered by out-of-sample forecasting tests are robust to the coefficient instability, since the regression parameters are updated as the sample size increases.

Thus, the ability of out-of-sample forecasting methods to detect the accurate specification of the export price in the presence of parameter instability represents the primary motivation behind our decision to use the forecasting methodology for testing the PTM by UK exporters. The next section describes the computation algorithm of out-of-sample forecasting tests.

3.5.6 Description of the out-of-sample tests of predictive ability

This section describes the algorithm for running split, rolling and recursive regressions. First, we explain the method for constructing the sample used to obtain the in-sample estimates of regression coefficients. Second, we describe the process for computing the one-step-ahead predictions of the dependent variable with the in-sample coefficient estimates. Third, we provide the formula for the average forecasting error of a model, which indicates the predictive power of the specification.

Out-of-sample tests represent an effective tool for detecting a superior model for forecasting the variable of interest. These tests are performed in two steps. First, a portion of sample is used to obtain the in-sample estimates of regression coefficients. In the second step, the coefficient estimates are applied to the remaining observations in the sample in order to generate out-of-sample forecasts of the dependent variable. The difference between the actual value of the dependent variable and its predicted value represents the forecasting error of the model and highlights its predictive accuracy. In order to determine the specification that performs the best in forecasting the dependent variable, one-period-ahead RMSFE are computed for each model and used as the formal measure of its predictive ability. The best performing forecasting model should deliver the smallest RMSFE.

Consider two competing (nested) models explaining the behaviour of the dependent variable, Y_t:

$$Y_t = c + \beta_1 X_{1t} + \beta_2 X_{2t} + \psi_t \,, \tag{26}$$

$$Y_t = c^a + \beta_1^a X_{1t} + \psi_t \,, \tag{26a}$$

where c and c^a denote constants. X_{1t} and X_{2t} stand for exogenous regressors. Variable ψ_t represents the error term of the regression and “a” denotes the parameters of the alternative specification (26a).

The algorithm for running an out-of-sample forecasting test consists of the following five steps:[11]

In the first step, we split the sample into two parts - the in-sample and the out-of-sample portions. Suppose that there are *R+P* time-series observations in the sample. Let the in-sample portion of the sample contain the observations that span *1* to *R*. Therefore, the out-of-sample portion consists of the observations that span *R+1* through *R+P*.

In the second step, the first *R* observations in the sample are used to obtain the in-sample estimates of the regression coefficients. Specifically, we run the OLS regression of the unrestricted (26) and restricted (26a) models on the in-sample portion of the sample in order to obtain the estimated parameters, $\{c^*, \beta_1^*, \beta_2^*, c^{a*}, \beta_1^{a*}\}$.

In the third step, we must use the in-sample coefficient estimates to compute the one-period-ahead forecasts of the dependent variable, Y_t^f and Y_t^{fa}, for the periods $t = R+1, R+2, ..., R+P$. For example, in order to compute Y_{R+1}^f and Y_{R+1}^{fa}, the in-sample coefficient estimates must be applied to the regressor values corresponding to the period $t = R + 1$. Thus, the estimated coefficients, $\{c^*, \beta_1^*, \beta_2^*, c^{a*}, \beta_1^{a*}\}$, must be inserted

[11] See Clark and McCracken (2001) for a detailed exposition of the computation algorithm that corresponds to the out-of-sample forecasting.

into equations (26) and (26a) as follows: $Y_{R+1}^{f} = c^{*} + \beta_1^{*} X_{1R+1} + \beta_2^{*} X_{2R+1}$ and $Y_{R+1}^{fa} = c^{a*} + \beta_1^{a*} X_{1R+1}$.

In the fourth step, we generate the one-step-ahead RMSFE for the unrestricted (26) and restricted (26a) models:

$$RMSFE = \sqrt{\frac{\sum_t \left(Y_{t+1} - Y_{t+1}^{f}\right)^2}{P}},$$

$$RMSFE^{a} = \sqrt{\frac{\sum_t \left(Y_{t+1} - Y_{t+1}^{fa}\right)^2}{P}}, \tag{26b}$$

where t = R, R+1, R+2,..., R+P-1. RMSFE represents a function of the one-step-ahead forecasting error defining the difference between the true value of the dependent variable and its forecast.

Finally, we compare the RMSFE of the unrestricted (26) and restricted (26a) models and choose the specification delivering the lowest out-of-sample RMSFE, since the model that minimizes the out-of-sample prediction error offers the “best” description of data.

The most commonly used tests of out-of-sample forecasting are split, rolling and recursive regressions. These tests follow the same method for constructing the one-step-ahead predicted values of the dependent variable, but differ in the algorithm for obtaining the in-sample coefficient estimates:

Split tests (a.k.a. fixed parameter models)*:* Split tests estimate the model parameters on a fixed portion of the sample and employ these coefficient values in forecasting the dependent variable in all subsequent periods. Thus, the model parameters are estimated only once and are not revised as the forecasting proceeds to the next time period. The five-step forecasting algorithm described at the beginning of this section represents an outline of the split test;

Recursive tests*:* In recursive regressions, the parameter estimates are updated as new data becomes available. For instance, in order to compute the one-step-ahead forecast, Y_{R+1}^{fa}, at time $t = R$, we run the OLS regression of the restricted model (26a) using the observations spanning 1 to R and obtain the estimated coefficients, c^{a*} and β_1^{a*}. In order to predict the value of the dependent variable for the subsequent period, Y_{R+2}^{fa}, we employ the coefficient estimates obtained from running the OLS regression of the equation (26a) on $R+1$ observations of the sample. Thus, each time when the forecasting advances through time, the subsample which is used for obtaining the in-sample estimates of the regression coefficients is enlarged. Unlike split tests, the recursive forecasting exploits possible time variation in the regression coefficients, since recursive tests re-estimate the model parameters over time;

***Rolling tests**:* Rolling forecasting explicitly accommodates the idea of time varying parameters (Stock and Watson, 1994). Similarly to the recursive forecasting, the sample which is used for estimating the in-sample coefficients is not stable over time. However, while in the recursive test the size of the estimation sample increases as the forecasting progresses through time, in the rolling forecasting the regression is run on a fixed window of the most recent observations. For instance, in order to obtain the one-period-ahead forecast of the dependent variable, Y_{R+1}^{fa}, at time $t = R$, we run the restricted regression (26a) on observations that span periods 1 to R. In order to obtain the one-period-ahead forecast for the subsequent period, Y_{R+2}^{fa}, the window of observations used for the parameter estimation is moved forward by one period, i.e. the new rolling window equals $\{t = 2,3,4,..., R+1\}$. Thus, the size of the window, which is measured by the number of observations, is kept fixed as the forecasting moves forward through the time.

Since split, rolling and recursive tests differ in their algorithms for re-estimating the regression coefficients, their average forecasting errors (RMSFE) are not equal to each other. The parameter updating scheme that minimizes the size of the one-period-ahead RMSFE represents the best performing forecasting technique.

However, split, rolling and recursive regressions follow the same method for testing model misspecification. Specifically, we should compare one-period-ahead RMSFE from the unrestricted (26) and restricted (26a) regressions. For example, if the RMSFE of the unrestricted (26) model is smaller than that of the restricted (26a) regression, the unrestricted model may have a superior predictive power. However, even if the RMSFE of the restricted (26a) regression exceeds that of the unrestricted (26) specification, the difference between the two RMSFE may not be statistically different from zero. In order to determine the statistical significance of the difference between the one-period-ahead

RMSFE of nested models, we use the ENC-NEW test statistic of forecast encompassing (Clark and McCracken, 2001), which is described in the next section.

3.5.7 ENC-NEW test of forecast encompassing (Clark and McCracken, 2001)

While Stock and Watson (1994) suggest comparing out-of-sample forecast errors of rival specifications in order to determine the "best" forecasting model, several recent studies designed formal test statistics to detect the superior forecasting model (Clark and McCracken, 2001; Diebold and Mariano, 1995). For instance, suppose that the mean squared forecast error of the restricted regression (26a) exceeds the *RMSFE* generated by the unrestricted model, i.e. $RMSFE^a > RMSFE$. In order to conclude that the unrestricted model (26) offers a superior forecasting performance, the difference between the average prediction errors of the nested models, $\left(RMSFE^a - RMSFE\right)$, must be positive and statistically significant. The statistical significance of the difference in the forecasting abilities of models can be tested using two types of tests, namely tests for equal prediction accuracy and tests of forecast encompassing of nested linear models (Clark and McCracken, 2001).

Clark and McCracken (2001) show that, in small samples, the most powerful out-of-sample forecast statistic is their New Encompassing Test, ENC-NEW. It represents a function of one-step-ahead forecast errors delivered by the OLS regression of two *nested* models:

$$ENCNEW = P\frac{\sum_t\left(u_{1,t+1}^2 - u_{1,t+1}u_{2,t+1}\right)}{\sum_t u_{2,t+1}^2}, \tag{27}$$

where P denotes the number of one-step-ahead predicted values of the dependent variable. $u_{1,t+1}$ and $u_{2,t+1}$ denote one-period-ahead forecast errors from the restricted (26a) and unrestricted (26) models, respectively:

$$u_{1,t+1} = Y_{t+1} - Y_{t+1}^{fa}. \tag{28}$$

$$u_{2,t+1} = Y_{t+1} - Y_{t+1}^{f}. \tag{28a}$$

Under the null hypothesis, one-period-ahead prediction errors from the unrestricted (26) and restricted (26a) regressions are equal for each forecasting period, i.e. $u_{1,t+1} = u_{2,t+1}$. In order to test this null hypothesis on forecasting error terms, the value of the ENC-NEW test statistic (27) must be compared to the appropriate critical value.[12]

In order to determine whether the variable X_2 has predictive content for the dependent variable, the value of the ENC-NEW test statistic (27) must be computed using one-step-ahead forecast errors of nested models (26) and (26a). If the statistic value fails to exceed the numerically generated critical value, we are unable to reject the null hypothesis that X_2 does not have predictive power.[13] If the value of the ENC-NEW test statistic surpasses the critical value, one can conclude that the regressor X_2 has predictive content for forecasting the dependent variable.

The asymptotic critical values for the ENC-NEW test statistic were generated numerically in Clark and McCracken (2001) for rolling, recursive and fixed regressions. Therefore, we are unable to test the statistical significance of the difference between the average prediction errors of nested RWCTVP regressions. However, since RWCTVP models are the most robust to parameter evolution among the four out-of-sample tests run in this chapter, we also report RMSFE from the unrestricted (23a) and restricted (23b) regressions of the RWCTVP model of the export price.

Similarly to the fixed, rolling and recursive tests, the RWCTVP test suggests computing one-step-ahead predictions of the dependent variable. However, RWCTVP tests use Kalman filter to correct the estimates of regression coefficients. The next section describes the algorithm for obtaining the filtered estimates of the RWCTVP regression coefficients.

3.5.8 Random walk coefficient time varying parameter (RWCTVP) estimation

RWCTVP methodology enables us to vary the magnitude of the coefficient evolution. Time varying parameter models represent a common tool to study linear relationships which may suffer from abrupt regime switches (Gamble and LeSage, 1993). The regime

---

[12] The limiting distribution of the ENC-NEW test is non-normal and depends on two parameters – k_2 and π. The parameter π equals $\frac{P}{R}$ and k_2 denotes the number of restrictions, i.e. the number of excess parameters in the unrestricted model. In our case, the number of parameter restrictions equals 1, since the unrestricted model (26) contains one excess parameter, β_2.

[13] The alternative definition of the null hypothesis states that the restricted model forecast encompasses the unrestricted model forecast. This definition has been reflected in the test's name.

switch implies the presence of structural breaks in the regression coefficients. Since time varying parameter tests estimate model parameters by recursive least squares, the instability in the relationships between the dependent variable and regressors is explicitly embedded in the RWCTVP methodology.

The main difference between the RWCTVP model and other out-of-sample tests lies in the procedure for obtaining the in-sample estimates of the regression coefficients, which are subsequently used in constructing one-period-ahead forecasts of the dependent variable. Specifically, each coefficient estimate obtained by running the regression on a portion of the sample is corrected with Kalman filter in order to alleviate the prediction error that results from using the uncorrected in-sample estimates.

The RWCTVP model is specified by the following system of equations:

$$y_t = x_t\theta_t + u_t \text{ s.t. } u_t \sim N\left(0, \sigma^2\right),$$
$$\theta_t = \theta_{t-1} + \eta_t \text{ s.t. } \eta_t \sim i.i.d.\left(0, \lambda^2\sigma^2 Q\right), \tag{29}$$

where $Q = E\left(x_t x_t'\right)^{-1}$. The dependent variable, y_t, is regressed on a vector of regressors, x_t. The error term, u_t, is assumed to follow a normal distribution with zero mean and constant variance, σ^2. The vector of the model parameters, θ_t, evolves over time according to a random walk process with zero drift. The error term, η_t, represents a random variable that is independent and identically distributed with zero mean and variance $\lambda^2\sigma^2 Q$.

Thus, the variance of the error term from the equation describing the evolution of the model parameters, θ_t, is a function of the error variance from the regression of the dependent variable, y_t. Moreover, the variance of η_t depends on the parameter λ that governs the degree of the coefficient evolution in the model. In the current study, we consider the following range of possible values of λ in order to account for various degrees of coefficient adaptivity: $\lambda = [0.0025, 0.005, 0.0075, 0.01, 0.015, 0.02]$. Large values of the parameter λ indicate high adaptivity of the regression coefficients, θ_t.

The time varying parameter model (29) may also include lags of the regressors, i.e. x_{t-l}. In this study, we choose the value of the adaptivity parameter, λ, and the number of lags of the regressors, l $(l=1,2)$, recursively by searching for the values that minimize the RMSFE of the model (29).

We conduct Kalman filter recursions of the equation system (29) in order to obtain the corrected estimates of the regression coefficients and compute one-period-ahead predictions of the dependent variable. The computation algorithm can be intuitively summarized into seven steps (for a more rigorous analytical exposition, see Garbade, 1977 and Lutkepohl, 2005):

In the first step, we initialize the recursive estimation by assuming that the parameters of the model (29) equal zero, i.e. $\theta_o = 0$[14], and equating the state covariance matrix to υI, where υ is an arbitrarily large scalar.

In the second step, we estimate the conditional expectation of the model parameters, $E(\theta_t \mid y_1, y_2, y_3,..., y_{t-1})$, by running the regression on all past observations. Essentially, since these parameter estimates are subsequently used for constructing one-step-ahead predictions of y_t, we assume the equality of the following two conditional expectations: $E(\theta_t \mid y_1, y_2, y_3,..., y_{t-1}) = E(\theta_{t-1} \mid y_1, y_2, y_3,..., y_{t-1})$.

In the third step, we estimate the conditional covariance matrix, $Cov(\theta_t \mid y_1, y_2, y_3,..., y_{t-1})$, using all past observations. Thus, we assume that the conditional covariance of the current parameters of the model can be obtained from the conditional covariance of the past parameters using the following rule:

$$Cov(\theta_t \mid y_1, y_2, y_3,..., y_{t-1}) = Cov(\theta_{t-1} \mid y_1, y_2, y_3,..., y_{t-1}) + \lambda^2 Q .$$

In the fourth step, we compute one-step-ahead predictions of the dependent variable using the estimates of the conditional expectations of the model parameters, $E(\theta_t \mid y_1, y_2, y_3,..., y_{t-1})$, which were obtained in the second step. Applying the

[14] Alternatively, Kalman recursions may be initialized by setting the parameter θ_0 to its in-sample estimate which is obtained using the OLS regression (Stock and Watson, 1994).

parameter estimates to the one-step-ahead values of the explanatory variables gives one-step-ahead forecasts of y_t:

$$E(y_t \mid y_1, y_2, y_3,..., y_{t-1}) = x_t E(\theta_t \mid y_1, y_2, y_3,..., y_{t-1}).$$

In the fifth step, we correct the coefficient estimates obtained in the second step by adding the information which is delivered by observation y_t. The corrected estimates of the model parameters, $E(\theta_t \mid y_1, y_2, y_3,..., y_t)$, are referred to as filtered estimates and represent the estimated expectation of parameters conditional upon all past and current observations:

$$E(\theta_t \mid y_1, y_2, y_3,..., y_t) = E(\theta_t \mid y_1, y_2, y_3,..., y_{t-1}) + K_t(y_t - E(y_t \mid y_1, y_2, y_3,..., y_{t-1})),$$

where K_t defines Kalman filter gain, $K_t = \dfrac{R_t x_t'}{x_t R_t x_t' + 1}$. R_t represents a function of the estimated conditional covariance of the model parameters, which was obtained in the third step: $R_t = \dfrac{1}{\sigma^2} Cov(\theta_t \mid y_1, y_2, y_3,..., y_{t-1})$. Kalman filter gain increases the precision of the coefficient estimates by adding the information which is absent from the observations used for obtaining the parameter estimates. Specifically, Kalman filter gain exploits the information delivered by observations for time *t*, while the coefficient estimates are generated by observations spaning the periods *1* to *t-1*. The information added by filtering the parameter estimates is reflected in the difference between the true value of the dependent variable and its one-step-ahead forecast: $(y_t - E(y_t \mid y_1, y_2, y_3,..., y_{t-1}))$.

In the sixth step, we correct the estimated conditional covariances obtained in the third step. In particular, we use Kalman filter in order to estimate the covariances of the model parameters conditional upon all past and current observations:

$$Cov(\theta_t \mid y_1, y_2, y_3,..., y_t) = \sigma^2 [R_t - K_t x_t R_t].$$

In the seventh step, we conduct Kalman recursions for the next time period, *t+1*, by repeating the first six steps of this algorithm. Specifically, we use the filtered estimates of the regression coefficients from the fifth step, $E(\theta_t \mid y_1, y_2, y_3,..., y_t)$, in order to estimate the expectations of the model parameters conditional upon the observations for all periods that preceeded *t+1*: $E(\theta_{t+1} \mid y_1, y_2, y_3,..., y_t)$.

Although the RWCTVP test follows a different method for obtaining the in-sample estimates of regression coefficients compared to split, rolling and recursive regressions, the choice of a superior forecasting model is analogous. In particular, the forecasting performance of the unrestricted (23a) and restricted (23b) models of the export price is examined by evaluating their RMSFE. The RMSFE of the RWCTVP model (29) is computed using the following formula:

$RMSFE = \sqrt{\dfrac{\sum_t \left(y_t - E\left(y_t \middle| y_1, y_2, ..., y_{t-1}\right)\right)^2}{F}}$, where F denotes the number of forecasts. The regression which delivers the lowest RMSFE is considered a superior forecasting model.

Running the RWCTVP regression is particularly useful for testing the stability of the PTM coefficients, since it accommodates a higher degree of coefficient evolution than rolling and recursive tests. Therefore, the forecasting superiority of RWCTVP tests indicates that the PTM parameters from the unrestricted regression (23a) of the export price are unstable. Specifically, the test of PTM instability is conducted by analyzing the differences among the average forecast errors of split, rolling, recursive and RWCTVP regressions. If the RWCTVP model of the export price delivers a smaller RMSFE than less adaptive forecasting techniques, model parameters are susceptible to instability.

This section presented the econometric methodology that we designed in order to test for the presence of PTM and its instability. First, we explained that the presence of PTM may be tested by examining the predictive content of the exchange rate for forecasting export prices. Second, we suggested testing the stability of PTM by varying the degree of the evolution of a model’s parameters. Third, we described the procedure for estimating the model parameters using split, rolling, recursive and RWCTVP tests of out-of-sample forecasting. Finally, we showed the algorithm for detecting the misspecification of a model through examining its average prediction error.

3.6 Data

This study employs monthly figures on export price indices of the UK trade in manufactures with the EU. Export price data was retrieved from the *Monthly Review of External Trade Statistics* released by the Office for National Statistics. The sample spans the period from January 1999 to April 2010 and yields 136 monthly observations. We chose this particular data source, because it provides detailed time series data disaggregated by commodity group in accordance with the Standard International Trade Classification.

It is important to use disaggregated data, since empirical evidence suggests that the extent of PTM varies substantially across commodities (Campa and Goldberg, 2002). Specifically, producers of differentiated goods are more likely to conduct PTM compared to firms producing homogeneous goods, because differentiated goods are produced by monopolistic competitors with market power. The market power of firms allows them to charge a mark-up of price over the marginal cost. In contrast, homogeneous goods are produced by perfectly competitive firms that set prices at the level of marginal cost due to the absence of market power. Without the price mark-up over the marginal cost, firms are unable to limit an increase of the import price following the depreciation of the importer's currency, because a reduction of the export price would not allow firms to cover their production costs. Therefore, homogeneous goods are unlikely to be subject to PTM.

Thus, this study examines disaggregated data on export prices and marginal costs, in order to avoid averaging across the price series whose regression parameters are fundamentally different. Moreover, we chose the Manufactures category, since manufactured goods possess more characteristics of the product differentiation, relative to raw materials. Therefore, manufactured goods are more likely to be susceptible to PTM. Furthermore, product differentiation is essential for testing our theoretic model, since it assumes the existence of substantial costs of researching product characteristics. Specifically, manufactured products are more likely to generate significant costs of choosing among varieties due to the product differentiation, as opposed to basic commodities (e.g. wheat, corn, crude oil).

The marginal cost of production is frequently approximated in the ERPT literature by the Producer Price Index, which is commonly abbreviated as PPI (Vigfusson et al., 2007). Therefore, we collected data on the PPI for the output of manufactured products from the *PPI First Release 2005=100,* which is provided by the Office for National Statistics.

In order to ensure a sufficient variation in the degree of the product differentiation, we use data on export price indices and PPI for 10 product categories, namely Food, Wood and

Cork Manufactures, Chemicals, Machinery, Electrical Machinery, Clothing, Paper and Paperboard, Miscellaneous Metal Manufactures, Tobacco, and Road Vehicles.

The exchange rate between the Great British Pound and the currencies of its trade partners from the EU is approximated by series on *Broad Sterling Effective Exchange Rate Index (BSEERI),* which is obtained from the *Financial Statistics Freestanding* release by the Office for National Statistics. Lynch and Whitaker (2004) offer a detailed explanation of the methodology followed by the Bank of England in constructing this index. The BSEERI summarizes the value of the Pound Sterling vis-à-vis a basket of the currencies of the UK's main trading partners by assigning a time varying trade weight to each partner. Since Europe receives the largest weight in the BSEERI, we ensure a measurement consistency between the dependent variable and the regressors in the unrestricted (23a) and restricted (23b) regressions of the export price. Specifically, we regress the export price indices of the UK trade with the EU on the Effective Exchange Rate Index, which is mainly determined by the bilateral exchange rates between the Pound Sterling and individual European currencies.

The unique feature of the BSEERI is reflected in its ability to account for the competition among producers selling in the importer's market. In particular, the index incorporates the proportion of the importing country's market, which is supplied by local producers. If local producers supply a greater proportion of the importer's market, the market share of the UK exporters falls. Moreover, in addition to considering the competition between the UK and local producers, the BSEERI measures the degree of the competition between the UK and any exporting country that supplies the EU market. Since the degree of the competition in the importer's market can make an important contribution to the size of the PTM by the UK exporters, preference was given to the BSEERI.

Suppose that the competition in the EU market intensifies and the market share of the British exporters falls. As a result of an increased competition, the UK exporters are expected to exercise PTM more actively by limiting potential increase of the import prices of the UK exports, in order to protect their vulnerable market shares. Therefore, we believe that the response of the export price to the depreciation of the importer's currency is stronger when the level of the competition among international suppliers of the EU market intensifies. Consequently, through employing the BSEERI we expect to detect PTM in the situations where the nominal exchange rate index fails to reveal the predictive power of the exchange rate for forecasting the export price.

The additional advantage of measuring fluctuations in the exchange rate with the BSEERI lies in its ability to pick up the effect of the aggregate price level in the importer's market, P^d, which we do not include among the regressors of the unrestricted (23a) and restricted (23b) models of the export price. This exchange rate index accommodates fluctuations in the price level, P^d, by taking into account depreciations and appreciations of the currencies of countries whose firms compete with the UK exporters in supplying the EU market. Specifically, import prices of goods exported to the EU increase (fall) following the appreciation (depreciation) of the exporter's currency. Since the aggregate price level of a good consists of the prices of all varieties of this good, the use of the BSEERI enables us to reflect P^d movements by measuring the values of producers' currencies.

The data series described in this section are seasonally unadjusted. However, potential seasonality in price data may impact estimation results. Specifically, prices of some products may vary substantially across seasons due to seasonal swings in the product demand. For example, since the demand for summer clothing is stronger in summer, as opposed to winter, summer clothing prices may be systematically higher in summer than in winter. In the case of winter clothing, prices observed in cold seasons are likely to exceed prices recorded in warm seasons. Therefore, in Section 3.8 we remove potential seasonal variation from the data, in order to disentangle the effect of each explanatory variable on the export price more accurately. Before we proceed to analyzing the PTM parameters estimated on seasonally adjusted data, we report in Section 3.7 the estimation results from running the unrestricted (23a) and restricted (23b) regressions of the export price on the series that have not been adjusted for seasonal effects.

3.7 Empirical results

This section reports out-of-sample RMSFE obtained by running the unrestricted (23a) and restricted (23b) models of the export price using four methods for estimating the in-sample regression coefficients, namely split, rolling, recursive and RWCTVP regressions. The purpose of this section is to determine whether the model containing the exchange rates, i.e.

PTM model (23a), forecasts the export price better than the non-PTM model (23b) that omits currency fluctuations. The unrestricted model (23a) represents the PTM model, because it accommodates the response of the export price to the importer's currency depreciation. In contrast, the restricted model (23b) is defined as the non-PTM model, because it does not incorporate the effect of the exchange rate on the export price. The PTM model (23a) delivers a superior forecasting performance if its out-of-sample RMSFE is significantly smaller than the average forecast error of the non-PTM model (23b) of the export price.

This section also reports whether the difference between the RMSFE corresponding to the PTM (23a) and non-PTM (23b) models of the export price is significantly different from zero. The statistical significance of the difference between the average forecasting errors of nested models is tested using the asymptotic critical values of the ENC-NEW test statistic of forecast encompassing by Clark and McCracken (2001). They generated asymptotic critical values for split, rolling and recursive regressions by conducting 5000 simulated draws from the statistic's limiting distribution.

Table 11 displays the RMSFE from estimating the PTM (23a) and non-PTM (23b) models of the export price on the monthly UK data on export price indices of manufactured products, PPI and BSEER. We apply eight forecasting models to the UK seasonally unadjusted data: rolling PTM, rolling non-PTM, recursive PTM, recursive non-PTM, split PTM, split non-PTM, RWCTVP PTM, and RWCTVP non-PTM. For each level of the product disaggregation, the forecasting superiority of the PTM (23a) model over the non-PTM model (23b) of the export price is indicated by symbols *c*, *b* or *a*. These symbols show the statistical significance of the difference between the RMSFE of the PTM and non-PTM models, i.e. $(RMSFE^{Non\text{-}PTM}\text{-}RMSFE^{PTM})$, at 1%, 5% and 10% levels of significance, respectively. If the absolute value of this error differential is not significantly different from zero, we are unable to reject the null hypothesis of the ENC-NEW test, which implies that the exchange rate has no power for predicting the export price. The rejection of this null hypothesis and the excess of $RMSFE^{Non\text{-}PTM}$ over $RMSFE^{PTM}$ jointly imply that the UK exporters conduct PTM by adjusting the export price following fluctuations in the Sterling effective exchange rate.

Our estimation results enable us to test the predictive ability of the PTM (23a) and non-PTM (23b) models of the export price for 11[15] levels of the product disaggregation. 8 forecasting models applied to 11 levels of disaggregation yield 88 average forecast errors and 44 cases for comparing predictive accuracies of the PTM (23a) and non-PTM (23b) models.

Our estimation results suggest that the PTM (23a) model has a strong ability to forecast the aggregate index of export prices of Manufactured products, since its out-of-sample RMSFE is smaller than the average forecast error of the non-PTM (23b) model in all out-of-sample tests. Moreover, the forecasting superiority of the PTM (23a) model is statistically significant in rolling, recursive and split regressions, since the numeric value of the ENC-NEW test statistic of forecast encompassing is significant at the 99% confidence level. Consequently, the exchange rate has a statistically significant effect on the aggregate export price of manufactured goods. The RMSFE of the PTM (23a) model is also lower than the average forecasting error of the non-PTM (23b) model of the export price when the RWCTVP regression is run. However, the statistical significance of this error differential cannot be verified, since the asymptotic critical values of the ENC-NEW test statistic are only applicable to split, rolling and recursive regressions (Clark and McCracken, 2001).

In the majority of the out-of-sample forecasts of the export price, the PTM model (23a) performs better than the non-PTM (23b) model. Specifically, in 27 cases out of 44, the PTM (23a) model of the export price delivers a lower out-of-sample RMSFE, as opposed to the non-PTM (23b) model. This empirical finding indicates that the product categories comprising these 27 cases are subject to the PTM by the UK exporters. Moreover, in 19 cases out of 44, the difference between the predictive abilities of the non-PTM (23b) and PTM (23a) models is statistically significant, since the difference between their average prediction errors, $(RMSFE^{Non\text{-}PTM}\text{-}RMSFE^{PTM})$, is positive and significantly different from zero, according to the asymptotic critical values of the ENC-NEW test.

In 17 of the 44 cases, the PTM model (23a) is an inferior tool for forecasting export prices of the Manufactures, since it delivered larger out-of-sample RMSFE than the non-PTM model (23b). However, for each level of the industry disaggregation, except the Paper and

[15] 10 product categories and one aggregate series, which encompass all goods in the Manufactures industry, give 11 levels of the product disaggregation.

Paperboard, there exists at least one forecasting test which displays the dominant predictive ability of the PTM (23a) model. Only the out-of-sample forecasts of Paper and Paperboard export prices could not deliver statistically significant evidence on the forecasting superiority of the PTM (23a) equation. Although the out-of-sample RMSFE from the RWCTVP regression suggests that the PTM (23a) model forecasts export prices of Paper and Paperboard more precisely than the non-PTM (23b) model, the statistical significance of this finding cannot be confirmed due to the unavailability of asymptotic critical values of the ENC-NEW test for nested RWCTVP models.

Table 11 reports the failure of split, rolling, recursive and RWCTVP regressions to deliver the same prediction on the relative forecasting ability of the PTM (23a) model of export price. For example, the rolling and recursive regressions of the Machinery export price suggest that the PTM (23a) model delivers a lower out-of-sample RMSFE, compared to the non-PTM (23b) model. In contrast, the split and RWCTVP regressions show that the average prediction error of the non-PTM (23b) model is smaller than that of the PTM (23a) model of export price. Failure of these four out-of-sample tests to deliver the same prediction is caused by differences in their robustness to the underlying instability of the regression parameters, which induce a divergence among their forecasting errors.

Split, rolling, recursive and RWCTVP regressions were designed for different degrees of parameter evolution. For example, the speed of parameter evolution in the RWCTVP model with high degree of coefficient evolution is likely to exceed the actual speed of the evolution of data relationships. In contrast, the speed of parameter updating in rolling and recursive regressions is likely to approach the “true” degree of coefficient evolution, since they follow a moderate speed of coefficient updating. Consequently, forecasting models with high adaptivity may accumulate larger forecasting errors than rolling and recursive regressions. Similarly, split tests are likely to generate larger out-of-sample forecasting errors than adaptive models, because fixed parameter tests fail to accommodate the evolution of regression coefficients over the sample period.

The divergence among the parameter updating techniques of split, rolling, recursive and RWCTVP regressions leads to differences among their out-of-sample RMSFE. Therefore, their predictions on the choice of the most appropriate forecasting model are different. Specifically, failure of a model to update regression parameters at an accurate pace may accumulate large forecasting errors and undermine the ability of the test to assess the predictive powers of nested models. Consequently, rolling, recursive, split and RWCTVP out-of-sample tests are not equally successful at detecting the predictive content of the exchange rate for forecasting export price indices.

In order to detect the estimation technique that minimizes forecasting errors in predicting export prices of manufactured goods, we should compare the RMSFE of an export price model across split, rolling, recursive and RWCTVP tests. In order to visualize the best PTM model for forecasting export prices, Figure 13 displays the RMSFE delivered by split, rolling, recursive and RWCTVP regressions of the PTM (23a) equation of export price. The format of the graph is continuous, in order to facilitate a simultaneous exposition of four series of out-of-sample RMSFE.

Figure 13 allows us to rank the four out-of-sample tests according to their forecasting performance. The best performing models for forecasting the UK export prices are recursive least squares and rolling regressions. These techniques deliver the smallest RMSFE among all out-of-sample methods considered in this study. RWCTVP regressions show a lower accuracy in predicting the export prices of all manufactured goods tested in this chapter. The average prediction errors of RWCTVP tests exceed the RMSFE of rolling and recursive regressions for all product categories. Split regressions offer the worst forecasting performance among the four out-of-sample tests of model misspecification. At each level of the product disaggregation, split RMSFE exceed the average forecast errors obtained by running recursive and rolling regressions. In half of the industries considered, the RMSFE of fixed parameter regressions overshoot the mean forecasting errors generated by the RWCTVP method.

Thus, according to our empirical results displayed in Figure 13, out-of-sample tests that accommodate moderate adaptivity in their regression parameters (i.e. rolling and recursive regressions) offer a superior forecasting performance, as opposed to tests with no parameter adaptivity (i.e. split tests) and models with high degree of coefficient evolution (i.e. RWCTVP models). These empirical findings are consistent with Stock and Watson (1994) who documented a poor performance of fixed parameter models in forecasting macroeconomic time series. They also reported that models with small degrees of adaptivity forecast the dependent variable better than more adaptive models with time varying parameters.

The inferior forecasting performance of models with high degree of coefficient evolution can be intuitively justified with a trade-off between the forecast accuracy and the extent of parameter instability. If regression parameters are updated frequently, the accuracy of coefficient estimates may be damaged. Specifically, by incorporating a high degree of coefficient evolution, we are likely to exceed the actual degree of parameter instability in data relationships and accumulate large forecasting errors. Thus, imprecise estimates of the regression coefficients obtained with RWCTVP tests may lead to substantial out-of-sample RMSFE.

In contrast, since models with moderate adaptivity offer a slower degree of parameter evolution, they are likely to approximate the "true" pattern of parameter instability more accurately than models with high adaptivity. By offering a more precise estimation of regression coefficients, moderately adaptive methods ensure a reduction of the out-of-sample forecasting error. This trade-off between the precision of regression parameter estimates and the degree of coefficient evolution may explain the superior performance of recursive and rolling tests in predicting the UK export prices of manufactured goods.

Finally, our empirical findings indicate a substantial degree of instability in the PTM coefficients, i.e. coefficients on the exchange rates in the PTM model (23a). In order to visualize the degree of the instability of the PTM by the UK exporters, Figure 14 plots the PTM coefficients estimated with rolling and recursive regressions that were run on aggregate data on the UK trade in manufactures with the EU. We plot the rolling and recursive estimates of the PTM coefficients, since these two out-of-sample tests were identified as the most accurate tools for forecasting the UK export prices. The Appendix also contains the graphs of the PTM coefficient estimates obtained using disaggregated data for the ten product categories selected in this study. Figures 14 and 16-25 effectively illustrate the time varying nature of the PTM by British exporters, since for each product category they display significant fluctuations in the PTM coefficients over time.

Since adaptive forecasting models (e.g. rolling and recursive regressions) show a better performance in forecasting the UK export prices, as opposed to fixed parameter (split) tests, we may conclude that the degree of PTM is not constant over time. Following Stock and Watson (1994), the superior forecasting performance of models accommodating parameter evolution over time indicates that the regression coefficients of a forecasting model are characterized by a time varying structure which cannot be captured by fixed parameter regressions.

This section provided strong statistical evidence in favour of the PTM by the UK exporters of manufactured goods through showing that the exchange rate has significant predictive content for the export price. Moreover, we determined that the degree of PTM is unstable over time for all product categories analysed in this chapter, since adaptive models predict the UK export prices more precisely than fixed parameter models. In the next section we conduct the robustness checks of our empirical findings, in order to determine whether our estimation results are robust to potential seasonality of the UK export price indices.

3.8 Robustness check

This section examines the sensitivity of the estimation results reported in Section 3.7 to potential seasonal effects in data on the UK export price indices. Seasonal effects in monthly price series is a common phenomenon in the time series econometrics. In order to understand possible causes of the seasonality of price data, let us consider the product category Food. Suppose that the current season yielded an amount of crop which is insufficient to satisfy the aggregate demand for agricultural output. As a result of the reduced supply of basic commodities, prices of food items are likely to increase in the absence of government interventions in the market. Therefore, export prices of Food may be abnormally high in "bad" seasons and relatively low in seasons offering a large harvest. In addition to factors pertaining to weather and climate, seasonal fluctuations in the demand for a product may also cause seasonal jumps and falls of a product price. For example, the demand for electric machinery used for heating is higher in cold seasons, as opposed to warm periods of a year. Therefore, this type of machinery is expected to be more expensive in cold times of a year than in warm seasons.

Thus, export prices may vary depending on the season in which a time-series observation is recorded. We propose to remove potential seasonal effects from data on the UK manufactured exports to the EU by transforming each variable from the PTM model (23a) into an annualized inflation rate. Annualized inflation rates represents a convenient tool to alleviate possible seasonality in export price indices. Note that both dependent and independent variables in the PTM (23a) and non-PTM (23b) regressions represent price indices. The dependent variable is the export price index, the marginal cost is measured by the Producer Price Index and the exchange rate is approximated by the Broad Sterling Effective Exchange Rate Index, which summarises the value of the Pound Sterling. Since all variables in the PTM (23a) and non-PTM (23b) models represent price indices, each index can be modified using the following formula for the annualized inflation over the *h*-month period, $\hat{X}_t^h$:

$$\hat{X}_t^h = \left(\frac{1200}{h}\right)\left[\log P_t - \log P_{t-h}\right], \tag{30}$$

where P_t stands for the value of a price index in month t. In order to obtain annualized inflation rates of the export price index, PPI and BSEERI, each variable must be substituted for P_t in the formula (30).

Therefore, the transformed variables from the PTM (23a) and non-PTM (23b) models of export price equal

$$\hat{p}_t^{12} = 100\left[\log p_t - \log p_{t-12}\right],$$

$$\hat{MC}_t^{12} = 100\left[\log MC_t - \log MC_{t-12}\right],$$

$$\hat{e}_t^{12} = 100\left[\log e_t - \log e_{t-12}\right], \tag{31}$$

where we substituted a value of 12 for parameter *h* in the annualized inflation rate formula (30). The purpose of this substitution is to remove from data any seasonality observed over a year. Thus, we aim to remove those price fluctuations which occur due to a coincidence between the time of an observation and a specific season.

In addition to possessing the power to alleviate seasonality, annualized inflation rates have the ability to remove potential non-stationarity in time series data since the levels of variables are transformed into annualized differences (Byrne et al., 2013). Note that the estimation in first differences was not conducted due to the nature of the data sample. Specifically, in some instances, the value of the dependent variable as well as those of regressors remain fixed for several consecutive months. Consequently, an application of the first-difference transformation yields zero entries which undermine the reliability of regression estimation. Table 12B illustrates this undesirable property of first-differenced series which we avoid by employing annualized inflation rates.

After transforming all data in the sample into annualized inflation rates, we re-estimate the PTM (23a) and non-PTM (23b) models of export price using split, rolling, recursive and

RWCTVP tests. By reaching the same empirical conclusions as in Section 3.7, we can prove the robustness of our previous findings to seasonal effects. First, we must show that the PTM (23a) model has a dominant power in predicting the seasonally adjusted series on the UK export prices of manufactured goods. Second, we must illustrate that adaptive models offer a superior forecasting performance, as opposed to the tests which do not embed the time variance of regression parameters.

Table 12 reports the average forecasting errors of the PTM (23a) and non-PTM (23b) models estimated using split, rolling, recursive and RWCTVP regressions with seasonally adjusted data. In order to judge the robustness of the estimation results reported in Section 3.7 to seasonal effects on the UK export prices, the estimation output summarised in Table 12 must be compared to the empirical results given in Table 11.

The output of the rolling and recursive regressions of the PTM (23a) model for the aggregate price indices of the UK manufactured exports is consistent with the estimation results corresponding to seasonally unadjusted data. Specifically, Tables 11 and 12 show that the out-of-sample RMSFE of the PTM (23a) model are significantly lower than the average forecast errors of the non-PTM (23b) model, when rolling and recursive tests are applied. However, the ENC-NEW test of forecast encompassing rejects the null hypothesis of no difference between the recursive RMSFE of the PTM (23a) and non-PTM (23b) models at a lower level of statistical significance than the ENC-NEW test applied to seasonally unadjusted data.

Table 12 reports that the split regression of the PTM (23a) model estimated with aggregate price data delivers a lower RMSFE than the fixed-parameter non-PTM (23b) model, although the statistical significance of the forecasting dominance of the PTM model cannot be confirmed by the ENC-NEW test of forecast encompassing. This finding can be explained by the aforementioned poor performance of fixed parameter tests in predicting macroeconomic time series (Stock and Watson, 1994), which generates large forecasting errors. Similarly, although the RMSFE of the RWCTVP PTM (23a) model exceeds the average forecasting error of the RWCTVP non-PTM (23b) model, we need not reject the PTM hypothesis due to our inability to test the statistical significance of the error differential. Moreover, out-of-sample tests with large degrees of coefficient evolution may not be reliable, since their algorithm for re-estimating the model parameters is likely to underestimate or overestimate the actual degree of parameter evolution, which underpins our data. Therefore, given potential forecasting inaccuracy of fixed parameter tests and excessively adaptive models (e.g. RWCTVP regressions), we may conclude that the UK exports of manufactured goods to the EU are subject to PTM, since the rolling and recursive regressions strongly support the predictive power of the exchange rate.

After the data has been adjusted for seasonal effects, the number of cases where the PTM (23a) model forecasts the UK export prices better than the non-PTM (23b) model has been reduced. Specifically, in 22 cases out 44, the out-of-sample RMSFE of the PTM (23a) model is lower than the average prediction error of the non-PTM (23b) model. In contrast, the results from the out-of-sample tests applied to seasonally unadjusted data suggest that the PTM (23a) model shows a dominant forecasting power in 27 cases. The number of cases where the ENC-NEW test confirmed that the forecasting superiority of the PTM (23a) model is statistically significant has also been reduced from 19 to 13. However, for all product categories, except Road Vehicles, there exists at least one out-of-sample test confirming that the PTM (23a) model forecasts export prices significantly better than the specification which excludes exchange rates (23b). This finding is consistent with the estimation output corresponding to seasonally unadjusted data, where for all levels of product disaggregation, except Paper and Paperboard, the PTM (23a) model displayed a significantly superior predictive performance.

Thus, the PTM (23a) model forecasts the UK export prices of the majority of manufactured products with a reasonable precision. In order to observe the most suitable out-of-sample test for predicting the UK export prices, Figure 15 displays average prediction errors generated by the PTM model (23a) using rolling, recursive, split and RWCTVP tests applied to 11 levels of product disaggregation. Similarly to our previous findings from seasonally unadjusted data (Figure 13), recursive and rolling regressions deliver the lowest RMSFE among the four out-of-sample tests. However, in contrast to the earlier empirical conclusions reported in Section 3.7, the RWCTVP test is the worst performing out-of-sample test, since its out-of-sample RMSFE exceeds the average prediction errors of split, rolling and recursive tests for all product types.

The poor ability of the RWCTVP model to predict the annualized rate of the export price inflation can be intuitively explained by the increase in the number variables that need to be forecasted. In order to construct a one-step-ahead prediction of the annualized inflation rate, $\hat{X}_{t+1}^{12} = 100[\log P_{t+1} - \log P_{t-11}]$, using the set of past observations, $\left(\hat{X}_1^{12}, \hat{X}_2^{12}, .., \hat{X}_t^{12}\right)$, we need to forecast the annual price differential, $100[\log P_{t+1} - \log P_{t-11}]$, which contains two variables, i.e. $\log P_{t+1}$ and $\log P_{t-11}$. However, with seasonally unadjusted data, only one variable is predicted, i.e. $\log P_{t+1}$. Given the increase in the number of forecasts that need to be constructed, out-of-sample forecasting errors are likely to increase. Therefore, an unexpected increase in the RMSFE of the RWCTVP model can be explained by a rise in the number of variables whose predictions must be computed.

A comparison of Figures 15 and 13 suggests that the adjustment of the UK trade data for seasonal effects led to an overall increase in the average forecasting errors of the PTM (23a) model. The reduction of the predictive accuracy of out-of-sample tests is due to the aforementioned increase in the number of one-step-ahead forecasts, since in each forecasting step we need to predict the export price at both the start date and the end date of the one-step-ahead annual period. However, despite the overall increase in the out-of-sample RMSFE of the PTM (23a) model, it remains significantly lower than the average forecast error of the non-PTM (23b) model for the majority of the manufactured products considered. Thus, our empirical findings suggest that the addition of the exchange rate to a model's set of explanatory variables significantly improves the accuracy of the predicted values of the export price.

While our estimation results suggest the existence of the PTM and its instability, the role of the exchange rate volatility has not been built into the econometric framework (23a), because the out-of-sample forecasting methodology only allows us to test the significance of an excess parameter in the nesting model. However, the reason for the coefficient instability remains beyond the scope of the out-of-sample method which assumes that both restricted and unrestricted models have a time varying parameter structure.

In order to determine whether the exchange rate volatility causes structural breaks in the degree of the PTM, we may run the following regression using OLS:

$$\begin{aligned} &\ln p_t = \delta + \beta_1 \ln p_{t-1} + \beta_2 \ln p_{t-2} + \beta_3 \ln MC_{t-1} + \\ &+ \beta_4 \ln MC_{t-2} + \beta_5 \ln e_{t-1} + \beta_6 \ln e_{t-2} + \beta_7 \sigma_{t-1} \ln e_{t-1} + \beta_8 \sigma_{t-2} \ln e_{t-2} + \mu_t \end{aligned} . \qquad (32)$$

The main difference between the baseline PTM model (23a) and the specification (32) lies in the inclusion of two interaction terms, $\sigma_{t-1} \ln e_{t-1}$ and $\sigma_{t-2} \ln e_{t-2}$. The annual average volatility of the exchange rate, σ_t, is computed as variance of the exchange rate observed over the past year:

$$\sigma_t = \frac{\sum_{i=0}^{12}\left(e_{t-i} - \bar{e}\right)^2}{12}, \tag{33}$$

where $\bar{e}$ denotes the annual mean of the exchange rate.

While in the baseline specification (23a) the degree of the PTM was measured by β_5 and β_6, in the modified regression (32) the response of the export price to the exchange rate is given by $\beta_5 + \beta_7\sigma_{t-1}$ and $\beta_6 + \beta_8\sigma_{t-2}$. If the volatility of the exchange rate generates a shift in the degree of PTM, coefficients β_7 and β_8 should be significantly different from zero. Table 12A reports the estimation results from running the PTM model (32).

The predictions of the augmented export price model (32) are broadly consistent with our initial findings from Section 3.7. Specifically, over half of the product categories considered exhibit a PTM pattern, since the coefficient on the first lag of the log-transformed exchange rate, β_5, is statistically significant at the 95% confidence level. The impact of the second lag of the log of the exchange rate is less important, since coefficient β_6 is statistically significant at the 99%, 95% or 90% confidence levels for 3 out of 11 series.

Thus, although the export price specification (32) does not accommodate potential instability of regression parameters, it still captures the effect of the exchange rate on the export price. However, the number of products that were found to be subject to the PTM is smaller compared to the results from running the baseline model (23a), since the PTM model (32) does not account for the evolution of regression parameters over time. This finding confirms Rossi's proposition that the likelihood of the rejection of the null hypothesis on the parameter of interest increases following the adoption of an estimation methodology that is robust to parameter instability (Rossi, 2006).

In contrast, the importance of the exchange rate volatility for the PTM is less evident. The estimation results reported in Table 12A suggest that the second lag of the exchange rate volatility reduces the degree of the PTM of food export prices, since β_8 is negative and statistically significant at the 95% confidence level. This finding is consistent with our theoretic hypothesis from Section 3.4 which suggested that during periods of a high exchange rate volatility exporters need to exercise the PTM more actively, since customers are likely to switch to a supplier offering a less volatile import price. However, we cannot confirm the importance of the exchange rate volatility for the PTM of other products.

It is worth noting that the annual average volatility of the exchange rate (33) is computed from past realizations of the exchange rate, i.e. $e_{t-1}, e_{t-2}, ..., e_{t-12}$. The resulting correlation between $\ln e_{t-i}$ and σ_{t-i}, where $i = 1$ or $i = 2$, induces multicollinearity into the export price specification (32). An undesirable consequence of the multicollinearity is the increase in the standard errors of parameter estimates (Belsley, 1976), which reduces the likelihood of rejecting the null hypothesis of the statistical insignificance of the coefficient of interest. Specifically, the effect of the exchange rate volatility may not be captured by coefficients β_7 and β_8, because the coefficients on past exchange rates, β_5 and β_6, absorb the impact of any variable that is highly correlated with the exchange rate. Therefore, even though coefficients β_7 and β_8 are predominantly insignificant in Table 12A, the exchange rate volatility may still affect the extent of the PTM. We will be able to analyze the link between the exchange rate volatility and the instability of the PTM parameters in the baseline model (23a) when the out-of-sample forecasting literature enables the forecasting algorithm to accommodate the source of coefficient instability.

3.9 Conclusion

In this chapter we developed several PTM tests which are robust to the instability of model parameters. Ensuring the robustness of the PTM coefficient estimates to possible time variation is essential, since the response of the export price to the exchange rate is likely to be unstable over time. In order to justify the instability of PTM, we developed a partial equilibrium framework of export price, which uses Krugman's suggestion that consumers dislike the volatility of prices (Krugman, 1986). Through solving the representative exporter's profit maximization problem, we showed that the response of the export price to a depreciation of the importer's currency is volatile, because the mark-up of the export price over the marginal cost varies with exchange rate volatility. We used four out-of-sample forecasting tests (i.e. rolling, recursive, split and RWCTVP) in order to test the sensitivity of the UK monthly export price indices to the value of the Pound Sterling vis-à-vis the currencies of the UK's trade partners. Out-of-sample tests represent a robust tool to test the significance of regression coefficients when model parameters are likely to be unstable, since these tests recursively estimate coefficients (Rossi, 2006).

We compared out-of-sample average forecasting errors of a model across various specifications of the export price and used the ENC-NEW test of forecast encompassing by Clark and McCracken (2001) in order to determine whether the difference between the average prediction errors of nested models is significantly different from zero. Our empirical findings argue in favour of the two major implications of our theoretic model. First, we discovered that an addition of the exchange rate to a forecasting model significantly reduces its mean error in predicting the export prices of nearly all product categories considered. Since the exchange rate has predictive content for the UK export prices, the UK exports of manufactured goods are subject to PTM. Second, we found substantial evidence of the instability in the degree of PTM, because forecasting models with time varying parameters predict future export prices with a lower mean forecasting error than fixed parameter models. This finding implies that the degree of the PTM by the UK exporters is unstable over time. However, overestimating the degree of the instability of the exchange rate coefficients may generate an inaccurate forecast of the export price, since highly adaptive models (i.e. RWCTVP tests) yielded larger mean forecasting errors than moderately adaptive regressions (i.e. rolling and recursive tests). Therefore, our empirical findings suggest that the degree of the evolution of the PTM parameters must be moderate, in order to minimize the average prediction error of an export price model.

It is worth noting that Krugman's proposition (Krugman, 1986) on consumers' preference for price stability is based on the assumption that it is costly to analyse an imported product. Thus, the import price volatility mainly affects the demand for those imports whose characteristics are sufficiently complex to necessitate a costly decision-making process. However, in the absence of product analysis costs, we are unable to justify the time variance of PTM, because the price mark-up over the marginal cost is insensitive to the import price volatility. In the next chapter, we propose a general equilibrium model, which generates the instability of the price mark-up without relying on the assumption of a costly product research.

4. Chapter 4: Reassessing the Stylized Facts about the PTM and ERPT Using Time varying Mark-ups

4.1 Introduction

In Chapters 2 and 3, we argued that the response of import and export prices to the exchange rate between the currencies of the exporter and importer may be unstable over time. The time variance of the PTM and ERPT was justified with the instability of the mark-up of the export price over the marginal cost. In this chapter, we continue exploring the time variance of the price mark-up within a Dynamic Stochastic General Equilibrium (DSGE) framework. Moreover, we use a time varying mark-up of price over the marginal cost in order to reassess selected stylized facts about the PTM and ERPT.

We build a two-country DSGE framework with subsistence points in consumption and investment. A consumption subsistence point represents a fixed fraction of a good's consumption, which is necessary in order to sustain the life of a household. An investment subsistence point defines a fixed proportion of a good's investment, which is required to sustain an investment process. In order to trace the dependence of the ERPT and PTM on the currency in which prices are invoiced, we analyse two types of firm, namely Producer Currency Pricing (PCP) and Local Currency Pricing (LCP). We attempt to offer a new perspective on several stylized facts about the international price discrimination. First, we will argue that setting a good's price in the importer's currency does not always stabilize its import price, because the variation of the price mark-up over the marginal cost leads to the volatility of the import price. Second, we will show that invoicing the price in the exporter's currency does not necessarily lead to a complete ERPT, since movements of the price mark-up prevent the import price from increasing one-to-one with a depreciation of the importer's currency. Finally, we will attempt to resolve the empirical puzzle which is frequently documented in the literature, namely the situation when the export price increases despite the importer's currency depreciation (Knetter, 1989). Specifically, we will justify this rise in the mark-up with a pro-cyclical price elasticity of the demand.

Since the definitions of the ERPT and PTM vary across the literature, let us clarify the definitions adopted in this chapter. The ERPT is defined as the response of the domestic price level to changes in the nominal exchange rate (Devereux and Yetman, 2002). The PTM represents the response of the export price to currency fluctuations (Rangan and Lawrence, 1993). Therefore, the degree of ERPT reflects the extent of PTM. For instance, if the importer's currency depreciates, a downward adjustment of the export price by firms reduces the degree of the import price increase caused by the depreciation.

After Krugman (1986) introduced the phenomenon of PTM, numerous studies attempted to model and estimate the ERPT. Their empirical findings may be neatly summarized by three stylized facts that are reassessed in this chapter. The first stylized fact specifies that, in the short run, the ERPT is complete for PCP goods, i.e. goods that are priced in the producer's currency (Obstfeld and Rogoff, 1995 and Chari et al., 2002). For example, if the price is fixed at X units of the exporter's currency, a 1% depreciation of the importer's currency leads to a 1% increase in the number of units of the importer's currency, which is required to purchase X units of the exporter's currency.

The second stylized fact, which logically follows from the first fact, states that the ERPT equals zero for LCP commodities, i.e. products whose prices are invoiced in the importer's currency (Obstfeld and Rogoff, 1995 and Chari et al., 2002). Specifically, when the price is fixed at Y units of the importer's currency, the depreciation of the importer's currency has no effect on the import price.

The third stylized finding concerns an empirical consensus suggesting that PCP firms decrease the export price when the importer's currency depreciates, in order to mitigate the rise in the import price (Marston, 1990). Therefore, evidence reflecting an increase of the export price despite the exporter's currency appreciation is considered as counterintuitive and "puzzling" (Knetter, 1989). This chapter attempts to resolve this empirical puzzle and demonstrates alternative interpretation of the abovementioned stylized facts about the PTM and ERPT.

There are three main differences between our DSGE framework and the seminal general equilibrium study by Betts and Devereux (1996). First, we employ a distinct consumption function, which includes subsistence points borrowed from Ravn et al. (2006). Thus, a household's consumption of a good is composed of two parts. The first component is time variant and falls in the relative price of the good. The second component is constant and independent of the price. This fixed portion of the good's consumption represents a minimum amount of the good, which is required for the survival of the household. Second, the export price is modelled as a time varying mark-up over the marginal cost, while the mark-up in Betts and Devereux (1996) is constant. The time variance of the mark-up originates from the existence of the subsistence consumption, which leads to pro-cyclical fluctuations in the price elasticity of the importer's demand. Pro-cyclical nature of the demand elasticity implies that the elasticity increases in the aggregate demand. Finally, our general equilibrium model incorporates stochastic elements, e.g. shocks to preferences and technology. The existence of these stochastic shocks allows us to simulate the response of the mark-up to positive shocks to the consumption and output.

This chapter is organized as follows. Section 4.2 presents the solutions to the optimization problems of households and firms. Specifically, through maximizing the profits of the representative LCP and PCP firms, we derive the optimal mark-ups of price over the marginal cost and compare the mark-ups of the two firm types. Section 4.3 computes the ERPT into the aggregate price level in the importer's country and examines the degrees of the good-specific ERPT into the PCP and LCP good prices. In particular, we analyse the effect of the time variance in the price mark-up on the ERPT and PTM. Section 4.4 compares our main findings to the aforementioned three stylized facts about the ERPT and PTM. In order to visualize this contrast, we simulate the response of the PCP and LCP mark-ups to positive technology and preference shocks. Finally, Section 4.5 summarizes the main contributions of this study to the literature on the international price discrimination.

4.2 Model

This study concentrates on one particular type of consumer preferences, namely a utility function with subsistence levels of consumption of each good. It extends the one-country framework developed by Ravn et al. (2006) into a two-country model with two types of firms (LCP and PCP), in order to introduce the exchange rate and explore its pass-through into export and import prices. Specifically, for each firm type, we derive the responses of the import and export prices to currency changes. We show that the depreciation of the importer's currency is followed by the variability of the import price irrespective of whether the firm sets its price in local currency or producer's currency. Even if firms invoice prices in the importer's currency, the import price will be inconstant due to mark-up movements.

The presence of subsistence points in consumption and investment determines the extent of the PTM and ERPT. We will show that, in the absence of the good-specific subsistence consumption and investment, the mark-up of price over the marginal cost is constant and the ERPT of PCP goods is complete. However, the introduction of the subsistence absorption induces a time variance of the mark-up, which prevents the PCP good's import price from increasing one-to-one with the depreciation of the importer's currency.

The model consists of two building blocks: utility-maximizing households owning physical capital and monopolistic firms setting prices in either domestic or foreign currency. First, the household's optimization problem is solved to determine the optimal conditions that govern the intertemporal allocation of consumption, the demand for real money balances and the supply of labour. Second, the solution to the monopolist firm's profit maximization problem is presented separately for the LCP and PCP cases. Specifically, we analyse the optimal mark-ups of the export price over the marginal cost, which determine the degree of the PTM and ERPT.

4.2.1 Household's optimization problem

A representative household in the home country has the following utility function, *U*:

$$U = E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \left(\frac{\left(x_{t+\tau}^c - v_{t+\tau}\right)^{1-\delta}}{1-\delta} + \gamma \frac{\left(1-h_{t+\tau}\right)^{1-\chi}}{1-\chi} + \frac{\mu}{1-\varepsilon} \left(\frac{M_{t+\tau}}{P_{t+\tau}} \right)^{1-\varepsilon} \right). \tag{1}$$

The preferences of foreign consumers are analogous to those of domestic consumers. Thus, the foreign utility function is presented by placing a superscript *f* (i.e. "foreign") over each variable in the utility function (1). The utility of the household is a function of a composite consumption good, $x_{t+\tau}^c$, preference shock, $v_{t+\tau}$, labour, $h_{t+\tau}$, and real money balances, $\frac{M_{t+\tau}}{P_{t+\tau}}$, where M_t stands for nominal money balances. Parameter δ defines the sensitivity of the utility to a marginal increase in the composite consumption, x_t^c. Similarly, parameters γ and χ define the response of the utility to a fall in the labour effort, h_t.

Finally, parameters μ and ε determine the elasticity of the utility with respect to real money holdings. β^{τ} denotes a subjective rate of discount.

The exogenous and stochastic preference shock, v_t, is modelled in both countries according to a univariate autoregressive process:

$$v_t \;= \rho_v \; v_{t-1} + \varpi_t \,, \tag{1a}$$

where the persistence parameter, ρ_v, falls within the range [0,1) and the innovation, ϖ_t, is $iid\left(0, \sigma_v\right)$.

The composite consumption good embeds the mechanism which induces time variance into the mark-up of price over the marginal cost:

$$x_t^c \;= \left[\int_0^1 \left(c_{it} - c_i^* \right)^{1-\frac{1}{\eta}} di \right]^{\frac{1}{1-\frac{1}{\eta}}} . \tag{2}$$

The composite consumption good (2) is composed of a continuum of differentiated products denoted by *i*, where $i \in [0,1]$. The composite consumption is determined by a time varying demand for individual goods, c_{it}, and a fixed level of the subsistence consumption of good *i*, c_i^*. Parameter η determines the elasticity of the demand for good *i* with respect to its price.

The demand for individual goods, c_{it}, is derived by minimizing the consumption expenditure, $\int_0^1 p_{it} c_{it} di$, subject to the composite consumption good's definition (2). The Lagrangean associated with this minimization problem is expressed as follows:

$$L = \int_0^1 p_{it} c_{it} di + \phi_t \left(x_t^c - \left[\int_0^1 \left(c_{it} - c_i^* \right)^{1-\frac{1}{\eta}} di \right]^{\frac{1}{1-\frac{1}{\eta}}} \right), \tag{3}$$

where ϕ_t represents the Lagrange multiplier. Differentiating the Lagrangean (3) with respect to the good-specific demand, c_{it}, and setting the resulting derivative to zero yields the following function of the demand for individual goods:

$$c_{it} = c_i^* + \left(\frac{p_{it}}{P_t} \right)^{-\eta} x_t^c \,, \tag{4}$$

where P_t is a nominal price index defined over a continuum of goods comprising the consumption basket:

$$P_t = \left[\int_0^1 p_{it}^{\;1-\eta} di \right]^{\frac{1}{1-\eta}}. \tag{5}$$

The aggregate price index, P_t, is comprised of prices of both domestic and foreign goods.

Thus, the demand function (4) represents a sum of two terms. The first term, c_i^*, is time-invariant and price-inelastic. c_i^* represents the amount of subsistence consumption, which is insensitive to price fluctuations, because the household needs to consume a minimum level of the good in order to sustain its living standard, irrespective of the price level. Any excess of consumption over the subsistence consumption, c_i^*, is governed by the relative price, $\left(\frac{p_{it}}{P_t}\right)$. Therefore, the time varying portion of the demand (4), i.e. $\left(\frac{p_{it}}{P_t}\right)^{-\eta} x_t^c$, varies with relative price movements. An increase of the relative price leads to a fall in the demand (4).

Since in this set-up the time variance of the price mark-up over the marginal cost is caused by the pro-cyclical nature of the price elasticity of the demand (4), let us derive the demand elasticity. The elasticity of demand with respect to price is defined as the relative change in the demand, $\frac{\partial c_{it}}{c_{it}}$, which results from a relative change in the price level, $\frac{\partial p_{it}}{p_{it}}$:

$$\left| \frac{\frac{\partial c_{it}}{c_{it}}}{\frac{\partial p_{it}}{p_{it}}} \right| = \left| \frac{\partial c_{it}}{\partial p_{it}} \frac{p_{it}}{c_{it}} \right| = \eta \left(1 - \frac{c_i^*}{c_{it}} \right). \tag{6}$$

Thus, the demand elasticity (6) is pro-cyclical. Specifically, an economic boom (i.e. an increase in c_{it}) raises the price elasticity of the demand (4), due to the existence of good-specific subsistence points in consumption, c_i^*.

If there was no subsistence consumption, i.e. $c_i^* = 0$ (see Rotemberg and Woodford, 1997), the absolute value of the price elasticity of demand for good *i* would be constant and equal to η $(\eta > 1)$. However, in a model featuring subsistence consumption, the demand elasticity (6) is different from η due to modifications in the consumption function (2). The introduction of the constant subsistence consumption, i.e. $c_i^* > 0$, leads to a reduction in the price elasticity of demand (6), compared to the case of $c_i^* = 0$. Moreover, an increase of the subsistence level of consumption of good i, c_i^*, decreases the demand elasticity (6). Thus, subsistence points in consumption induce a time variation in the demand elasticity with respect to price (6).

The time varying profile of the demand elasticity (6) has important implications for the degree of PTM and ERPT in this model, because variations in the demand elasticity imply a volatility of the market power of firms. The link between the variability of the demand elasticity and the time variance of the PTM and ERPT will become evident from the solution to the firms' profit maximization problems presented in the next section.

Following Ravn et al. (2006), a composite investment good that is analogous to the composite consumption good (2) is introduced:

$$x_t^i = \left[\int_0^1 \left(i_{it} - i_i^*\right)^{1-\frac{1}{\eta}} di\right]^{\frac{1}{\left(1-\frac{1}{\eta}\right)}}. \tag{7}$$

The investment process (7) is introduced in order to complete the law of motion (10) for the capital stock, k_t. The composite investment good (7) represents a continuum of differentiated investment goods indexed by i. Similarly to the composite consumption good (2), the investment composite good (7) contains a time-invariant level of investment, i_i^*, for each variety in the continuum. i_i^* can be interpreted as a minimum amount of investment good i, which is required to produce the composite capital good (7). Essentially, the subsistence points in investment, i_i^*, are determined by investment technology.

The time varying level of good-specific investment, i.e. i_{it}, can be found analogously to the case of the consumption demand (4) by choosing the level of i_{it} that minimizes the investment expenditure. This minimization problem implies a Lagrangean of the following form:

$$L = \int_0^1 p_{it} i_{it} di + \phi_t \left(x_t^i - \left[\int_0^1 \left(i_{it} - i_i^*\right)^{1-\frac{1}{\eta}} di\right]^{\frac{1}{1-\frac{1}{\eta}}} \right). \tag{8}$$

The solution to the investment expenditure minimization problem is symmetric to the consumption demand (4). Specifically, differentiating the Lagrangean (8) with respect to i_{it} and equating the resulting derivative to zero yields the following demand function for investment good *i*:

$$i_{it} = i_i^* + \left(\frac{p_{it}}{P_t}\right)^{-\eta} i_t^i . \qquad (9)$$

Thus, the demand for investment good (9) has a time-invariant subsistence component that is unresponsive to price fluctuations, i_i^*, and a time varying portion falling in the relative price of good *i*. Maintaining a symmetry across various components of the aggregate demand (i.e. consumption and investment) facilitates isolating the effect of subsistence points (Ravn et al., 2006).

The household's optimization problem implies maximizing utility (1) subject to a budget constraint. The household receives income from several sources. First, households are entitled to pure profits, Φ_t, which are earned by firms in their ownership. Second, they receive rental income, $u_t k_t$, from firms that borrow from households capital, k_t, at rate u_t. Capital evolves over time according to the following law of motion:

$$k_{t+1} = (1-\sigma)k_t + x_t^i , \qquad (10)$$

which suggests that the capital depreciates at the rate σ and grows with the composite investment, x_t^i. Third, households generate a real wage income, $w_t h_t$, through labour effort, where w_t denotes the real wage rate. Fourth, households receive a payoff, d_t, from trading in a complete contingent claim market. Finally, each period households inherit nominal money holdings from the previous period, M_{t-1}.

As far as the household's expenditures are concerned, households allocate their income among the real consumption and investment, $x_t^c + x_t^i + \int_0^1 \frac{p_{it}}{P_t}\left(c_i^* + i_i^*\right) di$, nominal money holdings, M_t, and asset holdings that pay d_{t+1} in the next period. Random future payments are discounted using a stochastic factor, $r_{t,t+1}$, where $E_t r_{t,t+1} d_{t+1}$ denotes the current price of a random future payment, d_{t+1}.

The domestic household's decision problem is to choose the time paths for composite consumption, x_t^c, composite investment, x_t^i, labour supply, h_t, capital, k_t, and the holdings of money and assets, M_t and d_{t+1}. Thus, the household maximizes the utility (1) subject to the following budget constraint

$$x_t^c + \int_0^1 \frac{p_{it}}{P_t}\left(c_i^* + i_i^*\right)di + x_t^i + E_t r_{t,t+1} d_{t+1} + \frac{M_t}{P_t} = d_t + w_t h_t + \Phi_t + u_t k_t + \frac{M_{t-1}}{P_t}, \tag{11}$$

where the processes $v_t, w_t, r_{t,t+1}, u_t$ and Φ_t are given. Foreign households' budget constraint is defined by placing a superscript f over each variable in the constraint (11).

The domestic household's utility maximization problem is solved by equating to zero the derivatives of the following Lagrangean with respect to $x_{t+\tau}^c$, $x_{t+\tau}^i$, $h_{t+\tau}$, $k_{t+\tau}$, $M_{t+\tau}$,and $d_{t+\tau}$:

$$\begin{aligned} L = & E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \left(\frac{\left(x_{t+\tau}^c - v_{t+\tau}\right)^{1-\delta}}{1-\delta} + \gamma \frac{\left(1-h_{t+\tau}\right)^{1-\chi}}{1-\chi} + \frac{\mu}{1-\varepsilon}\left(\frac{M_{t+\tau}}{P_{t+\tau}}\right)^{1-\varepsilon} \right) + \\ & + \lambda_{t+\tau}\left(x_{t+\tau}^c + \psi_{t+\tau} + x_{t+\tau}^i + E_{t+\tau} r_{t+\tau,t+\tau+1} \frac{d_{t+\tau+1}}{P_{t+\tau}} + \frac{M_{t+\tau}}{P_{t+\tau}} - \frac{d_{t+\tau}}{P_{t+\tau}} - w_{t+\tau} h_{t+\tau} - \Phi_{t+\tau} - u_{t+\tau} k_{t+\tau} - \frac{M_{t+\tau-1}}{P_{t+\tau}} \right) + \\ & + \theta_{t+\tau}\left(k_{t+\tau+1} - (1-\sigma) k_{t+\tau} - x_{t+\tau}^i\right), \end{aligned} \tag{12}$$

where $\psi_{t+\tau} = \int_0^1 \frac{p_{it+\tau}}{P_{t+\tau}}\left(c_i^* + i_i^*\right)di$. The equilibrium conditions for consumption, investment, labour supply, capital and the holdings of assets and money are defined as

$$\frac{\partial L}{\partial x_{t+\tau}^c} = \beta^{\tau}\left(x_{t+\tau}^c - v_{t+\tau}\right)^{-\delta} + \lambda_{t+\tau} = 0, \tag{13}$$

$$\frac{\partial L}{\partial x_{t+\tau}^i} = \lambda_{t+\tau} - \theta_{t+\tau} = 0, \tag{14}$$

$$\frac{\partial L}{\partial h_{t+\tau}} = -\beta^{\tau}\gamma\left(1-h_{t+\tau}\right)^{-\chi} - \lambda_{t+\tau} w_{t+\tau} = 0, \tag{15}$$

$$\frac{\partial L}{\partial k_{t+\tau}} = -\lambda_{t+\tau} u_{t+\tau} + \theta_{t+\tau-1} - (1-\sigma)\theta_{t+\tau} = 0, \tag{16}$$

$$\frac{\partial L}{\partial d_{t+\tau}} = \lambda_{t+\tau-1} E_{t+\tau-1} r_{t+\tau-1,t+\tau} \frac{1}{P_{t+\tau-1}} - \lambda_{t+\tau}\frac{1}{P_{t+\tau}} = 0, \tag{17}$$

$$\frac{\partial L}{\partial M_{t+\tau}} = \beta^{\tau}\mu P_{t+\tau}^{\varepsilon-1} M_{t+\tau}^{-\varepsilon} + \frac{\lambda_{t+\tau}}{P_{t+\tau}} - \frac{\lambda_{t+\tau+1}}{P_{t+\tau+1}} = 0. \tag{18}$$

Combining the conditions (13) and (17) yields the following equation for the optimal intertemporal allocation of consumption:

$$\beta\left(x_t^c - v_t\right)^{-\delta} = \left(x_{t-1}^c - v_{t-1}\right)^{-\delta} \frac{P_t}{P_{t-1}} E_{t-1} r_{t-1,t}. \tag{19}$$

Iterating the condition (19) forward by one period gives

$$\beta E_t \left(x_{t+1}^c - v_{t+1}\right)^{-\delta} = \left(x_t^{\ c} - v_t\right)^{-\delta} E_t \frac{P_{t+1}}{P_t} E_t r_{t,t+1}. \tag{19a}$$

The optimality condition (19a) represents the Euler condition, which governs the optimal intertemporal allocation of consumption by equalizing the marginal utilities of consumption across time.

Using the condition for money holdings (18), the definition of the Lagrange multiplier (13) and the intertemporal allocation of consumption (19a), the following identity for the optimal money balances may be derived:

$$\mu\left(\frac{M_t}{P_t}\right)^{-\varepsilon} = \left(x_t^c - v_t\right)^{-\delta}\left(1 - E_t r_{t,t+1}\right), \tag{20}$$

which states that the demand for real money balances increases in consumption and the stochastic discount factor. Intuitively, a higher discount factor, $r_{t,t+1}$, implies a higher current price of the future random payment, $E_t r_{t,t+1} d_{t+1}$. Therefore, the attractiveness of money balances relative to the complete contingent claims increases in the discount factor, which determines the opportunity cost of holding money.

Substituting the Lagrange multiplier definition (13) for $\lambda_{t+\tau}$ in the labour supply condition (15) yields:

$$\gamma\left(1 - h_t\right)^{-\chi} = w_t\left(x_t^c - v_t\right)^{-\delta}. \tag{21}$$

The condition (21) states that leisure is falling in the real wage rate, since the latter represents the opportunity cost of leisure. A higher wage rate encourages the labour effort and reduces the leisure time.

Finally, combining the Lagrange multiplier definition (14) with the capital condition (16) and the consumption allocation (13) imposes an additional restriction on the intertemporal allocation of consumption:

$$\beta^{-1}\left(x_{t-1}^c - v_{t-1}\right)^{-\delta} = \left(u_t + 1 - \sigma\right)\left(x_t^c - v_t\right)^{-\delta}. \tag{22}$$

Iterating the condition (22) forward by one period yields

$$\left(x_t^c - v_t\right)^{-\delta} = \beta E_t\left(u_{t+1} + 1 - \sigma\right)\left(x_{t+1}^c - v_{t+1}\right)^{-\delta}. \tag{23}$$

The condition (23) states that the current consumption falls in the discounted rate of interest, $\beta E_t u_{t+1}$. Intuitively, a higher interest rate generates a greater return on investment and encourages the household to shift its resources from consumption to savings.

Following Betts and Devereux (1996), domestic and foreign households are assigned homogeneous preferences. Therefore, the foreign household's optimization problem is analogous to the domestic household's utility maximization problem. Thus, the foreign household's optimality conditions are expressed by adding a superscript f to each variable in equilibrium conditions (13)-(23).

4.2.2 Firms' optimization problem

There is a continuum of monopolistic firms in the economy. Each firm produces its own variety denoted by $i \in [0;1]$ and follows a Cobb-Douglas production technology with a Hicks-neutral technological progress. The firm's output of good i must be sufficient to satisfy the aggregate demand for this product:

$$A_t k_{it}^{\alpha} h_{it}^{1-\alpha} \geq c_{it} + i_{it} + c_{it}^{f} + i_{it}^{f} , \tag{24}$$

where A_t refers to an aggregate technology shock. Labour, h_t, and capital, k_t, represent two inputs of the production process (24). The left hand side of the condition (24) represents the output of a given variety, while the right hand side defines the aggregate demand for this differentiated good. The aggregate demand is composed of the domestic demand for investment and consumption goods, $c_{it} + i_{it}$, and the foreign demand, $c_{it}^{f} + i_{it}^{f}$. Parameter α denotes the elasticity of output with respect to capital:

$$\frac{\partial\left(A_t k_{it}^{\alpha} h_{it}^{1-\alpha}\right)}{\partial k_{it}} \frac{k_{it}}{A_t k_{it}^{\alpha} h_{it}^{1-\alpha}} = \alpha , \tag{25}$$

where $0 < \alpha < 1$.

Similarly to households, firms solve their respective optimization problems. The firm's optimization problem depends on the type of firm. Following Betts and Devereux (1996), we assume that PCP firms set a single price for both home and foreign markets, while LCP firms charge a unique price in each market. The currency in which prices are invoiced differs across the PCP and LCP cases. Specifically, in the PCP case, price is set in the exporter's currency, while the LCP case implies that prices are invoiced in the importer's currency.

In an economy with no subsistence points in the aggregate absorption, this distinction between two types of firm matters for the degree of ERPT. Consider a foreign PCP firm that fixes the price of its good, p_{it}^{f}, in the exporter's currency. The price paid by the domestic importer is given by $e_t p_{it}{}^f$, where e_t denotes the exchange rate in units of the domestic currency per one unit of the foreign currency. Assuming no movement in the export price, p_{it}^f, the depreciation of the importer's currency (i.e. an increase in e_t) by 1% increases the import price, $e_t p_{it}{}^f$, by 1%. Thus, the ERPT into the import price is complete. In contrast, the LCP firm fixes prices in the importer's currency. Suppose that the foreign firm sets a price of q_{it}^f for the domestic market. Since the price is fixed in the importer's currency, it is entirely insensitive to movements of the exchange rate, e_t. Therefore, the extent of the ERPT into the import price is zero.

In an economy with subsistence points in consumption and investment, the ERPT is no longer complete in the PCP case, because the export price, p_{it}^f, varies with currency movements. Similarly, the ERPT into the LCP good's import price is different from zero, because the import price varies with fluctuations in the exchange rate. In order to show that the ERPT is unstable irrespective of firm type, this section solves firms' optimization problems and obtains the equilibrium conditions governing the behaviour of the optimal export price. The LCP firm's profit maximization problem is different from the PCP firm's optimization problem. However, in both cases, subsistence points in the aggregate absorption generate time varying mark-ups of export price over the marginal cost, which induce deviations from the complete ERPT (PCP) and zero pass-through (LCP).

4.2.2.1 LCP firm's optimization problem

This section derives the optimal export price set by an LCP firm. Consider a domestic LCP firm, i, which sells a portion of its output at home and exports the remainder abroad. It sets a distinct nominal price for each market by charging p_{it} at home and q_{it} abroad. p_{it} is expressed in the home currency, while q_{it} is invoiced in the foreign currency. Thus, the firm is receiving revenue $e_t q_{it}$ from selling the good abroad. The firm's optimization problem implies choosing the optimal levels of capital, k_{it}, labour, h_{it}, and nominal prices for each market, p_{it} *and* q_{it}. The firm must maximize the present discounted value of real profits subject to three constraints, namely consumption good demand (4), investment good demand (9) and the inequality (24) containing the production technology and the resource constraint.

Profits represent the difference between the revenues from domestic and foreign sales and joint costs of production:

$$E_0 \sum_{t=0}^{\infty} r_{0,t} \left\{ \frac{p_{it}}{P_t}\left(c_{it} + i_{it}\right) + \frac{e_t q_{it}}{P_t}\left(c_{it}^f + i_{it}^f\right) - w_t h_{it} - u_t k_{it} \right\}, \tag{26}$$

where the processes $r_{0,t}, w_t, u_t, A_t, x_t^c, x_t^i, x_t^{cf}, x_t^{if}, e_t$ are given and foreign demands for consumption and investment goods are defined, respectively, as follows:

$$\begin{aligned} c_{it}^f &= c_i^{*f} + \left(\frac{q_{it}}{P_t^f}\right)^{-\eta} x_t^{cf} \\ i_{it}^f &= i_i^{*f} + \left(\frac{q_{it}}{P_t^f}\right)^{-\eta} x_t^{if} \end{aligned} \quad . \tag{27}$$

Variable P_t^f denotes price level in the foreign country.

The Lagrangean associated with the domestic LCP firm's profit maximization problem is

$$L = E_o \sum_{t=0}^{\infty} r_{0,t} \left\{ \begin{aligned} & p_{it}\left(c_i^* + \left(\frac{p_{it}}{P_t}\right)^{-\eta} x_t^c + i_i^* + \left(\frac{p_{it}}{P_t}\right)^{-\eta} x_t^i \right) + \\ & e_{it} q_{it}\left(c_i^{*f} + \left[\frac{q_{it}}{P_t^f}\right]^{-\eta} x_t^{cf} + i_i^{*f} + \left[\frac{q_{it}}{P_t^f}\right]^{-\eta} x_t^{if} \right) - w_t h_{it} - u_t k_{it} \end{aligned} \right\} -$$

$$- MC_{it} \left\{ c_i^* + \left(\frac{p_{it}}{P_t}\right)^{-\eta} x_t^c + i_i^* + \left(\frac{p_{it}}{P_t}\right)^{-\eta} x_t^i + c_i^{*f} + \left(\frac{q_{it}}{P_t^f}\right)^{-\eta} x_t^{cf} + i_i^{*f} + \left(\frac{q_{it}}{P_t^f}\right)^{-\eta} x_t^{if} - A_t k_{it}^{\alpha} h_{it}^{1-\alpha} \right\}. \tag{28}$$

Note that we substituted the demands for consumption and investment goods into the Lagrangean (28). Lagrange multiplier on the constraint (24) is denoted by MC_{it}, which stands for marginal cost.

In order to check that the Lagrange multiplier represents the marginal cost, let us derive the first order conditions with respect to capital and labour:

$$\frac{\partial L}{\partial h_{it}} = -w_t + (1-\alpha) MC_{it} A_t \left(\frac{k_{it}}{h_{it}}\right)^{\alpha} = 0, \tag{29}$$

$$\frac{\partial L}{\partial k_{it}} = -u_t + \alpha MC_{it} A_t \left(\frac{k_{it}}{h_{it}}\right)^{\alpha-1} = 0. \tag{30}$$

Combining the conditions (29) and (30) gives the marginal cost definition:

$$MC_{it} = \frac{u_t}{\alpha A_t \left(\frac{k_{it}}{h_{it}}\right)^{\alpha-1}} = \frac{w_t}{(1-\alpha)A_t \left(\frac{k_{it}}{h_{it}}\right)^{\alpha}}. \tag{31}$$

The marginal cost definition (31) suggests that MC_{it} equals the derivative of the input cost with respect to total output, y_{it}:

$$MC_{it} = \frac{\partial(k_t u_t)}{\partial y_{it}} = \frac{u_t}{\frac{\partial y_t}{\partial k_{it}}} = \frac{u_t}{\alpha A_t \left(\frac{k_{it}}{h_{it}}\right)^{\alpha-1}}, \tag{31a}$$

$$MC_{it} = \frac{\partial(w_t h_{it})}{\partial y_{it}} = \frac{w_t}{\frac{\partial y_{it}}{\partial h_{it}}} = \frac{w_t}{(1-\alpha)A_t \left(\frac{k_{it}}{h_{it}}\right)^{\alpha}}. \tag{31b}$$

Solving the marginal cost identity (31) for $\frac{h_{it}}{k_{it}}$ defines the optimal labour-to-capital ratio for the production process:

$$\frac{h_{it}}{k_{it}} = \frac{1-\alpha}{\alpha}\frac{u_t}{w_t}. \tag{32}$$

Thus, the optimal labour-to-capital ratio (32) for producer i is proportionate to the ratio of payments attributed to each factor of production. Equation (32) implies that producers prefer the cheapest input in the production process. Specifically, an increase of the wage rate (w_t) relative to the cost of renting the capital stock (u_t) raises the size of capital (k_{it}) relative to the amount of labour employed (h_{it}).

The first order conditions with respect to the nominal prices charged in the domestic and foreign markets are obtained by differentiating the Lagrangean (28) with respect to p_{it} and q_{it}:

$$\frac{\partial L}{\partial p_{it}} = (c_i^* + i_i^*) + (1-\eta)(x_t^c + x_t^i)\left(\frac{p_{it}}{P_t}\right)^{-\eta} - (-\eta)(x_t^c + x_t^i)MC_{it}(p_{it})^{-\eta-1}\left(\frac{1}{P_t}\right)^{-\eta} = 0, \tag{33}$$

$$\frac{\partial L}{\partial q_{it}} = e_t(c_i^{*f} + i_i^{*f}) + e_t(1-\eta)(x_t^{cf} + x_t^{if})\left(\frac{q_{it}}{P_t^f}\right)^{-\eta} - (-\eta)(x_t^{cf} + x_t^{if})MC_{it}q_{it}^{-\eta-1}\left(\frac{1}{P_t^f}\right)^{-\eta} = 0 \tag{34}$$

The conditions (33) and (34) describe the LCP firm's price-setting policy governed by the mark-up of the nominal price over the marginal cost. Solving the first order conditions (33) and (34) for the reverse of the price mark-up over the marginal cost gives

$$\frac{MC_{it}}{p_{it}} = \frac{\eta-1}{\eta} - \frac{c_i^* + i_i^*}{\eta\left(\frac{p_{it}}{P_t}\right)^{-\eta}\left(x_t^c + x_t^i\right)}, \tag{35}$$

$$\frac{MC_{it}}{q_{it}e_{it}} = \frac{\eta-1}{\eta} - \frac{c_i^{*f} + i_i^{*f}}{\eta\left(\frac{q_{it}}{P_t^f}\right)^{-\eta}\left(x_t^{cf} + x_t^{if}\right)}. \tag{36}$$

In order to facilitate the analysis of the mark-up dynamics, let us simplify the definitions (35) and (36) using the demand functions (4), (9) and (27):

$$\frac{MC_{it}}{p_{it}} = 1 - \frac{c_{it} + i_{it}}{\eta\left(c_{it} + i_{it} - \left(c_i^* + i_i^*\right)\right)}, \tag{37}$$

$$\frac{MC_{it}}{q_{it}e_t} = 1 - \frac{c_{it}^{\ f} + i_{it}^{\ f}}{\eta\left(c_{it}^{\ f} + i_{it}^{\ f} - \left(c_i^{*f} + i_i^{*f}\right)\right)}. \tag{38}$$

Finally, denoting the subsistence absorptions at home and abroad by $y_i^* = c_i^* + i_i^*$ and $y_i^{*f} = c_i^{*f} + i_i^{*f}$, respectively, yields a more convenient representation of the optimal mark-ups of the domestic LCP firm:

$$\frac{p_{it}}{MC_{it}} = \mu_1 = \left\{\frac{\eta-1}{\eta} - \frac{1}{\eta\left(\frac{c_{it} + i_{it}}{y_i^*} - 1\right)}\right\}^{-1}, \tag{39}$$

$$\frac{q_{it}e_t}{MC_{it}} = \mu_2 = \left\{\frac{\eta-1}{\eta} - \frac{1}{\eta\left(\frac{c_{it}^f + i_{it}^f}{y_i^{*f}} - 1\right)}\right\}^{-1}. \tag{40}$$

The identity (39) shows the mark-up of price for the domestic market, while the equation (40) represents the mark-up set for the foreign market. Since the profit-maximization problem of foreign LCP firms is analogous to that of the domestic LCP firm, foreign LCP mark-ups set for the domestic and foreign markets also equal μ_1 and μ_2, respectively.

Both mark-ups are expressed in the exporter's currency and consist of two components. The first component is a constant fraction determined by the demand elasticity parameter, η. Note that parameter η describes the price elasticity of both domestic and foreign demands, since we assume that the domestic and foreign households have identical preferences. Therefore, the constant component of the reverse of the mark-up, $\frac{\eta-1}{\eta}$, is identical in both locations. However, the second component of the price mark-up is market-specific. It is determined by the ratio of the aggregate local demand, $c_{it}^{(f)}+i_{it}^{(f)}$, to the subsistence country-specific absorption, $y_i^{*(f)}$. An increase of the share of the subsistence absorption in the aggregate demand for good *i*, $\frac{y_i^{*(f)}}{c_{it}^{(f)}+i_{it}^{(f)}}$, leads to a rise in the mark-up.

The introduction of good-specific subsistence points in consumption and investment leads to fundamental changes in the optimal mark-up of the export price over the marginal cost. Intuitively, a rise of the subsistence consumption from zero to a positive constant leads to a fall in the absolute value of the price elasticity of demand (6). A lower demand elasticity implies a higher market power of the monopolistic firm. The demand elasticity is inversely related to the firm's market power, because individual goods become more distant substitutes for each other when the price elasticity of demand falls. Therefore, a marginal increase of the price by a firm would not lead to a significant fall in the demand for its product, since close substitutes are not available. Consequently, firms' market power increases when the price elasticity of demand falls (see Walsh, 2003).

It is worth noting that the mark-ups pertaining to the model with no subsistence absorption, i.e. $y_i^{*(f)}=0$, are smaller than the mark-ups (39) and (40). If there were no subsistence points in consumption and investment, these two mark-ups would equal the same value:

$$\frac{q_{it}e_t}{MC_{it}}=\frac{p_{it}}{MC_{it}}=\frac{\eta}{\eta-1}. \tag{40a}$$

The introduction of subsistence points (i.e. $y_i^{*(f)}>0$) decreases the price elasticity of the demand, compared to the case with no subsistence absorption (i.e. $y_i^{*(f)}=0$), because the existence of subsistence consumption prevents the demand from falling significantly with a price increase. Specifically, households need a minimum level of the good's consumption to survive, irrespective of its price. Consequently, the reduced elasticity of the demand with respect to price enables the producer to exploit his increased market power by charging a higher mark-up.

Thus, due to the introduction of the subsistence absorption, the mark-up of price over the marginal cost is time variant. Its dynamics depends on the current stage of the business cycle. Namely, the mark-up falls during an economic boom (i.e. an increase in $c_{it}^{(f)} + i_{it}^{(f)}$) and increases during a recession (i.e. a fall in $c_{it}^{(f)} + i_{it}^{(f)}$). The negative effect of the economic expansion on the mark-up is explained by the pro-cyclical nature of the price elasticity of demand (6). Specifically, the absolute value of the demand elasticity (6) increases with a rise of c_{it} and reduces the market power of the firm.

Comparing the mark-ups (39) and (40) provides an insight into the international price discrimination reflected in systematic differences among the prices of the same good across the world, when all prices are expressed in a common currency (Corsetti and Dedola, 2005). Since the mark-ups charged in the home (39) and foreign (40) markets are generally different, our model generates deviations from the law of one price (LOP), i.e. $q_{it}e_t \neq p_{it}$. The LOP only holds in two special cases. First, the home mark-up (39) is identical to the foreign mark-up (40) and equals $\frac{\eta}{\eta - 1}$ in the absence of subsistence points, i.e. $y_i^* = y_i^{*f} = 0$. Therefore, prices are equalized across the two countries when expressed in the exporter's currency, i.e. $p_{it} = e_t q_{it}$. Second, the LOP is also observed in the situation when the ratio of the subsistence absorption to the aggregate demand is the same in both markets, i.e. $\frac{y_i^*}{c_{it} + i_{it}} = \frac{y_i^{*f}}{c_{it}^f + i_{it}^f}$. Specifically, the firm charges a price mark-up of $\frac{\eta}{\eta - 1}$ in both domestic and foreign markets.

Thus, subsistence points in consumption and investment represent a useful tool to explain the international price discrimination. If the consumption function (4) had no subsistence points (i.e. $y_i^* = y_i^{*f} = 0$), the domestic (39) and foreign (40) mark-ups would be constant and equal to $\frac{\eta}{\eta - 1}$. Thus, the only way to explain international price differentials in the absence of subsistence absorption would be to assume that the preferences of domestic and foreign households are heterogeneous. In particular, the price elasticity of the domestic demand, η, must differ from its foreign counterpart, η^f, in order for the optimal mark-up to vary across markets:

$$\frac{p_{it}}{MC_{it}} = \frac{\eta}{\eta - 1}, \frac{q_{it}e_t}{MC_{it}} = \frac{\eta^f}{\eta^f - 1}. \tag{41}$$

However, in the presence of subsistence consumption points, i.e. $y_i^{*(f)} \neq 0$, the assumption of preference heterogeneity is not necessary to generate mark-up inequalities across markets.

Our model explains international price differentials with a counter-cyclical nature of the time varying LCP mark-up, which depends on the current stage of the business cycle in the importer's country. Since different economies are likely to operate at different stages of the business cycle, mark-ups are likely to vary across destinations. For example, if the foreign economy experienced a boom relative to the domestic country ($c_{it}{}^f + i_{it}^f > c_{it} + i_{it}$), the mark-up charged in the foreign country (40) would fall below the home mark-up (39), i.e. $\frac{q_{it}e_t}{MC_{it}} < \frac{p_{it}}{MC_{it}}$. Intuitively, as the foreign market experiences the boom, a greater number of substitutes for good *i* becomes available, which increases the price elasticity of the demand for the good. Consequently, the firm's market power abroad is weaker than at home. When the domestic mark-up (39) exceeds its foreign counterpart (40), the price paid by foreign customers of domestic good *i* falls below the price charged at home, i.e. $p_{it} > q_{it}e_t$. Thus, the LOP does not hold when countries operate at different points of the business cycle.

Although the LCP firm sets the price for the foreign market in the importer's currency, the degree of the ERPT into the import price is different from zero. LCP does not insulate the import price from currency fluctuations because of the time varying profile of the mark-up. Before showing that LCP does not completely stabilize import prices in this model, we solve a PCP firm's optimization problem in the next section.

4.2.2.2 PCP firm's optimization problem

Unlike LCP firms, PCP firms set the same price for all markets. Consider a domestic PCP firm charging a nominal price p_{it} in both domestic and foreign markets. Since prices are set in the exporter's currency, foreign consumers pay a nominal price $\frac{p_{it}}{e_t}$ for good *i*. Thus, the PCP firm's profit maximization problem is slightly different from that of the LCP firm.

Specifically, similarly to the LCP case outlined in the previous section, the PCP firm maximizes the present discounted value of real profits,

$$E_0 \sum_{t=0}^{\infty} r_{0,t} \left\{ p_{it} \left(c_{it} + i_{it} + c_{it}^f + i_{it}^f \right) - w_t h_{it} - u_t k_{it} \right\}, \tag{42}$$

subject to the resource restriction (24), the domestic demand constraints (4) and (9), as well as the foreign demand constraints:

$$\begin{aligned} c_{it}^f &= c_i^{*f} + \left(\frac{\frac{p_{it}}{e_t}}{P_t^f} \right)^{-\eta} x_t^{cf} \\ i_{it}^f &= i_i^{*f} + \left(\frac{\frac{p_{it}}{e_t}}{P_t^f} \right)^{-\eta} x_t^{if} \end{aligned} \quad . \tag{43}$$

Specifically, the PCP firm chooses the time paths for p_{it}, h_{it} and k_{it} given the processes $r_{0,t}, w_t, u_t, A_t, x_t^c, x_t^i, x_t^{cf}, x_t^{if}$ and e_t .

The Lagrangean associated with the PCP firm's profit-maximization problem is:

$$\begin{aligned} L = E_o \sum_{t=0}^{\infty} r_{0,t} & \left\{ \begin{array}{l} p_{it} \left(c_i^* + \left(\frac{p_{it}}{P_t} \right)^{-\eta} x_t^c + i_i^* + \left(\frac{p_{it}}{P_t} \right)^{-\eta} x_t^i + c_i^{*f} + \left(\frac{\frac{p_{it}}{e_t}}{P_t^f} \right)^{-\eta} x_t^{cf} + i_i^{*f} + \left(\frac{\frac{p_{it}}{e_t}}{P_t^f} \right)^{-\eta} x_t^{if} \right) - \\ - w_t h_{it} - u_t k_{it} \end{array} \right\} - \\ - MC_{it} & \left\{ c_i^* + \left(\frac{p_{it}}{P_t} \right)^{-\eta} x_t^c + i_i^* + \left(\frac{p_{it}}{P_t} \right)^{-\eta} x_t^i + c_i^{*f} + \left(\frac{\frac{p_{it}}{e_t}}{P_t^f} \right)^{-\eta} x_t^{cf} + i_i^{*f} + \left(\frac{\frac{p_{it}}{e_t}}{P_t^f} \right)^{-\eta} x_t^{if} - A_t k_{it}^{\alpha} h_{it}^{1-\alpha} \right\} \end{aligned} \tag{44}$$

The first-order conditions with respect to capital, k_{it}, and labour, h_{it}, are identical to the LCP firm's optimality conditions (29) and (30).

However, the derivative of the Lagrangean (44) with respect to price is different:

$$\begin{aligned} \frac{\partial L}{\partial p_{it}} &= c_i^* + i_i^* + (1-\eta)\left(x_t^c + x_t^i\right)\left(\frac{p_{it}}{P_t} \right)^{-\eta} + c_i^{*f} + i_i^{*f} + (1-\eta)\left(x_t^{cf} + x_t^{if}\right) p_{it}^{-\eta} \left(\frac{1}{e_t P_t^f} \right)^{-\eta} - \\ &- (-\eta)\left(x_t^c + x_t^i\right) MC_{it}\, p_{it}^{-\eta-1} \left(\frac{1}{P_t} \right)^{-\eta} - (-\eta)\left(x_t^{cf} + x_t^{if}\right) MC_{it}\, p_{it}^{-\eta-1} \left(\frac{1}{e_t P_t^f} \right)^{-\eta} = 0. \end{aligned} \tag{45}$$

Solving the equation (45) for the reverse of the optimal price mark-up over the marginal cost yields

$$\frac{MC_{it}}{p_{it}}=\frac{\eta-1}{\eta}-\frac{\left(c_i^*+i_i^*+c_i^{*f}+i_i^{*f}\right)}{\eta\left[\left(\frac{p_{it}}{P_t}\right)^{-\eta}\left(x_t^c+x_t^i\right)+\left(\frac{p_{it}}{e_tP_t^f}\right)^{-\eta}\left(x_t^{cf}+x_t^{if}\right)\right]}. \tag{46}$$

Using the demand conditions (4), (9) and (43), the reverse of the optimal mark-up (46) is transformed into

$$\frac{MC_{it}}{p_{it}}=1-\frac{c_{it}+i_{it}+c_{it}^f+i_{it}^f}{\eta\left(c_{it}+i_{it}+c_{it}^f+i_{it}^f-\left(c_i^*+i_i^*+c_i^{*f}+i_i^{*f}\right)\right)}. \tag{47}$$

Finally, reversing the ratio (47) and substituting $y_i^{*(f)}$ for $c_i^{*(f)}+i_i^{*(f)}$ gives the following optimal mark-up of the export price over the marginal cost:

$$\frac{p_{it}}{MC_{it}}=\mu_3=\left\{\frac{\eta-1}{\eta}-\frac{1}{\eta\left(\frac{c_{it}+i_{it}+c_{it}^f+i_{it}^f}{y_i^*+y_i^{*f}}-1\right)}\right\}^{-1}. \tag{48}$$

Thus, since the PCP firm sets the same price for foreign and domestic markets, we observe only one optimal mark-up (48) instead of two separate mark-ups (39) and (40) in the LCP case.

The PCP mark-up of the export price over the marginal cost is qualitatively similar to the LCP mark-ups (39) and (40). The mark-up (48) contains a time-invariant ratio driven by the elasticity parameter, η, and a time varying component, which falls in the ratio of the aggregate demand to the total subsistence absorption, $\frac{c_{it}+i_{it}+c_{it}^f+i_{it}^f}{y_i^*+y_i^{*f}}$. However, in contrast to the LCP mark-ups (39) and (40), the PCP mark-up features the sum of the home and foreign absorptions, $y_i^*+y_i^{*f}$, since the PCP firm sets the same price for both markets.

Comparing the PCP mark-up (48) to the mark-ups (39) and (40), which are charged by LCP firms, also reveals several similarities. Specifically, in both LCP and PCP, the existence of subsistence absorption leads to an increase of the mark-up, compared to the case of no subsistence points in consumption and investment, i.e. $y_i^*=y_i^{*f}=0$:

$$\mu_{1(2)} = \left\{ 1 - \frac{1}{\eta\left(1 - \dfrac{y_i^{*(f)}}{c_{it}^{(f)} + i_{it}^{(f)}}\right)} \right\}^{-1} > \frac{\eta}{\eta - 1}, \tag{49a}$$

$$\mu_3 = \left\{ 1 - \frac{1}{\eta\left(1 - \dfrac{y_i^* + y_i^{*f}}{c_{it} + i_{it} + c_{it}^f + i_{it}^f}\right)} \right\}^{-1} > \frac{\eta}{\eta - 1}. \tag{49b}$$

If there is a positive level of subsistence absorption, the LCP (49a) and PCP (49b) mark-ups of the export price over the marginal cost are generally different. The three mark-ups converge to the same value only in one special case. In particular, the subsistence-to-demand ratio should be the same in these three cases:

$$\frac{y_i^*}{c_{it} + i_{it}} = \frac{y_i^{*f}}{c_{it}^f + i_{it}^f} = \frac{y_i^* + y_i^{*f}}{c_{it} + i_{it} + c_{it}^f + i_{it}^f}. \tag{49c}$$

Despite the differences among the mark-ups of the LCP (49a) and PCP (49b) firms, all three mark-ups successfully justify one of the major puzzles in the macroeconomic literature, namely the violation of the LOP. The next section summarizes the conditions under which prices are not equal across countries even when converted to a common currency.

4.2.2.3 International price differentials

The behaviour of the domestic and foreign subsistence absorptions has a significant impact on the international price differentials for variety *i*. The implications of our model for the international price discrimination may be summarized by three propositions.

Proposition 1*: If* $y_i^* = y_i^{*f} = 0$, then $\mu_1 = \mu_2 = \mu_3 = \dfrac{\eta}{\eta - 1}$.

In the absence of subsistence absorption, i.e. $y_i^* = y_i^{*f} = 0$, the export price is invariant to the type of firm, since both LCP and PCP firms charge the same mark-up over the marginal cost, i.e. $\dfrac{\eta}{\eta - 1}$. Moreover, since the LCP mark-up charged at home is identical to the LCP mark-up set for the foreign market, the international price discrimination is absent.

Thus, when all prices are converted to a common currency, variety *i* costs the same in all countries, irrespective of the type of the firm that produced it (PCP or LCP).

Proposition 2: *When* $y_i^* / (c_{it} + i_{it}) < y_i^{*f} / (c_{it}^f + i_{it}^f), \mu_1 < \mu_2$ *;*
when $y_i^* / (c_{it} + i_{it}) > y_i^{*f} / (c_{it}^f + i_{it}^f), \mu_1 > \mu_2$*.*

If the share of the subsistence absorption in the aggregate demand is higher in the foreign market, than in the domestic market, the LCP mark-up set for the foreign buyer (40) is higher than its domestic counterpart (39). Therefore, foreign consumers pay a higher price for good *i*, compared to home consumers. Intuitively, firms enjoy a greater market power abroad, because foreign agents require a higher minimum amount of the good to sustain their standard of living. Therefore, the foreign demand is less elastic with respect to price changes, compared to the domestic demand. Consequently, the domestic LCP firm can afford a marginal increase in the export price without significantly depressing the volume of exports.

Similarly, if the share of the home subsistence absorption in the total domestic demand is higher than its foreign counterpart, the mark-up set by the domestic LCP firm for domestic consumers exceeds the mark-up charged in the foreign market. In this case, domestic consumers face higher prices, as opposed to foreign buyers.

Proposition 3 : *A rise in either* y_i^* *or* y_i^{*f} *leads to an increase in* μ_3*.*

Interestingly, home consumers are affected by price movements resulting from a change of foreign consumption patterns. For instance, an increase in the foreign subsistence absorption, y_i^{*f}, leads to a rise of the PCP mark-up (48). Thus, both domestic and foreign consumers face an increased export price, p_{it}. Intuitively, an increase in either foreign or home subsistence absorption leads to a rise of the firm's market power and its ability to increase the mark-up, because higher levels of the subsistence absorption make the demand less sensitive to price changes. Since the PCP firm sets the same price for both markets, both domestic and foreign consumers pay a higher price, even if only foreign households have increased their subsistence consumption. This finding suggests that shocks to the foreign consumption may be transmitted to the domestic economy, if domestic firms set prices in their own currency and supply both foreign and home markets.

In this section, we solved the profit maximization problems of the domestic LCP and PCP firms selling their output to the home and foreign markets. The purpose of this optimization was to show the determination of the optimal export and import prices by each type of firm. We observed that, although the pricing rules of the LCP and PCP firms differ, both firms set the export price as a time varying mark-up over the marginal cost. In particular, the existence of subsistence points in consumption and investment generates time variance in the price elasticity of demand, which introduces instability into the pirce mark-up. We also addressed the issues of the international price discrimination using the optimal mark-up rules for LCP and PCP firms. We concluded that, in the presence of subsistence absorption, the LOP does not hold even for PCP goods.

The inconstancy of the mark-up has important implications for the degree of ERPT, because mark-up movements may either mitigate or exacerbate the response of the import price to changes in the exchange rate. The next section discusses the effect of exchange rate movements on the export and import prices of LCP and PCP goods.

4.3 Pricing-to-market and exchange rate pass-through

In this section, we compute the degree of ERPT and PTM for four cases – LCP with no subsistence points in the aggregate absorption, PCP with no subsistence points in the aggregate absorption, LCP with subsistence points in consumption and investment, and PCP with subsistence points in consumption and investment. The purpose of this section is to determine whether the shape of consumers' preferences and the type of firm (LCP or PCP) are important for determining the response of the export and import prices to currency fluctuations.

Since we assume no imported inputs for computational simplicity, the pass-through of an exchange rate change into the marginal cost is zero. Therefore, the only determinant of the size of ERPT and PTM is the price mark-up, which is adjusted following the depreciation of the domestic importer's currency. Intuitively, importer currency depreciation makes imported PCP goods relatively expensive. A downward adjustment of the mark-up of price over the marginal cost limits this increase of the import price, while the increase of the mark-up magnifies the rise in the import price.

This section contains two parts. First, we compute the degree of the good-specific ERPT, which defines the response of a good's import price to currency movements. The good-specific ERPT is essentially the elasticity of the import price with respect to the exchange rate (Parsley, 1993). When the absolute value of the ERPT into the import price equals one, the extent of the pass-through is complete.

4.3.1 PCP with no subsistence absorption

If there are no subsistence points in the aggregate absorption, the optimal export price is modelled as a constant mark-up (40a) over the marginal cost in both domestic and foreign markets. Given that neither the mark-up nor the marginal cost varies across buying countries, international price differentials for a PCP firm's good are absent. Since the export price is fixed in the exporter's currency, the depreciation of the importer's currency increases the import price. However, because the price mark-up is fixed, the PCP firm cannot decrease the mark-up in order to protect its market share abroad and prevent the increase of the import price.

For instance, suppose that a foreign PCP firm sets a unique export price, p_{it}^{f}, in its own currency. The import price paid by home importers is given by

$$p_{it}{}^{f} e_t = \left\{ \frac{\eta}{\eta - 1} \right\} MC_{it}^{f} e_t = \vartheta MC_{it}^{f} e_t . \tag{50}$$

Suppose that the home currency depreciates. The depreciation leads to an increase in e_t and raises the import price (50). If the price mark-up, ϑ, was time varying, the firm could adjust the mark-up downwards in order to protect consumers from the import price increase. However, since the price mark-up is fixed at $\left\{ \frac{\eta}{\eta - 1} \right\}$, the derivative of the mark-up with respect to the exchange rate is zero. Thus, it is not possible to offset fluctuations of the import price by adjusting the export price.

In order to confirm that the degree of PTM is zero in the PCP case with no subsistence absorption, let us compute the elasticity of the *export* price with respect to the exchange rate. Price elasticity represents a relative change of price, which results from a relative change of the exchange rate:

$$\frac{\partial p_{it}{}^{f}}{\partial e_t}\frac{e_t}{p_{it}^{f}} = \frac{\partial\left(\vartheta MC_{it}^{f}\right)}{\partial e_t}\frac{e_t}{\vartheta MC_{it}^{f}} = MC_{it}^{f}\frac{\partial \vartheta}{\partial e_t}\frac{e_t}{\vartheta MC_{it}^{f}} = 0\,. \qquad (51)$$

The PTM definition (51) shows that the degree of PTM is zero due to the unresponsiveness of the mark-up of the export price over the marginal cost to currency movements, i.e. $\left(\frac{\partial \vartheta}{\partial e_t} = 0\right)$.

Since the export price, p_{it}^{f}, does not react to changes in the exchange rate, the import price (50) rises by the full amount of the depreciation. In order to prove that the ERPT into the import price is complete, let us compute the elasticity of the import price with respect to the exchange rate:

$$\frac{\partial\left(MC_{it}^{f}\vartheta e_t\right)}{\partial e_t}\frac{e_t}{MC_{it}^{f}\vartheta e_t} = MC_{it}^{f}\vartheta\frac{e_t}{MC_{it}^{f}\vartheta e_t} = 1\,. \qquad (52)$$

The ERPT equation (52) suggests that a 1% depreciation of the importer's currency causes a 1% increase of the import price, i.e. the pass-through of the exchange rate change into the import price is complete.

Thus, in the absence of subsistence absorption, the import price of a PCP good moves one-to-one with the exchange rate, because the degree of PTM is zero due to the constancy of the mark-up of the export price over the marginal cost. In the next section, we relax the assumption of a constant mark-up by changing the shape of consumer preferences. Introducing a time varying price mark-up dramatically changes our predictions on the PTM and ERPT.

4.3.2 PCP with subsistence absorption

The introduction of subsistence points in consumption and investment generates variable mark-ups of price over the marginal cost. Specifically, the PCP mark-up (48) falls following an increase in either foreign or domestic demand, because a rise of the demand reduces the firm's market power by increasing the price elasticity of demand (6).

In order to observe the effect of the mark-up variability on the ERPT, let us compute the elasticity of the import price with respect to the exchange rate:

$$\frac{\partial\left(MC_{it}^{f}\mu_3 e_t\right)}{\partial e_t}\frac{e_t}{MC_{it}^{f}\mu_3 e_t} = MC_{it}{}^{f}\left(\mu_3 + e_t\frac{\partial \mu_3}{\partial e_t}\right)\frac{e_t}{MC_{it}^{f}\mu_3 e_t} = 1 + \frac{\partial \mu_3}{\partial e_t}\frac{e_t}{\mu_3}\ , \tag{53}$$

where $\frac{\partial \mu_3}{\partial e_t} = \frac{\partial \mu_3}{\partial\left(c_{it} + i_{it} + c_{it}^{f} + i_{it}^{f}\right)}\frac{\partial\left(c_{it} + i_{it} + c_{it}^{f} + i_{it}^{f}\right)}{\partial e_t}$. Unlike the ERPT with no subsistence points (52), the ERPT (53) is not complete, since its value is different from one.

A movement of the exchange rate, e_t, affects the demand in the domestic and foreign markets. Intuitively, currency fluctuations affect the aggregate price level and encourage the consumer to restructure her consumption basket. Specifically, the importer's currency depreciation (i.e. a rise in e_t) leads to an increase in the aggregate price level, P_t, as the imported goods comprised by the aggregate price index become relatively expensive. Therefore, good i's relative price, $\frac{e_t p_{it}^{f}}{P_t}$, is likely to fall and lead to an increase in the domestic demand (4) for this good. [16] The foreign demand is also affected by the depreciation of the domestic currency, since the foreign currency appreciates. Therefore, the aggregate price level in the foreign economy, P_t^{f} , decreases, because the imported goods become relatively cheap. Consequently, good i's relative price, $\frac{p_{it}^{f}}{P_t^{f}}$, rises and leads to a fall in the foreign demand for this good. Thus, the depreciation of the domestic currency raises the domestic demand for good i, $c_{it} + i_{it}$, and reduces the foreign demand for the same variety, $c_{it}^{f} + i_{it}^{f}$.

Since the absorptions $c_{it} + i_{it}$ and $c_{it}^{f} + i_{it}^{f}$ move in the opposite directions following the depreciation of the domestic currency, the sign of the derivative $\frac{\partial \mu_3}{\partial e_t}$ is ambiguous. If the absolute value of the increase of the domestic absorption is larger than the extent of the fall in the foreign absorption, the mark-up μ_3 falls and leads to an incomplete ERPT (53), i.e.

[16] Note that the relative price, $\frac{e_t p_{it}^{f}}{P_t}$, may also increase, if the numerator of the ratio increases more than the denominator following the depreciation. However, since the price index, P_t , comprises many imported varieties, we assume that the magnitude of the increase of the price index is larger than that of the rise of good i's import price. This assumption may be relaxed and we may assume instead that the relative price paid by the domestic importer of the foreign PCP good increases. In this case, the domestic demand would fall and the mark-up would unambiguously rise because of the fall of the price elasticity of the domestic demand (6).

$\frac{\partial \mu_3}{\partial e_t} < 0$ and *ERPT<1*. If the fall of the foreign demand outweighs the increase of the domestic aggregate absorption, the mark-up μ_3 increases, i.e. $\frac{\partial \mu_3}{\partial e_t} > 0$ and *ERPT>1*. Since the degree of the ERPT (53) exceeds one, a 1% depreciation of the importer's currency leads the import price to increase by more than 1%. The degree of the ERPT may also be complete if the increase of the domestic demand fully offsets the decrease in the foreign demand, i.e. $\frac{\partial \mu_3}{\partial e_t} = 0$.

Similarly, the elasticity of the export price with respect to the exchange rate is generally different from zero, unlike the PCP case with no subsistence points. The degree of PTM is computed as the ratio of the proportionate change of the export price to the proportionate change in the exchange rate:

$$\frac{\partial\left(MC_{it}^{f} \mu_3\right)}{\partial e_t} \frac{e_t}{MC_{it}^{f} \mu_3} = \frac{\partial \mu_3}{\partial e_t} \frac{e_t}{\mu_3}. \tag{54}$$

Since the mark-up is adjusted as a result of fluctuations in either foreign or domestic demand, $\frac{\partial \mu_3}{\partial e_t} \neq 0$, the degree of the PTM (54) is ambiguous. The export price may fall, increase or remain unchanged following the depreciation of the domestic currency, depending on the reaction of the mark-up to currency movements. The discussion of the ERPT (53) mentioned that the derivative of the mark-up with respect to the exchange rate may be zero, positive or negative, depending on the relative magnitudes of the changes in the foreign and domestic demand, which result from the depreciation. Consequently, the degree of the PTM (54) may be zero, positive or negative, respectively.

Thus, the response of the export price to the depreciation of the importer's currency depends on demand fluctuations in the foreign and domestic markets. It is not certain that the foreign exporter would decrease the mark-up of price over the marginal cost, in order to protect the domestic consumer from the increase of the import price. The PCP mark-up may even increase with the depreciation, if the rise of the domestic demand, $c_{it} + i_{it}$, is outweighed by the fall of the foreign demand, $c_{it}^{f} + i_{it}^{f}$. Therefore, our model provides a logical explanation for the increase of the mark-up following the depreciation of the importer's currency, although many studies suggest that a mark-up rise during the importer currency depreciation is counterintuitive (Knetter, 1989). We justify the increase in the mark-up, which occurs despite the appreciation of the exporter's currency, with the presence of subsistence points in the aggregate absorption.

4.3.3 LCP with no subsistence absorption

Consider a foreign LCP firm that supplies the domestic market with no subsistence points in consumption and investment. The optimal LCP mark-up (40) suggests that the price paid by the domestic importer represents a constant mark-up over the marginal cost:

$$q_{it}^f = \left\{\frac{\eta}{\eta-1}\right\} MC_{it}^f = \vartheta MC_{it}^f \,. \tag{55}$$

The import price definition (55) implies that q_{it}^f is insensitive to currency fluctuations $\left(\frac{\partial q_{it}^f}{\partial e_t} = 0\right)$, because the mark-up is constant and the marginal cost does not depend on the exchange rate by assumption. Therefore, the degree of the ERPT into the import price is zero:

$$\frac{\partial\left(MC_{it}^f \vartheta\right)}{\partial e_t} \frac{e_t}{MC_{it}^f \vartheta} = MC_{it}^f \frac{\partial \vartheta}{\partial e_t} \frac{e_t}{MC_{it}^f \vartheta} = 0\,, \tag{55a}$$

because $\frac{\partial \vartheta}{\partial e_t} = 0$. Thus, a 1% depreciation of the domestic currency has no effect on the import price, because the LCP firm fixes the price in the importer's currency.

However, the effect of the exchange rate on the export price is different from zero. Export price represents a good's price in units of the exporter's currency:

$$\frac{q_{it}^f}{e_t} = \left\{\frac{\eta}{\eta-1}\right\} \frac{MC_{it}^f}{e_t} \,. \tag{56}$$

The export price definition (56) suggests that the depreciation of the importer's currency (i.e. an increase in e_t) reduces the export price. Since the price is fixed in the importer's currency, fewer units of the exporter's currency can be obtained for q_{it}^f units of the importer's currency after the depreciation. The elasticity of the export price (56) with respect to the exchange rate gives the degree of PTM:

$$\frac{\partial\left(\frac{q_{it}^f}{e_t}\right)}{\partial e_t} \frac{e_t}{q_{it}^f / e_t} = -\vartheta \frac{MC_{it}^f}{e_t^{\,2}} \frac{e_t^2}{MC_{it}^f \vartheta} = -1\,. \tag{57}$$

Thus, the export price (56) falls one-to-one with the depreciation of the importer's currency.

4.3.4 LCP with subsistence absorption

In the presence of subsistence points in consumption and investment, the optimal price is denominated in the importer's currency according to the optimal LCP mark-up (40):

$$q_{it}^{f} = \left\{ 1 - \frac{1}{\eta\left(1 - \frac{y_i^*}{c_{it} + i_{it}}\right)} \right\}^{-1} MC_{it}^{f} = \mu_2 MC_{it}^{f} . \tag{58}$$

However, unlike the LCP case with no subsistence absorption, the import price (58) varies with the depreciation of the importer's currency. Specifically, the depreciation (an increase of e_t) raises the domestic demand (4) for the imported variety *i*, since its relative price, $\frac{q_{it}^f}{P_t}$, falls because of the rise of the aggregate price level. Since the increase in the domestic demand raises the price elasticity of demand (6), the firm's market power falls and causes a decrease in the mark-up, μ_2. Thus, although the import price is set in the local currency, it varies with the exchange rate, i.e. $\frac{\partial q_{it}^f}{\partial e_t} \neq 0$, due to the counter-cyclical nature of the mark-up of price over the marginal cost, i.e. $\frac{\partial \mu_2}{\partial (c_{it} + i_{it})} < 0$.

In order to understand that denominating prices in the importer's currency does not fully insulate the import price from currency fluctuations, let us compute the ERPT as the elasticity of the import price (58) with respect to the exchange rate:

$$\frac{\partial\left(\mu_2 MC_{it}^f\right)}{\partial e_t} \frac{e_t}{\mu_2 MC_{it}^f} = MC_{it}^f \frac{\partial \mu_2}{\partial e_t} \frac{e_t}{\mu_2 MC_{it}^f} = \frac{\partial \mu_2}{\partial e_t} \frac{e_t}{\mu_2} < 0 . \tag{59}$$

The magnitude of the ERPT (59) equals the elasticity of the mark-up, μ_2, with respect to the exchange rate. Since the mark-up falls in the exchange rate due to the increased price elasticity of the importer's demand, the ERPT is unambiguously negative. A depreciation of the importer's currency leads to a fall of the import price. Thus, despite the fact that prices are set in the local currency, the import price is not immune to currency fluctuations when there exists subsistence absorption.

Since the mark-up of price over the marginal cost is counter-cyclical, the response of the export price to the exchange rate is also time variant. In order to determine the sign of the effect of the exchange rate on the export price, let us compute the PTM as the elasticity of the export price with respect to the exchange rate:

$$\frac{\partial\left(\frac{MC_{it}^{f}\mu_2}{e_t}\right)}{\partial e_t}\frac{e_t}{MC_{it}^{f}\mu_2/e_t}=\frac{MC_{it}^{f}}{e_t}\left(\frac{\partial\mu_2}{\partial e_t}-\frac{1}{e_t}\mu_2\right)\frac{e_t}{MC_{it}^{f}\mu_2/e_t}=$$
$$=\left(\frac{\partial\mu_2}{\partial e_t}-\frac{1}{e_t}\mu_2\right)\frac{e_t}{\mu_2}=\frac{\partial\mu_2}{\partial e_t}\frac{e_t}{\mu_2}-1. \qquad (60)$$

The sign of the PTM effect (60) is unambiguously negative, because the mark-up is counter-cyclical, i.e. $\frac{\partial\mu_2}{\partial e_t}\frac{e_t}{\mu_2}<0$. Moreover, the absolute value of the degree of PTM (60) exceeds one, which implies that a 1% depreciation of the importer's currency reduces the export price by more than 1%.

This section computed the degree of ERPT and PTM at disaggregated level by examining the effect of exchange rate changes on a good's import and export prices. We demonstrated that the degree of ERPT into the good's import price depends on whether it is produced by a LCP or PCP firm. Moreover, the size of the ERPT crucially depends on the presence of subsistence points in the aggregate demand function. Our findings offer a new interpretation of several stylized facts about the local currency price stability and international price discrimination. Before reassessing these stylized facts in the light of our DSGE model, let us complete the ERPT discussion by deriving the ERPT into the aggregate price level.

4.3.5 Aggregate ERPT

Aggregate ERPT is defined as the response of the aggregate domestic price level (5) to the depreciation of the domestic exchange rate. The existence of subsistence points in consumption and investment has important implications for the degree of the aggregate ERPT.

In order to compute the aggregate ERPT, we must define the aggregate domestic price index. Let us assume a continuum of monopolistically competitive firms, where each firm produces one differentiated variety, *i*. There are four types of goods traded in the domestic economy, namely home LCP goods, home PCP goods, foreign LCP varieties and foreign PCP varieties. Let us denote the prices of these four goods by $p_{it}^{H,LCP}$, $p_{it}^{H,PCP}$, $q_{it}^{F,LCP}$ and $e_t p_{it}^{F,PCP}$, respectively, where all prices are expressed in the domestic currency. Following Betts and Devereux (1996), let us assume that domestic firms produce fraction *n* of all traded goods. The remaining portion, *(1-n)*, is supplied by foreign firms. Let us also suppose that fraction *s* of the domestic firms is LCP, while *(1-s)* denotes the fraction of home PCP firms. The shares of the LCP and PCP firms in the foreign country's total number of firms are also denoted by *s* and *(1-s)*.

Thus, the domestic market is supplied by *ns* domestic LCP firms, *n(1-s)* domestic PCP firms, *(1-n)s* foreign LCP firms and *(1-n)(1-s)* foreign PCP firms. Substituting into the aggregate domestic price index (5) the fractions of each firm type and their respective prices gives

$$P_t = \left[\int_0^{ns} \left(p_{it}^{H,LCP}\right)^{1-\eta} di + \int_{ns}^{n} \left(p_{it}^{H,PCP}\right)^{1-\eta} di + \int_{n}^{n+(1-n)s} \left(q_{it}^{F,LCP}\right)^{1-\eta} di + \int_{n+(1-n)s}^{1} \left(p_{it}^{F,PCP} e_t\right)^{1-\eta} di \right]^{1/(1-\eta)} . \quad (61)$$

The aggregate price index for the home country (61) suggests that the price level responds to the depreciation of the domestic currency, because the prices of the foreign PCP goods, $p_{it}^{F,PCP}$, must be converted into the domestic currency using the exchange rate, e_t. However, the aggregate price level is also affected by the pass-through of exchange rate movements into the prices of other goods, namely $p_{it}^{H,LCP}$, $p_{it}^{H,PCP}$, $q_{it}^{F,LCP}$. Since the mark-up of price over the marginal cost is time varying in our model, all four prices that constitute the aggregate price index, P_t, are sensitive to the exchange rate.

In order to simplify the definition of the aggregate price index (61), let us express it as a percentage deviation around the steady state. Using the symbol "^" to denote linear approximation around the zero-shock equilibrium yields:

$$\hat{P}_t = \Gamma + (1-n)(1-s)\hat{e}_t , \quad (62)$$

where $\Gamma = ns\hat{p}_{it}^{H,LCP} + n(1-s)\hat{p}_{it}^{H,PCP} + (1-n)s\hat{q}_{it}^{F,LCP} + (1-n)(1-s)\hat{p}_{it}^{F,PCP}$. The aggregate price definition (62) allows us to compute the degree of the ERPT into the domestic price level. Since all variables in the index (62) represent percentage deviations around the steady state, the response of the price index to a movement of the exchange rate is defined as the ratio of the price level to the exchange rate, $\hat{P}_t / \hat{e}_t$. The size and the sign of this ratio depend on the shape of the aggregate demand function.

Suppose that there are no subsistence points in consumption and investment. Therefore, both PCP and LCP firms set the export price as a fixed mark-up over the marginal cost:

$$p_{it}^{H,LCP} = \frac{\eta}{\eta - 1} MC_{it}, \tag{62a}$$

$$p_{it}^{H,PCP} = \frac{\eta}{\eta - 1} MC_{it}, \tag{62b}$$

$$q_{it}^{F,LCP} = \frac{\eta}{\eta - 1} MC_{it}^{f}, \tag{62c}$$

$$e_t \, p_{it}^{F,PCP} = e_t \frac{\eta}{\eta - 1} MC_{it}^{f}. \tag{62d}$$

Since prices $p_{it}^{H,LCP}$, $p_{it}^{H,PCP}$ and $q_{it}^{F,LCP}$ are insensitive to currency fluctuations, the percentage deviations of these prices in response to an exchange rate shock are zero, i.e. $\hat{p}_{it}^{H,LCP} = \hat{p}_{it}^{H,PCP} = \hat{q}_{it}^{F,LCP} = 0$. Thus, in the absence of subsistence absorption, the ERPT into the domestic price level equals

$$\frac{\hat{P}_t}{\hat{e}_t} = (1-n)(1-s), \tag{63}$$

which is constant and unambiguously positive. Specifically, the domestic currency depreciation (a rise in $\hat{e}_t$) leads to an increase in the domestic price level, because both n and s are positive fractions, i.e. $0 < n < 1$ and $0 < s < 1$. The aggregate price level is sensitive to the exchange rate due to the presence of the foreign PCP goods in the domestic consumption basket. Since the imported PCP goods become relatively expensive with the depreciation of the domestic currency, the ERPT into the domestic price level is positive. Moreover, the degree of the aggregate ERPT is less than one, because $(1-n) < 1$ and $(1-s) < 1$.

Thus, the aggregate ERPT is generally incomplete and only a fraction of an exchange rate movement is transmitted into the domestic price level. This implies that a 1% depreciation of the domestic currency causes the aggregate domestic price level to increase by less than 1%. The aggregate ERPT would be complete only in one extreme case. Specifically, the aggregate ERPT (63) equals one when the domestic market is entirely supplied by the foreign PCP firms, i.e. $n=0$ and $s=0$. Intuitively, any change in the exchange rate would be fully passed through into the domestic price level, because the domestic consumption basket does not contain products whose prices are insensitive to the exchange rate.

Thus, in the case of no subsistence absorption, the magnitude of the response of the domestic price level to an exchange rate change depends only on the share of foreign firms in the home market, *(1-n)*, and the share of PCP firms in the total number of firms, *(1-s)*. An increase of the share of foreign goods in the domestic consumption basket raises the response of the domestic price index to an exchange rate movement. Similarly, a reduction of the fraction of PCP firms mitigates the effect of exchange rate fluctuations on the domestic price index. Thus, the responsiveness of the domestic price index to the exchange rate increases in the fraction of goods whose prices are sensitive to currency movements.

The predictions of our model for the aggregate ERPT are dramatically different in the case of non-zero subsistence absorption. When the aggregate demand function has subsistence points, all goods that constitute the domestic consumption basket are priced as a counter-cyclical mark-up over the marginal cost:

$$p_{it}^{H,LCP} = \left\{ 1 - \frac{1}{\eta\left(1 - \dfrac{y_i^*}{c_{it} + i_{it}}\right)} \right\}^{-1} MC_{it}, \tag{64a}$$

$$p_{it}^{H,PCP} = \left\{ 1 - \frac{1}{\eta\left(1 - \dfrac{y_i^* + y_i^{*f}}{c_{it} + i_{it} + c_{it}^f + i_{it}^f}\right)} \right\}^{-1} MC_{it}, \tag{64b}$$

$$q_{it}^{F,LCP} = \left\{ 1 - \frac{1}{\eta\left(1 - \dfrac{y_i^*}{c_{it} + i_{it}}\right)} \right\}^{-1} MC_{it}^f, \tag{64c}$$

$$e_t p_{it}^{F,PCP} = \left\{ 1 - \frac{1}{\eta\left(1 - \dfrac{y_i^* + y_i^{*f}}{c_{it} + i_{it} + c_{it}^f + i_{it}^f}\right)} \right\}^{-1} MC_{it}^f. \tag{64d}$$

Thus, all prices contained in the domestic price index (61) respond to the exchange rate because of the counter-cyclical nature of the mark-up. The price of the domestic LCP good falls in the exchange rate, i.e. $\dfrac{\hat{p}_{it}^{H,LCP}}{\hat{e}_t} < 0$. Specifically, the depreciation of the domestic exchange rate raises the aggregate price level and decreases the relative price of good *i*. The reduction of the relative price increases the demand for this good and the price elasticity of the demand (6). Consequently, the firm's mark-up of price over the marginal cost falls as a result of a reduction of the market power. Similarly, the import price of the foreign LCP good falls in the exchange rate due to the counter-cyclical nature of the mark-up, i.e. $\frac{\hat{q}_{it}^{F,LCP}}{\hat{e}_t} < 0$.

However, the effect of currency fluctuations on PCP goods' prices, $\hat{p}_{it}^{H,PCP}$ and $e_t \hat{p}_{it}^{F,PCP}$, is uncertain, because the impact of the exchange rate on the PCP mark-up (48) is ambiguous. Section 4.3.2 explained that the depreciation of the domestic currency has a two-fold effect on the aggregate demand by raising the domestic demand for good *i* and reducing the foreign demand for this good. Since the domestic and foreign demands, $c_{it} + i_{it}$ and $c_{it}^f + i_{it}^f$, move in the opposite directions following the depreciation of the domestic currency, the effect of currency movements on the price mark-up over the marginal cost is uncertain.

Since the response of the PCP mark-up to the exchange rate is unpredictable, we are unable to forecast the degree of the ERPT into the domestic price level. However, we can define the ERPT using the aggregate price index (62):

$$\frac{\hat{P}_t}{\hat{e}_t} = (1-n)(1-s) + \frac{\Gamma}{\hat{e}_t}. \tag{65}$$

Thus, in the presence of subsistence points in the aggregate absorption, the aggregate ERPT (65) represents a sum of two terms. The first term is a fixed fraction standing for the share of foreign PCP firms in the domestic market. The second term represents a time varying ratio determined by the response of traded goods' prices to currency fluctuations. Since both PCP and LCP mark-ups of price over the marginal cost are sensitive to the exchange rate, the sign and the magnitude of the aggregate ERPT (65) are ambiguous.

In this section, we constructed the ERPT into the aggregate domestic price level, in order to examine the effect of subsistence points in the aggregate demand on the response of the domestic price index to the exchange rate. We showed that, in the absence of subsistence points, the aggregate ERPT is unambiguously positive and incomplete, which implies that the aggregate price index increases only by a fraction of the domestic currency depreciation. However, in the case of subsistence absorption, we are unable to draw unambiguous predictions on the sign and degree of the aggregate ERPT, because the effect of the exchange rate on the PCP mark-up of price over the marginal cost is unpredictable.

4.4 Reassessing the stylized facts about the ERPT and PTM

Our findings on the good-specific and aggregate ERPT into import prices enable us to revisit several stylized facts about international price differentials and local currency price stability. First, we compare the import price dynamics implied by our model with the stylized findings on the ERPT (Obstfeld and Rogoff, 1995 and Chari et al., 2002). Second, we contrast the export price behaviour predicted by our model with the stylized facts about PTM (Knetter, 1989).

The main difference between our framework and the stylized model of PTM and ERPT lies in the counter-cyclical nature of the mark-up of price over the marginal cost, which implies an inverse relationship between the mark-up and the aggregate demand. Specifically, a change in the exchange rate affects domestic and foreign demands for good i by altering the relative price of the good, which represents the ratio of the good's price over the aggregate price level. Since the exchange rate affects the aggregate demand in the domestic and foreign markets, the price mark-up responds to currency fluctuations. The counter-cyclical nature of the mark-up offers a fresh interpretation of the main stylized facts about PTM and ERPT.

4.4.1 Stylized facts about ERPT

The crucial role of invoicing currency for the ERPT determination is widely acknowledged in the benchmark literature on exporters' price-setting behaviour. For example, the stylized partial equilibrium framework (Gopinath et al., 2010) suggests that the PCP case delivers a complete ERPT, while the LCP yields a zero ERPT. This result is based on the assumptions about the currency used to invoice prices. The PCP firm fixes the price of its good in the exporter's currency. Consequently, the import price fluctuates one-to-one with the exchange rate, increasing by the full amount of the importer's currency depreciation. In contrast, the import price of an LCP good is insensitive to currency fluctuations, since prices are fixed in the importer's currency. By deriving the degree of ERPT into the LCP and PCP import prices for the case of no subsistence points in the aggregate absorption, we reached the same conclusion in Sections 4.3.1 and 4.3.3 of this chapter. In particular, we showed that the LCP fully stabilizes the import price, while the PCP leads the import price to move one-to-one with the exchange rate.

The DSGE model proposed in this chapter suggests a more complicated relationship between the invoicing currency choice and the ERPT due to the variability of the mark-up of price over the marginal cost. Even if prices are denominated in the importer's currency, the volatility of the mark-up induces the import price variability. The ERPT definition (59) suggests that the LCP does not fully insulate the import price from currency movements, because the price mark-up shifts following the depreciation or appreciation of the importer's currency. In particular, the import price falls following the depreciation of the importer's currency due to the downward adjustment of the price mark-up. Thus, the LCP limits the increase of the good's price after the depreciation, but the good-specific ERPT is different from zero. Since the LCP mitigates import price movements induced by the exchange rate, the share of LCP firms affects negatively the degree of the aggregate ERPT (65) into the domestic price level.

Similarly, Section 4.3.2 demonstrated that the PCP does not necessarily lead import prices to move one-to-one with exchange rate changes, since counter-cyclical variations of the price mark-up cause deviations from the complete ERPT. Specifically, the mark-up of price over the marginal cost (48) represents a function of the domestic and foreign demands and falls during an economic boom in either of the two countries. By affecting the demand both at home and abroad, currency movements induce a volatility of the mark-up, which either exacerbates or mitigates the import price rise resulting from the depreciation of the importer's currency. Thus, even if firms set prices in their own currency, exchange rate movements may not generate proportional changes of the import price.

Therefore, irrespective of the type of firm (PCP or LCP), import prices respond to currency fluctuations because price mark-ups are sensitive to demand changes that result from exchange rate movements. However, the extent of the import price response depends on the invoicing currency. Specifically, while the price mark-up of a foreign PCP firm fluctuates following a demand change in either domestic or foreign country, the LCP mark-up responds only to a movement of the importer's demand. Thus, the LCP protects the importer from the increase of the PCP price mark-up (48), which is caused by a fall of the demand in the exporter's country.

4.4.2 Stylized facts about PTM

The background literature on PTM is dominated by the proposition that firms undertake a downward adjustment of the mark-up of price over the marginal cost following the importer's currency depreciation, in order to limit the import price rise caused by the depreciation (Marston, 1990). Intuitively, firms are expected to protect their market share abroad and absorb a portion of the increase in import prices by a downward mark-up adjustment. However, an upward mark-up adjustment that magnifies the import price rise generated by the depreciation is considered puzzling and counterintuitive (Knetter, 1989).

We resolve this puzzle by modelling an environment where subsistence absorption constitutes a significant proportion of the aggregate demand. Section 4.3.2 showed that the PCP mark-up (48) may exacerbate the effect of the importer's currency depreciation by rising as a result of a reduction of the aggregate demand, i.e. $c_{it} + i_{it} + c_{it}^{f} + i_{it}^{f}$. Consider the mark-up charged by a foreign PCP firm exporting to the domestic economy. A depreciation of the domestic currency (i.e. an increase in e_t) inevitably affects the domestic and foreign demands for the foreign PCP good. The foreign demand for good *i* falls, because the depreciation of the domestic currency increases the relative price of good *i*, $\frac{p_{it}}{P_t^f}$, by lowering the aggregate price level abroad. Specifically, the aggregate price index in the foreign country, P_t^f , is depressed by the depreciation of the domestic currency, which means that PCP goods imported by foreign agents from the domestic country become relatively cheap.

The effect of the domestic currency depreciation on the domestic demand for good *i* is ambiguous, because both numerator and denominator of the relative price ratio, $\frac{e_t p_t}{P_t}$, increase. First, the depreciation raises the import price of the foreign PCP good, $p_{it}e_t$. Second, the depreciation increases the domestic price level, P_t, because foreign PCP goods become relatively expensive. If the increase of the import price exceeds the rise of the domestic price level, the relative price of good *i* increases and depresses the domestic demand for this good. Similarly, if the rise of the domestic price level outweighs the import price increase, the relative import price falls and raises the domestic demand for good *i*. Therefore, the effect of the exchange rate on the domestic demand for good *i* depends on the response of its relative price to currency fluctuations.

An upward adjustment of the PCP mark-up (48) after the depreciation of the domestic currency is possible if the sum of the domestic and foreign demands, $c_{it} + i_{it} + c_{it}^{f} + i_{it}^{f}$, falls. Thus, an upward mark-up adjustment is consistent with two scenarios. In the first scenario, both foreign and domestic demands for good *i* fall after the depreciation. In the second case, the domestic demand increases and the foreign demand decreases, but the reduction of the foreign demand outweighs the rise of the domestic demand, i.e. $c_{it} + i_{it} + c_{it}^{f} + i_{it}^{f}$ falls. In both scenarios, the reduction of the aggregate demand raises the PCP mark-up (48) and exacerbates the effect of the depreciation by causing a marginal increase in the foreign PCP good's import price, $p_{it}e_t$.

Thus, a rise in the mark-up of price over the marginal cost despite the importer's currency depreciation is reconciled with the theory if one adds subsistence absorption to the model. The introduction of subsistence absorption generates a positive relationship between the demand level and the demand elasticity (6), which is inversely related to the firm's market power. Consequently, an aggregate demand fall resulting from the depreciation causes a rise of the price mark-up over the marginal cost, since the firm's market power increases.

A puzzling increase in the price mark-up over the marginal cost during the importer's currency depreciation may describe the price dynamics of any good for which a subsistence level of consumption exists. In particular, this good must represent a necessary element of the consumption basket, which should always comprise a fixed amount of the good, irrespective of its price. Intuitively, the producer of such good can afford increasing the price mark-up, because the demand for its good does not fall significantly in the price, due to the importance of the good for households' minimum standard of living. Therefore, the puzzling behaviour of the price mark-up over the marginal cost may be justified with a high market power of the firms whose products are necessary for the subsistence of the household.

4.5 Simulations

Section 4.3 demonstrated that, in the presence of subsistence absorption, setting prices in the local currency does not stabilize import prices because of counter-cyclical movements of the price mark-up. Similarly, fixing prices in the producer's currency does not guarantee a complete ERPT, if subsistence consumption constitutes a portion of the aggregate demand. Irrespective of whether the firm is LCP or PCP, import prices mimic the behaviour of the counter-cyclical mark-up of price over the marginal cost.

In this section, we compare the behaviour of the domestic LCP firm's mark-up with that of the domestic PCP mark-up by simulating our DSGE model. The simulation traces the effect of technology and preference shocks on the economy. Following Mankiw and Summers (1986) and Betts and Devereux (1996), a value of one is assigned to parameter ε of the utility function (1), which determines the marginal utility of real money holdings. Parameter μ, which represents an additional determinant of the marginal utility of money balances, has been assigned an arbitrarily low value, following the suggestion in Erceg et al. (2006). Preference parameter χ has been given a value of 3.08 (Ravn et al., 2008). Exogenous shock specifications are borrowed from Ravn et al. (2008). Specifically, the logarithm of the technology shock, $log\ A_t$, is modelled as a first-order autoregressive process. The persistence of both technology and preference shocks is set to 0.9. The calibration of the remaining structural parameters of the economy follows Ravn et al. (2006) and is summarized in Table 14.

Figure 26 presents the impulse response of the domestic LCP mark-up to a preference shock, where the impulse response is defined as percent deviation of the variable from its steady state. Namely, we introduced a positive shock to foreign and domestic preferences, $\nu_t^{(f)}$ (1a), in order to boost the levels of the foreign and domestic consumption, x_t^{cf} and x_t^{c}. The graph demonstrates that a positive preference shock leads to a drop in the LCP mark-up due to a rise in the importer's consumption. This illustration confirms the counter-cyclical nature of the mark-up (40), which falls following a positive shock to the aggregate demand in the importer's country. The mark up fall results from the increase of the price elasticity of the demand (6), which implies a decrease of the firm's market power.

Interestingly, the behaviour of the PCP mark-up (Figure 27) in response to a positive shock to domestic and foreign preferences is similar to that of the LCP mark-up, although the PCP and LCP firms use different invoicing currencies. In both cases, a fall in the mark-up is observed, since a consumption rise generated by the positive preference shock increases the price elasticity (6) of the aggregate demand and decreases the firm's market power. However, the PCP case exhibits a larger fall in the mark-up, since the PCP mark-up (48) absorbs the increase of both countries' consumption, while the LCP mark-up (40) responds only to fluctuations in the importer's consumption.

The effect of the technology shock on the mark-ups is qualitatively similar to that of the preference shock. Figures 28 and 29 represent the impulse responses of the domestic LCP and PCP mark-ups to a positive shock to the domestic and foreign technologies. Increased productivity of the technological process leads to a fall of both LCP and PCP mark-ups. Intuitively, an increase in the country's productivity leads to a higher local output and income, which allows households to raise their consumption. Consequently, mark-ups fall following positive technology shocks due to an inverse relationship between the aggregate demand and the price mark-up over the marginal cost. However, similarly to the case of preference shocks, the PCP mark-up (48) exhibits a stronger fall, since it absorbs the effect of the demand increase in both markets, while the LCP mark-up (40) responds only to demand fluctuations of the importer's economy.

The impulse responses of the domestic PCP and LCP mark-ups to positive preference and technology shocks confirm the main conclusions reached in Section 4.3. First, we showed that both LCP and PCP mark-ups respond negatively to any shock that leads to a higher absorption in the economy. The counter-cyclical nature of the mark-up is due to a pro-cyclical profile of the price elasticity of the demand (6). Specifically, an increase of the aggregate demand raises the demand elasticity. Since the firm's market power falls in the demand elasticity for its product, the mark-up decreases during economic booms.

Second, the simulations highlighted that the size of the mark-up adjustment depends on the extent of the change of the aggregate absorption, since the impulse response of the PCP mark-up displays a stronger fall, compared to that of the LCP mark-up. Specifically, a stronger increase of the aggregate demand implies a larger fall of the mark-up of price over the marginal cost.

Finally, Figures 26-29 illustrated that the domestic PCP mark-up absorbs the effects of positive technology and preference shocks in both countries, while the LCP mark-up responds only to the shocks in the importer's country. Thus, if the domestic and foreign demands were simultaneously hit by a positive shock, the PCP mark-up would fall faster than the LCP mark-up. This finding clarifies the aggregate ERPT definition (65) which suggests that the ERPT is governed by the fraction of PCP firms. Since the PCP mark-up is more sensitive to macroeconomic shocks, compared to the LCP mark-up, the responsiveness of the aggregate price level to currency fluctuations rises in the market share of PCP firms.

4.6 Conclusion

In this chapter we reassessed several stylized facts about the international price discrimination using the concept of subsistence consumption borrowed from Ravn et al. (2006). The existence of subsistence points in consumption and investment generates a time variance of the price mark-up, which causes an inconstancy of ERPT and PTM. We built a two-country DSGE framework with subsistence points in the aggregate demand and two types of producers, namely LCP and PCP firms. Through solving the household's utility maximization problem and the firms' profit maximization problems, we examined the importance of the firm type for the degree of ERPT and PTM.

We determined that setting prices in the importer's currency does not lead to a zero pass-through of exchange rate changes into the import prices of goods that are essential for maintaining the household's minimum standard of living. Similarly, setting prices in the exporter's currency does not necessarily lead the import price to move one-to-one with currency changes. The reason for the deviation of our model from the cases of the zero and complete ERPT lies in the price mark-up over the marginal cost. Specifically, the mark-up varies with business cycles because the presence of subsistence absorption generates a pro-cyclical elasticity of demand with respect to price. Therefore, the price mark-up fluctuates with movements in the aggregate demand for both LCP and PCP firms.

In order to illustrate the similarity between the responses of the LCP and PCP mark-ups to economic booms, we simulated the impulse responses of the PCP and LCP mark-ups to a positive shock to preferences and technology in the domestic and foreign markets. We showed that the mark-up drops following both shocks, irrespective of the currency in which prices are set. Since the exchange rate affects the aggregate demand in the domestic and foreign countries, currency movements are expected to shift both mark-ups and alter the pass-through of currency fluctuations into the import prices of PCP and LCP goods.

Thus, our definitions of the optimal mark-ups set by LCP and PCP firms offer a new perspective on the local currency stability and international price differentials. Unlike the stylized models predicting a complete ERPT for PCP goods and a zero EPRT for LCP goods (Gopinath et al., 2010), our model suggests that import prices fluctuate with the importer's currency depreciation in both PCP and LCP cases. Moreover, the degree of the good-specific ERPT is determined by the effect of the exchange rate on the aggregate demand, due to the aforementioned counter-cyclical profile of the price mark-up.

Our predictions on the aggregate ERPT also differ from the stylized model of Betts and Devereux (1996) where the degree of the aggregate ERPT into the domestic price level depends only on the fraction of the foreign PCP firms. Although the fraction of the foreign PCP firms is also one of the main determinants of the aggregate ERPT in our model, the effect of an exchange rate change on the domestic price level cannot be predicted based only on this fraction. In particular, the degree of the aggregate ERPT is determined by the effect of currency movements on the aggregate demand, because mark-ups fall during economic booms and rise during slowdowns.

In addition to examining the ERPT, our model sheds new light on the stylized findings about PTM. By exploiting the counter-cyclical nature of the mark-up, the model justifies the "puzzling" evidence suggesting that the price mark-up increases during the importer's currency depreciation and magnifies the import price increase caused by the depreciation, instead of mitigating it (Knetter, 1989). We argue that the depreciation of the importer's currency raises the PCP mark-up, if the currency change depresses the sum of the aggregate demands of the domestic and foreign countries by affecting relative prices of the PCP good. Since the price mark-up over the marginal cost increases following a fall of the aggregate demand in our model, empirical evidence on the increase of the mark-up despite the importer's currency depreciation can be reconciled with theory.

Thus, our DSGE model of a time varying price mark-up over the marginal cost is capable of justifying empirical evidence on the ERPT and PTM in the situations which stylized frameworks consider to be puzzling. Moreover, since our model features a time varying price mark-up, it provides a theoretical justification for the PTM inconstancy found in the UK export price data in Chapter 3. Therefore, models containing a time varying mark-up of price over the marginal cost are expected to fit data better than fixed mark-up models by accommodating an unstable PTM and ERPT. Since the time variance of PTM and ERPT underpins all chapters of this thesis, the next chapter concludes this work by discussing policy implications of an inconstant effect of the exchange rate on export and import prices.

5 Chapter 5: Summary of Main Findings and their Policy Implications

This thesis discussed the non-linearity of the exchange rate effect on the export and import prices of a traded good by focusing on the time variation of the PTM and ERPT. After outlining the background theoretical and empirical literature on the international price discrimination and local currency price stability in Chapter 1, we developed three models of the optimal export price – two partial equilibrium set-ups and a dynamic stochastic general equilibrium framework.

Chapter 2 offered a partial equilibrium model with a non-linear elasticity of the importer's demand with respect to the import price. We argued that the demand for the exporter's good is more elastic when its import price is significantly higher than the import price of a suitable substitute, because the importer has an incentive to switch to a cheaper variety. However, the demand for the imported variety is less elastic in the situations when a cheaper substitute is not available because of high switching costs. Since the firm's market power falls in the price elasticity of demand, the mark-up of price over the marginal cost follows a two-regime process. The first regime is characterized by a low price elasticity of the import demand and a large mark-up, while the second regime corresponds to a high demand elasticity and a low mark-up.

The non-linearity of the price mark-up generates a two-regime process for the ERPT. In the regime containing large mark-up values, the degree of ERPT is higher than in the regime corresponding to low mark-up magnitudes. Intuitively, when the firm's market power is high, the exporter does not need to protect his market share abroad by limiting the import price increase resulting from the importer's currency depreciation. Similarly, when the firm's market power falls, the ERPT decreases, since the exporter adjusts the price mark-up downwards in order to prevent the importer from switching to cheaper substitutes.

We applied the threshold regression methodology by Hansen (1999) in order to estimate structural breaks in the ERPT into the US import prices of selected European goods for the period 1995-2011. We estimated the threshold parameter by searching for the threshold value which maximizes the concentrated sum of squared errors from the regression of the import price on the exchange rate and other explanatory variables. The statistical significance of threshold estimates was tested using asymptotic p-values of the F_1 statistic proposed by Hansen (1999) in order to test the null hypothesis of no structural change in the relationship between the dependent variable and the regressor of interest. Finally, we tested the precision of the threshold estimate by constructing its asymptotic confidence intervals. These intervals encompass all values of the threshold parameter, which satisfy the null hypothesis suggesting that a given threshold value equals the “true” value of the threshold parameter.

Our estimation results show a positive and statistically significant effect of the exchange rate on the import prices of the majority of product categories considered. The sensitivity of import prices to currency movements suggests that prices are set in the producer’s currency, since under the PCP a depreciation of the importer’s currency increases the number of units of the importer’s currency required to purchase a fixed amount of the exporter’s currency. The empirical findings for some products enabled us to confirm the main predictions of our theoretical model. First, we obtained a statistically significant estimate of the threshold effect in the ERPT, which suggests that the response of the import price to exchange rates is non-linear and depends on the difference between the import price of the exporter’s good and that of its substitute. Second, we found that the ERPT is larger in the regime where the exporter has a significant price advantage over competitors, compared to the regime where this advantage is absent. This finding is consistent with our model where the exporter decreases the price mark-up in the situations when the importer has a strong incentive to switch to a cheaper supplier. Consequently, a decrease in the mark-up of price over the marginal cost reduces the extent of the import price increase caused by the depreciation of the importer’s currency. The plots of asymptotic confidence intervals of the threshold estimates display narrow intervals implying a high precision of the parameter estimates.

We concluded Chapter 2 by checking the robustness of our empirical findings to omitted variables bias and serial correlation among regressors. The robustness to omitted variables bias was tested by augmenting the regression with several non-linear terms that help reducing the risk of spurious correlations resulting from omitted regressors. The robustness to potential serial correlation among independent variables was checked by removing the regressors that may be serially correlated with the exchange rate. By running the threshold regression algorithm by Hansen (1999) on the adjusted specifications, we did not detect significant changes in either the point estimates of the ERPT parameters or their statistical significance. Therefore, our initial empirical findings on the ERPT into the US import prices are robust to omitted variables bias and serial correlation among independent variables.

In an attempt to find the evidence of a non-linear ERPT for a larger number of products, we continue exploring the time variance of the link between the exchange rate and traded goods prices in Chapter 3. However, instead of examining the response of import prices to the exchange rate, we investigate the sensitivity of the export price to currency movements using a forecasting methodology. We develop a new partial equilibrium model of the PTM in order to justify the instability of the relationship between the exchange rate and the export price. Using Krugman's hypothesis suggesting that consumers of differentiated goods dislike the instability of prices (Krugman, 1986), we proposed a new type of demand function where the volatility of the exchange rate negatively affects the importer's demand. Through solving the exporter's profit maximization problem, we showed that the response of the export price to currency movements depends on the exchange rate volatility. Since the exchange rate volatility is generally inconstant, the degree of PTM is also unstable over time.

Due to the instability of the effect of the exchange rate on the export price, we use out-of-sample forecasting tests to test whether the exchange rate has predictive content for the export price. Rossi (2006) shows that out-of-sample tests are the most appropriate tests of model mis-specification in the situation of parameter instability, because they are suitable for testing a joint null hypothesis on a coefficient. The first part of this joint hypothesis suggests that the coefficient equals a constant value. The second part restricts this constant value to zero. We apply fixed, rolling, recursive and random walk coefficient time varying parameter regressions to the UK price indices of manufactured exports to the EU for the period 1999-2010. In order to determine whether the addition of the exchange rate significantly improves the forecasting performance of an export price model, we use the forecast encompassing test by Clark and McCracken (2001), which assesses the difference between the average forecast errors of nested models.

Our empirical findings strongly support the main predictions of our theoretical model. First, the exchange rate has a statistically significant predictive power for the export prices of almost all product categories analyzed. Specifically, the inclusion of exchange rate terms in the export price regression significantly reduces its average prediction error. Second, the relationship between the export price and the exchange rate is unstable, because regressions that are robust to parameter instability predict the export price significantly better than fixed parameter models. In order to confirm the robustness of our estimation output to potential seasonality of the price data, we repeat all regressions using a modified dataset where each price index has been transformed into annualized inflation rate. Our new empirical findings mimic the results obtained from seasonally unadjusted data. Specifically, the predictive power of the exchange rate and the forecasting superiority of adaptive regressions remain uncontested.

After obtaining robust empirical evidence of the non-linearity of PTM and ERPT within a partial equilibrium framework in Chapters 2 and 3, we design a general equilibrium model of a time varying PTM with two types of firm – local currency pricing and producer currency pricing. The main difference between our DSGE model from Chapter 4 and related literature on international price discrimination (Betts and Devereux, 1996) lies in the consumption function, which contains subsistence points borrowed from Ravn et al. (2006). Subsistence consumption of a good represents a fixed amount consumed irrespective of the good's price level due to the importance of this product for maintaining the basic living standard of the household.

Through solving the consumer's utility maximization problem and the firm's profit maximization problem we show that the mark-up of price over the marginal cost is time varying for both LCP and PCP firms. The mark-up falls during economic booms and increases during slowdowns, because an increase in the aggregate demand of the economy raises the elasticity of the demand with respect to price. Since the relationship between the mark-up and the demand elasticity is inverse, mark-ups fall in the aggregate demand. The counter-cyclical nature of the price mark-up causes a time varying relationship between the exchange rate and import or export prices. Thus, irrespective of the firm type, the PTM and ERPT are inconstant, because the price mark-up fluctuates with business cycles. Specifically, currency movements affect the aggregate demand in the economy by changing the purchasing power of the domestic currency. Since the price mark-up responds to aggregate demand fluctuations, our model generates a time varying relationship between the exchange rate and the mark-up.

In addition to justifying the time variance of PTM and ERPT, the predictions of our DSGE model offer a fresh interpretation of several stylized facts about international price differentials and local currency price stability (Gopinath et al., 2010 and Knetter, 1989). First, we showed that the LCP does not insulate import prices from currency fluctuations, because the LCP price mark-up is inconstant and absorbs the effect of the exchange rate change on the aggregate demand. Second, we proved that the PCP does not necessarily lead the import price to move one-to-one with currency fluctuations due to the aforementioned counter-cyclical profile of the price mark-up. Finally, we showed that the PCP firm’s mark-up of price over the marginal cost can be adjusted either upwards or downwards, depending on the effect of the exchange rate on the aggregate demand. Thus, it is not certain that the exporter would adjust his mark-up downwards following the depreciation of the importer’s currency, in order to protect the importer from an increase of the import price.

We concluded Chapter 4 by illustrating the time varying nature of the PCP and LCP mark-ups with their impulse responses to positive shocks to consumer preferences and production technology. Specifically, both PCP and LCP mark-ups fall in response to positive shocks to preferences and technology. Since both mark-ups respond to aggregate demand shocks, the degree of the aggregate ERPT into the domestic price level cannot be predicted from the shares of PCP and LCP firms, unlike the case of a constant mark-up (Betts and Devereux, 1996). In order to forecast the extent of the aggregate ERPT, we need to predict the response of each mark-up to the exchange rates change.

The motivation behind studying the time variance of PTM and ERPT relates to inflation policy, because the degree of PTM determines the extent of the ERPT into the domestic price level. By conducting PTM, foreign suppliers either limit the response of the import price level to currency movements or magnify it. Thus, the variation of PTM and ERPT over time determines the evolution of the inflation rate.

In order to illustrate the effect of the ERPT inconstancy on the inflation policy, let us suppose that the policy maker decided to devalue the domestic currency in the next period. The weakening of the domestic currency boosts the domestic exports by reducing its prices measured in units of the foreign importer’s currency. However, the policy-maker is aware that the currency devaluation may lead to an uncontrollable rate of inflation. In order to examine the inflationary consequences of the domestic currency devaluation, she must forecast the inflation rate of the next period.

In the first step, she regresses the domestic inflation rate, π_t, on a constant, c, nominal exchange rate in units of the domestic currency per one unit of the basket of the currencies of the main trade partners, e_t, and a set of M controls, x_{it}:

$$\pi_t = c + \beta e_t + \sum_{i=1}^{M} \lambda_i x_{it} + \tau_t , \tag{1}$$

where τ_t denotes the error term of the inflation regression (1). The specification (1) is a linear model with stable parameters, which is estimated using historic data spanning periods from 1 through t , i.e. $\{1, 2, 3, \ldots, t\}$. Note that β denotes the aggregate ERPT, i.e. the sensitivity of the domestic price level to the depreciation of the home currency.

After obtaining the parameter estimates from the regression[17] (1), i.e. c^*, β^* and λ_i^*, the policy maker predicts the one-step-ahead value of the inflation rate, π_{t+1}, in the second step. She uses the target value of the exchange rate after the intended currency devaluation, e_{t+1}, and the forecasts of other regressors, x_{it+1}^f:

$$\pi_{t+1}^f = c^* + \beta^* e_{t+1} + \sum_{i=1}^{M} \lambda_i^* x_{it+1}^f . \tag{2}$$

The one-step-ahead forecast (2) of the inflation rate is based on the policy maker's assumption that the regression coefficients, β and λ_i, are constant over time. She assumes that the parameter estimates obtained using historic data remain valid for future periods and enable her to produce accurate forecasts of the inflation rate.

Let us hypothesize that the policy maker's assumption of the constancy of the ERPT coefficient, β, is wrong. Instead of the specification (1), the inflation rate should be modelled according to the following equation:

$$\pi_t = c + \beta_t e_t + \sum_{i=1}^{M} \lambda_i x_{it} + \tau_t , \tag{3}$$

where the ERPT parameter, β_t, is time varying. The one-step-ahead value of the inflation rate, which corresponds to the inflation model (3), is represented by

$$\pi_{t+1} = c + \beta_{t+1} e_{t+1} + \sum_{i=1}^{M} \lambda_i x_{it+1} + \tau_{t+1} . \tag{4}$$

---

[17] Note that subscript t is absent from β, since parameter constancy is assumed.

Thus, forecasting the future inflation rate (4) using the forecasting model (2) is not accurate, because the ERPT estimate, β^*, is not applicable to future periods. An accurate forecasting model should embed potential time variance of the relationship between the exchange rate and the price level. We can compute the error resulting from forecasting the future inflation rate (4) with the fixed parameter model (2):

$$\pi_{t+1} - \pi_{t+1}^f = \left(c - c^*\right) + \left(\beta_{t+1} - \beta^*\right)e_{t+1} + \sum_{i=1}^M \lambda_i x_{it+1} - \sum_{i=1}^M \lambda_i^* x_{it+1}^f + \tau_{t+1}. \quad (5)$$

The prediction error (5) increases in the difference between the true ERPT parameter, β_{t+1}, and its constant estimate, β^*. Therefore, underestimating or overestimating the value of the ERPT parameter, i.e. $\beta^* < \beta_{t+1}$ or $\beta^* > \beta_{t+1}$, increases the absolute value of the forecasting error (5). Moreover, the prediction error (5) increases in the degree of parameter evolution, because a faster parameter evolution implies a larger distance between the fixed estimate, β^*, and the "true" parameter, β_{t+1}. Thus, using a fixed parameter regression in the situation of parameter inconstancy increases forecast errors due to the poor predictive ability of the constant parameter model (1).

If the policy maker underestimates the response of the domestic price level to currency fluctuations, i.e. $\beta^* < \beta_{t+1}\ \left(\beta^* > 0, \beta_{t+1} > 0\right)$, the currency devaluation (i.e. an increase of e_t) would lead to an unexpected surge in inflation. Thus, the export boom resulting from the depreciation of the domestic currency would be generated at the expense of price stability. Moreover, this inflation jump may offset the welfare increment stemming from the increase of exports.

Thus, basing the monetary policy on an outdated estimate of the ERPT can have detrimental inflationary consequences for the economy. Similarly, overestimating the degree of PTM by foreign exporters may increase the inflation rate beyond the allowed limit. For example, suppose that the policy maker determined from historic data that the aggregate ERPT was low because of PTM by foreign exporters, who decreased their profit margins following a depreciation of the domestic currency, in order to protect their market shares abroad. However, the firm's ability to conduct PTM by absorbing the effect of the deprecation into its profit margins may vary over time. If the policy maker erroneously expected foreign suppliers to limit the ERPT in periods when exporters would not conduct PTM, she would fail to predict the rise of the domestic inflation in response to a planned devaluation of the domestic currency.

Therefore, policy recommendations aimed at keeping the future inflation level under control should accommodate potential evolution of PTM and ERPT over time. Thus, analyzing the time variance of PTM and ERPT is as important as focusing on the sources of international price differentials and local currency price stability.

6 Appendix

6.1 Proof (Krugman, 1986)

The algorithm of this proof follows Parsley (1993). Let us assume a linear demand function, $D = -aP + b$, where $-a$ denotes the slope and b stands for the intercept. The elasticity of the demand with respect to price is

$$E = -\frac{\partial D}{\partial P}\frac{P}{D} = \frac{aP}{b-aP} = -1 + \frac{b}{b-aP}. \tag{1}$$

Given that $\partial \ln X = \frac{\partial X}{X}$, the derivative $\frac{\partial \ln E}{\partial \ln P}$ represents

$$\frac{\partial \ln E}{\partial \ln P} = \frac{\partial E}{\partial P}\frac{P}{E} = \frac{\partial\left(-1+\frac{b}{b-aP}\right)}{\partial P}\frac{P}{\frac{aP}{b-aP}} = \frac{b}{b-aP}. \tag{2}$$

Similarly, the derivative $\frac{\partial \ln(E-1)}{\partial \ln P}$ is computed as

$$\frac{\partial \ln(E-1)}{\partial \ln P} = \frac{\partial(E-1)}{\partial P}\frac{P}{E-1} = \frac{\partial\left(\frac{b}{b-aP}-2\right)}{\partial P}\frac{P}{\frac{2aP-b}{b-aP}} = \frac{abP}{(b-aP)(2aP-b)}. \tag{3}$$

Using the definitions (1), (2), (3) and $E-1 = \frac{2aP-b}{b-aP}$, the ERPT (Eq.9, Ch.1) equals

$$\begin{aligned}\frac{\partial \ln P}{\partial \ln e} &= -\frac{1}{1-\frac{\partial \ln E}{\partial \ln P}+\frac{\partial \ln(E-1)}{\partial \ln P}} = -\frac{1}{1-\frac{b}{b-aP}+\frac{abP}{(b-aP)(2aP-b)}} = \\ &= -\frac{1}{1-(E+1)+\frac{bE}{(E-1)(b-aP)}} = -\frac{1}{-E+\frac{E(E+1)}{(E-1)}}.\end{aligned} \tag{4}$$

Thus, the absolute value of the ERPT equals

$$\left|\frac{\partial \ln P}{\partial \ln e}\right| = \frac{1}{\frac{E(E+1)}{(E-1)}-E} = \frac{E-1}{2E} = \frac{1}{2} - \frac{1}{2E}. \tag{5}$$

Since the price elasticity of the demand for a monopolist's good is $E > 1$ by definition, the absolute ERPT (5) is *always* less than one-half, i.e. $\left|\frac{\partial \ln P}{\partial \ln e}\right| < \frac{1}{2}$.

6.2 Tables

Table 1 - Import Unit-value Dataset

Commodity code	AT	CH	CZ	DE	DK	FI	GR	HU	NL	NO	PL	SE	UK
1124	NA	NA	NA	**A**	**A**	**A**	**A**	NA	NA	NA	NA	**A**	**A**
1222	NA	**A**	NA	**A**	**A**	NA	**A**	NA	**A**	NA	NA	NA	**A**
533	**A**	NA	**A**	**A**	**A**	**A**	**A**	NA	**A**	NA	NA	**A**	**A**
6123	**A**	**A**	**A**	**A**	NA	NA	NA	NA	**A**	NA	**A**	NA	**A**
621	**A**	**A**	**A**	**A**	**A**	**A**	**A**	NA	**A**	**A**	**A**	**A**	**A**
6353	NA	**A**	NA	**A**	**A**	**A**	NA	NA	**A**	**A**	NA	**A**	**A**
6421	**A**	**A**	**A**	**A**	**A**	**A**	**A**	NA	**A**	**A**	**A**	**A**	**A**
678	**A**	NA	**A**	**A**	**A**	**A**	**A**	NA	**A**	NA	NA	**A**	NA
7525	**A**	NA	**A**	**A**	**A**	**A**	NA	NA	**A**	NA	NA	**A**	NA
79312	NA	NA	NA	**A**	**A**	**A**	NA	NA	**A**	NA	NA	**A**	NA
84722	**A**	NA	NA	**A**	**A**	**A**	NA	**A**	**A**	NA	NA	**A**	NA
89286	**A**	NA	**A**	**A**	NA	**A**	**A**	NA	**A**	NA	NA	**A**	NA

Notes: 1. Import unit-values are constructed using data on import values and quantities from the OECD International Trade by Commodity Statistics. 2. Commodities are denoted by the Standard International Trade Classification codes explained in Table 2. 3. “A” and “NA” denote available and unavailable values, respectively. 4. Country names are abbreviated as follows: AT – Austria, CH – Switzerland, CZ - Czech Republic, DE – Germany, DK – Denmark, FI – Finland, GR – Greece, HU – Hungary, NL – Netherlands, NO – Norway, PL – Poland, SE – Sweden, UK – United Kingdom.

Table 2 - Commodity Codes and Sample Periods

Commodity code	Commodity description	Period
1124	Spirits (other than 51216); liqueurs	1995-2011
1222	Cigarettes containing tobacco	1995-2009
533	Pigments, paints, varnishes and related materials	1996-2011
6123	Parts of footwear	1996-2010
621	Materials of rubber (pastes, plates, sheets, etc.)	1996-2010
6353	Builders' joinery and carpentry of wood	1995-2010
6421	Cartons, bags, other containers, of paper, paperback, etc.	1996-2010
678	Tubes, pipes and fittings, of iron or steel	1996-2011
7525	Peripheral units, including control and adapting units	1996-2011
79312	Sailboats, not inflatable, with auxiliary motor or not	1995-2011
84722	Stockings, ankle-socks and the like	1996-2006
89286	Trade advertising material, commercial catalogues, etc.	1996-2011

Notes: 1. Commodity codes refer to the Standard International Trade Classification representing the current international standard for classifying internationally traded commodities. 2. Code 51216 denotes "Ethyl alcohol and other spirits, denatured".

Table 3 - Industries Constituting the PPI Dataset

Commodity	Industry
Spirits (other than 51216); liqueurs	Manufacture of beverages
Cigarettes containing tobacco	Manufacture of tobacco products
Pigments, paints, varnishes and related materials	Manufacture of chemicals and chemical products; basic pharmaceutical products and pharmaceutical preparations
Parts of footwear	Manufacture of leather and related products
Materials of rubber (pastes, plates, sheets, etc.)	Manufacture of rubber and plastic products
Builders' joinery and carpentry of wood	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
Cartons, bags, other containers, of paper, paperback, etc.	Manufacture of paper and paper products
Tubes, pipes and fittings, of iron or steel	Manufacture of basic metals and fabricated metal products, except machinery and equipment
Peripheral units, including control and adapting units	Manufacture of computer, electronic and optical products; manufacture of electrical equipment
Sailboats, not inflatable, with auxiliary motor or not	Manufacture of motor vehicles, trailers, semi-trailers and of other transport equipment
Stockings, ankle-socks and the like	Manufacture of textiles and wearing apparel
Trade advertising material, commercial catalogues, etc.	Manufacture of paper and paper products; printing and reproduction of recorded media

Note: Industry PPI data was retrieved from the Eurostat Short-term Business Statistics database.

Table 4 – Euro Adoption Chronology

Year	Country
1999	Austria
1999	Germany
1999	Finland
1999	Netherlands
2001	Greece
N/A	Czech Republic
N/A	Denmark
N/A	Hungary
N/A	Norway
N/A	Poland
N/A	Sweden
N/A	Switzerland
N/A	UK

Note: "N/A" indicates that the country has not adopted the Euro as its national currency.

Table 5 - Threshold Regression Coefficients and Standard Errors (Eq. 27, Ch.2)

Commo-dity code	**DF**	**CV**	β_1 **(s.e.)**	β_2 **(s.e.)**	β_3 **(s.e.)**	β_4 **(s.e.)**	β_5 **(s.e.)**
1124	85	2.64 (99%) 1.99 (95%) 1.66 (90%)	0.68 (0.58)	-8.57 (10.96)	4.21 (5.43)	**0.55**[c] **(0.12)**	-0.01 (0.04)
1222	73	2.65 (99%) 1.99 (95%) 1.67 (90%)	**-0.39**[a] **(0.22)**	2.01 (2.42)	-0.37 (0.55)	-0.05 (0.04)	0.04 (0.03)
533	121	2.63 (99%) 1.98 (95%) 1.66 (90%)	0.51 (0.32)	-0.86 (2.80)	0.23 (0.61)	-0.04 (0.03)	**0.14**[c] **(0.03)**
6123	86	2.64 (99%) 1.99 (95%) 1.66 (90%)	-2.07 (1.49)	-0.10 (6.89)	0.06 (1.53)	0.10 (0.21)	**0.53**[a] **(0.30)**
621	151	2.61 (99%) 1.98 (95%) 1.65 (90%)	**2.56**[c] **(0.87)**	4.57 (4.03)	-0.93 (0.88)	**-0.21**[c] **(0.07)**	-0.02 (0.04)
6353	107	2.63 (99%) 1.98 (95%) 1.66 (90%)	**-10.09**[c] **(1.84)**	27.58 (20.34)	-6.22 (4.49)	**-1.32**[c] **(0.36)**	-0.41 (0.39)
6421	151	2.61 (99%) 1.98 (95%) 1.65 (90%)	-0.23 (0.69)	5.11 (4.02)	-1.02 (0.87)	**-0.10**[a] **(0.06)**	0.04 (0.04)
678	107	2.63 (99%) 1.98 (95%) 1.66 (90%)	**3.28**[c] **(0.40)**	**6.94**[c] **(1.86)**	**-1.43**[c] **(0.41)**	-0.05 (0.04)	0.16 (0.11)
7525	93	2.64 (99%) 1.99 (95%) 1.66 (90%)	1.96 (1.90)	6.94 (5.50)	-1.52 (1.20)	-0.05 (0.19)	**-0.39**[b] **(0.17)**
79312	70	2.65 (99%) 1.99 (95%) 1.67 (90%)	**3.84**[a] **(2.24)**	3.32 (7.25)	-0.73 (1.57)	0.16 (0.42)	-0.44 (0.31)
84722	58	2.67 (99%) 2.00 (95%) 1.67 (90%)	-1.89 (4.31)	**-21.77**[b] **(9.99)**	**4.77**[b] **(2.20)**	**0.52**[b] **(0.26)**	0.12 (0.20)
89286	93	2.64 (99%) 1.99 (95%) 1.66 (90%)	0.62 (0.88)	**9.62**[b] **(4.08)**	**-2.12**[b] **(0.88)**	**0.11**[c] **(0.04)**	-0.04 (0.05)

Notes**:** 1. This table presents the estimated coefficients from the unrestricted regression of the import price (Eq.27, Chapter 2). The coefficients β_1, β_2 and β_3 define the responses of the import price to the marginal cost, price differential, and the product of the marginal cost and price differential, respectively. Coefficients β_4 and β_5 represent the ERPT in the lower and upper regimes, respectively. 2. The expected signs of the coefficients are as follows: $\beta_1>0$, $\beta_2<0$, $\beta_4>0$, and $\beta_5>0$, where $\beta_4>\beta_5$. The sign of the coefficient β_3 is ambiguous. 3. "DF" denotes the degrees of freedom, $df = (T-2)K-5$, where T is the number of time periods and K stands for the number of exporting countries. Number *5* reflects the number of regressors in the import price model (Eq.27, Ch.2). 4. "CV" denotes the critical values for the 2-tail T-test at the 90%, 95% and 99% confidence levels. 5. "s.e." denotes the standard errors. 6. Commodity codes refer to the Standard International Trade Classification presented in Table 2. 7. Superscripts "c", "b" and "a" indicate the statistical significance of the coefficient estimate at the 99%, 95% and 90% confidence levels, respectively.

Table 6 - Statistical Significance of Threshold Estimates (Eq.27, Ch.2)

Commo -dity code	$\hat{\gamma}$ **(threshold estimate)**	F_1 **test (LR)**	F_1 **CV (bootstrap)**	F_1 **p-value (bootstrap)**	**95% confidence region for** γ
1124	**-0.14** [c]	**23.26**	18.33 (99%) 14.30 (95%) 12.49 (90%)	**0.003**	[-0.14, -0.14]
1222	-0.21	5.83	20.86 (99%) 13.86 (95%) 12.30 (90%)	0.430	[-0.31, 1.03]
533	**0.40** [c]	**23.12**	22.09 (99%) 13.47 (95%) 10.47 (90%)	**0.010**	[0.20, 0.40]
6123	1.20	4.56	13.23 (99%) 10.92 (95%) 8.63 (90%)	0.387	[-0.40, 1.20]
621	***-0.08***	***9.04***	13.49 (99%) 10.36 (95%) 9.41 (90%)	***0.117***	[-0.08, 0.92]
6353	***-0.10***	***22.30***	33.13 (99%) 26.61 (95%) 23.80 (90%)	***0.150***	[-0.10, -0.10]
6421	***-0.10***	***6.89***	13.86 (99%) 10.22 (95%) 8.35 (90%)	***0.167***	[-0.33, 1.20]
678	1.33	4.30	14.49 (99%) 11.07(95%) 9.17 (90%)	0.567	[-0.42, 1.46]
7525	-0.25	5.38	11.70 (99%) 9.16 (95%) 8.05 (90%)	0.360	[-0.48, 2.46]
79312	-1.60	4.44	20.27 (99%) 16.41 (95%) 13.50 (90%)	0.557	[-1.60, 2.02]
84722	***1.42***	***5.44***	11.00 (99%) 7.94(95%) 5.67 (90%)	***0.113***	[-0.44, 2.30]
89286	***0.70***	***11.97***	30.94 (99%) 23.48 (95%) 17.97 (90%)	***0.153***	[0.61, 0.93]

Notes**:** 1. This table presents the results of the bootstrap replications conducted to examine the significance of the threshold estimate, $\hat{\gamma}$, in the import price equation (Eq.27, Ch.2). Superscript "c" indicates the statistical significance of the threshold estimate at the 99% confidence level. 2. The F_1 test represents the LR test (Eq.28, Ch.2). The null hypothesis implies no structural change in the exchange rate coefficient. This test compares the concentrated sums of squared errors from the restricted (Eq.26, Ch.2) and unrestricted (Eq.27, Ch.2) regressions of the import price. 3. Commodity codes refer to the Standard International Trade Classification presented in Table 2. 4. Asymptotic p-values for the LR F_1 test (Eq.34, Ch.2) are computed by simulating the F_1 statistic through conducting 300 repeated estimations of the unrestricted and restricted import price equations. The null hypothesis of the ERPT stability is rejected if the bootstrap p-value is smaller than the desired significance level. 5. "CV" denotes the bootstrap critical values for the LR F_1 test at the 90%, 95% and 99% confidence levels. The excess of the statistic value over the critical value implies the rejection of the null hypothesis of no structural change in the coefficient on the log-transformed exchange rate.

Table 7 - Threshold Regression Coefficients and Standard Errors (Eq. 41, Ch.2)

Commodity code	**DF**	**CV**	β_1 **(s.e.)**	β_2 **(s.e.)**	β_3 **(s.e.)**
1124	87	2.64 (99%) 1.99 (95%) 1.66 (90%)	0.87 (0.53)	**0.56**[c] **(0.10)**	-0.007 (0.04)
1222	75	2.66 (99%) 2.00 (95%) 1.67 (90%)	**-0.53**[b] **(0.20)**	0.02 (0.03)	-0.08 (0.05)
533	123	2.63 (99%) 1.98 (95%) 1.66 (90%)	**0.52**[a] **(0.30)**	-0.02 (0.03)	**0.14**[c] **(0.03)**
6123	88	2.64 (99%) 1.99 (95%) 1.66 (90%)	**-2.55**[a] **(1.38)**	0.09 (0.21)	0.36 (0.25)
621	153	2.63 (99%) 1.98 (95%) 1.66 (90%)	**1.71**[c] **(0.53)**	-0.03 (0.04)	**-0.13**[b] **(0.05)**
6353	109	2.63 (99%) 1.98 (95%) 1.66 (90%)	**-10.61**[c] **(1.84)**	**-1.53**[c] **(0.34)**	-0.59 (0.38)
6421	153	2.63 (99%) 1.98 (95%) 1.66 (90%)	**-1.05**[a] **(0.54)**	0.02 (0.04)	**-0.10**[b] **(0.05)**
678	109	2.63 (99%) 1.98 (95%) 1.66 (90%)	**2.36**[c] **(0.30)**	0.04 (0.04)	**-0.20**[c] **(0.06)**
7525	95	2.64 (99%) 1.99 (95%) 1.66 (90%)	-0.36 (0.48)	-0.12 (0.18)	**-0.38**[b] **(0.17)**
79312	72	2.66 (99%) 2.00 (95%) 1.67 (90%)	3.38 (2.11)	0.16 (0.41)	-0.46 (0.29)
84722	60	2.66 (99%) 2.00 (95%) 1.67 (90%)	**7.95**[c] **(2.75)**	-0.07 (0.27)	0.18 (0.20)
89286	95	2.64 (99%) 1.99 (95%) 1.66 (90%)	-0.80 (0.64)	**0.14**[c] **(0.04)**	0.01 (0.05)

Notes**:** 1. This table presents the estimated coefficients from the unrestricted regression of the import price (Eq.41, Ch.2). The coefficient β_1 defines the response of the import price to the log of the marginal cost. The coefficients β_2 and β_3 represent the ERPT in the lower and upper regimes, respectively. 2. The expected signs of the coefficients are as follows: $\beta_1>0$, $\beta_2>0$, $\beta_3>0$, where $\beta_2>\beta_3$. 3. "DF" denotes the degrees of freedom, $df = (T-2)K-3$, where T is the number of time periods and K stands for the number of exporting countries. Number *3* reflects the number of regressors in the import price model. 4. "CV" denotes the critical values for the 2-tail T-test at the 90%, 95% and 99% confidence levels. 5. "s.e." denotes the standard errors. 6. Commodity codes refer to the Standard International Trade Classification presented in Table 2. 7. Superscripts "c", "b" and "a" indicate the statistical significance of the coefficient estimate at the 99%, 95% and 90% confidence levels, respectively.

Table 8 - Statistical Significance of Threshold Estimates (Eq.41, Ch.2)

Commo-dity code	$\hat{\gamma}$ **(threshold estimate)**	F_1 **test (LR)**	F_1 **CV (bootstrap)**	F_1 **p-value (bootstrap)**	**95% confidence region for** γ
1124	**-0.14** [c]	**35.50**	25.01 (99%) 16.08 (95%) 11.05 (90%)	**0.000**	[-0.14, -0.14]
1222	0.47	4.20	14.63 (99%) 11.89 (95%) 9.99 (90%)	0.560	[-0.31, 1.03]
533	**0.40** [b]	**20.28**	21.03 (99%) 14.20 (95%) 9.93 (90%)	**0.017**	[0.20. 0.40]
6123	1.20	3.62	18.57 (99%) 12.34 (95%) 8.92 (90%)	0.510	[-0.40, 1.20]
621	0.92	7.33	17.25 (99%) 13.20 (95%) 9.82 (90%)	0.263	[-0.08, 1.47]
6353	***-0.10***	***24.04***	35.32 (99%) 27.50 (95%) 26.19 (90%)	***0.173***	[-0.10, -0.10]
6421	***0.93***	***8.34***	16.82 (99%) 12.73 (95%) 10.58 (90%)	***0.187***	[-0.30, 1.20]
678	**0.23** [a]	**19.70**	33.65 (99%) 22.99 (95%) 18.80 (90%)	**0.093**	[-0.09, 0.31]
7525	-0.25	3.86	11.75 (99%) 9.50 (95%) 8.16 (90%)	0.380	[-0.48, 2.46]
79312	***-1.60***	***6.35***	15.64 (99%) 10.57 (95%) 8.26 (90%)	***0.163***	[-1.60, 2.02]
84722	0.35	2.28	5.83 (99%) 4.85 (95%) 4.18 (90%)	0.490	[-0.44, 2.30]
89286	***0.70***	***10.39***	25.58 (99%) 16.37 (95%) 12.81 (90%)	***0.146***	[0.52, 1.36]

Notes: 1. This table presents the results of the bootstrap replications conducted to examine the significance of the threshold estimate, $\hat{\gamma}$, in the import price equation (Eq.41, Ch.2). Superscripts "c", "b" and "a" indicate the statistical significance of the threshold estimate at the 99%, 95% and 90% confidence levels, respectively. 2. The F_1 test (Eq.28, Ch.2) represents the LR test. The null hypothesis implies no structural change in the exchange rate coefficient. This test compares the concentrated sums of squared errors from the restricted (Eq.42, Ch.2) and unrestricted (Eq.41, Ch.2) regressions of the import price. 3. Commodity codes refer to the Standard International Trade Classification presented in Table 2. 4. Asymptotic p-values for the LR F_1 test are computed by simulating the F_1 statistic (Eq.34, Ch.2) through conducting 300 repeated estimations of the unrestricted and restricted import price equations. The null hypothesis of the ERPT stability is rejected if the bootstrap p-value is smaller than the desired significance level. 5. "CV" denotes the bootstrap critical values for the LR F_1 test at the 90%, 95% and 99% confidence levels. The excess of the statistic value over the critical value implies the rejection of the null hypothesis of no structural change in the coefficient on the log-transformed exchange rate.

Table 9A - Threshold Regression Coefficients and Standard Errors (Eq. 43, Ch. 2)

Commo-dity code	DF	CV	β_1 (s.e)	β_2 (s.e)	β_3 (s.e)	β_4 (s.e)	β_5 (s.e)
1124	81	2.64 (99%) 1.99 (95%) 1.66 (90%)	**-1294.68**[b] (607.85)	**670.51**[b] (314.86)	**-115.48**[b] (54.27)	-0.98 (13.02)	**2.29**[a] (1.25)
1222	69	2.66 (99%) 2.00 (95%) 1.67 (90%)	528.45 (352.43)	-118.74 (79.78)	8.87 (6.01)	0.42 (2.72)	-0.13 (0.49)
533	117	2.63 (99%) 1.98 (95%) 1.66 (90%)	**-1517.99**[a] (779.39)	**327.38**[a] (169.52)	**-23.51**[a] (12.28)	0.75 (2.67)	**0.12**[b] (0.06)
6123	82	2.64 (99%) 1.99 (95%) 1.66 (90%)	5141.05 (4803.14)	-1137.40 (1073.99)	83.80 (80.01)	**17.89**[a] (10.69)	0.02 (0.18)
621	147	2.63 (99%) 1.98 (95%) 1.66 (90%)	-488.71 (1864.47)	102.00 (412.10)	-7.04 (30.35)	2.42 (3.90)	**0.65**[c] (0.23)
6353	103	2.63 (99%) 1.98 (95%) 1.66 (90%)	**33065.89**[c] (10307.75)	2232.07 (1556.11)	**517.03**[c] (161.08)	-63.28 (51.95)	0.63 (0.85)
6421	147	2.63 (99%) 1.98 (95%) 1.66 (90%)	-4178.97 (2609.18)	910.89 (565.58)	-66.17 (40.86)	4.99 (4.28)	-0.20 (0.33)
678	103	2.63 (99%) 1.98 (95%) 1.66 (90%)	**-2978.39**[c] (576.07)	**656.26**[c] (126.67)	**-48.11**[c] (9.28)	**4.54**[b] (1.97)	-0.24 (0.20)
7525	89	2.64 (99%) 1.99 (95%) 1.66 (90%)	**-918.74**[c] (313.25)	**183.73**[c] (63.40)	**-12.23**[c] (4.27)	-5.52 (5.57)	**-0.26**[b] (0.10)
79312	66	2.66 (99%) 2.00 (95%) 1.67 (90%)	6022.98 (16593.15)	-1366.07 (3620.33)	103.20 (263.26)	**22.63**[b] (10.76)	-0.09 (0.08)
84722	54	2.70 (99%) 2.02 (95%) 1.68 (90%)	-473.74 (25502.97)	60.88 (5672.44)	-1.26 (420.48)	**-21.33**[a] (11.62)	-0.59 (0.47)
89286	89	2.64 (99%) 1.99 (95%) 1.66 (90%)	1796.46 (1729.85)	-397.29 (380.98)	29.28 (27.95)	**11.71**[b] (4.55)	**0.69**[b] (0.32)

Note: See notes to Table 9B.

Table 9B - Threshold Regression Coefficients and Standard Errors (Eq. 43, Ch. 2)

Commo-dity code	**DF**	**CV**	**β_6**	**β_7**	**β_8**	**β_9**
1124	81	2.64 (99%) 1.99 (95%) 1.66 (90%)	-3.14 (2.84)	0.60 (6.45)	**0.64**[c] (0.13)	-0.06 (0.04)
1222	69	2.66 (99%) 2.00 (95%) 1.67 (90%)	0.09 (0.33)	-0.02 (0.62)	-0.04 (0.04)	0.06 (0.04)
533	117	2.63 (99%) 1.98 (95%) 1.66 (90%)	**-0.28**[c] (0.07)	-0.01 (0.58)	-0.01 (0.03)	**0.16**[c] (0.03)
6123	82	2.64 (99%) 1.99 (95%) 1.66 (90%)	**-0.05**[a] (0.03)	**-3.89**[a] (2.34)	0.33 (0.22)	0.00 (0.31)
621	147	2.63 (99%) 1.98 (95%) 1.66 (90%)	-0.17 (0.12)	-0.55 (0.86)	-0.05 (0.04)	0.15 (0.10)
6353	103	2.63 (99%) 1.98 (95%) 1.66 (90%)	0.98 (0.93)	13.34 (11.18)	**-1.31**[c] (0.34)	-0.54 (0.38)
6421	147	2.63 (99%) 1.98 (95%) 1.66 (90%)	0.11 (0.19)	-0.98 (0.91)	**-0.11**[a] (0.06)	0.04 (0.04)
678	103	2.63 (99%) 1.98 (95%) 1.66 (90%)	0.09 (0.06)	**-0.93**[b] (0.44)	-0.06 (0.04)	**-0.24**[c] (0.08)
7525	89	2.64 (99%) 1.99 (95%) 1.66 (90%)	**0.08**[c] (0.03)	1.20 (1.21)	**-0.44**[b] (0.17)	-0.02 (0.25)
79312	66	2.66 (99%) 2.00 (95%) 1.67 (90%)	-0.03 (0.05)	**-4.86**[b] (2.37)	-0.72 (0.49)	-0.24 (0.34)
84722	54	2.70 (99%) 2.02 (95%) 1.68 (90%)	0.26 (0.17)	**4.61**[a] (2.60)	**0.59**[a] (0.30)	0.07 (0.23)
89286	89	2.64 (99%) 1.99 (95%) 1.66 (90%)	**-0.20**[b] (0.09)	**-2.68**[c] (0.99)	**0.11**[b] (0.05)	-0.01 (0.06)

Notes: 1. This table presents the estimated coefficients from the unrestricted regression of the import price (Eq.43, Ch.2). The coefficients β_1, β_2 and β_3 define the responses of the import price to the marginal cost, the squared marginal cost and the marginal cost raised to the power of 3, respectively. The coefficients β_4, β_5 and β_6 represent the effects of the price differential, the squared price differential and the price differential raised to the power of 3, respectively, on the import price. The coefficient β_7 defines the impact of the product of the marginal cost and the price differential. The ERPT in the lower and upper regimes is reflected in the coefficients β_8 and β_9, respectively. 2. The expected signs of the coefficients are as follows: $\beta_1>0$, $\beta_2>0$, $\beta_3>0$, $\beta_4<0$, $\beta_6<0$, $\beta_8>0$, $\beta_9>0$, where $\beta_8>\beta_9$. The sign of the coefficients β_5 and β_7 is ambiguous. 3. "DF" denotes the degrees of freedom, $df = (T-2)K-9$, where T is the number of time periods and K stands for the number of exporting countries. Number *9* reflects the number of regressors in the import price model. 4. "CV" denotes the critical values for the 2-tail T-test at the 90%, 95% and 99% confidence levels. 5. "s.e." denotes the standard errors. 6. Commodity codes refer to the Standard International Trade Classification presented in Table 2. 7. Superscripts "c", "b" and "a" indicate the statistical significance of the coefficient estimate at the 99%, 95% and 90% confidence levels, respectively.

Table 10 - Statistical Significance of Threshold Estimates (Eq.43, Ch.2)

Commo-dity code	$\hat{\gamma}$ **(threshold estimate)**	F_1 **test (LR)**	F_1 **CV (bootstrap)**	F_1 **p-value (bootstrap)**	**95% confidence region for** γ
1124	**-0.14**[c]	**36.89**	25.25 (99%) 18.12 (95%) 14.45 (90%)	**0.000**	[-0.14, -0.14]
1222	-0.21	5.38	13.81 (99%) 10.66 (95%) 8.16 (90%)	0.310	[-0.31, 1.03]
533	**0.40**[c]	**27.19**	22.96 (99%) 18.16 (95%) 14.48 (90%)	**0.000**	[0.20, 0.40]
6123	1.15	3.81	17.45 (99%) 11.74 (95%) 7.93 (90%)	0.440	[-0.40, 1.20]
621	1.27	4.58	17.00 (99%) 14.91 (95%) 11.57 (90%)	0.570	[-0.08, 1.47]
6353	***-0.10***	***18.05***	25.82 (99%) 21.50 (95%) 19.64 (90%)	***0.173***	[-0.10, -0.10]
6421	-0.10	6.49	18.19 (99%) 12.20 (95%) 9.54 (90%)	0.307	[-0.33, 1.20]
678	0.90	6.59	17.99(99%) 13.50 (95%) 12.10 (90%)	0.353	[-0.42, 1.46]
7525	2.46	3.11	16.34 (99%) 11.94 (95%) 10.34 (90%)	0.787	[-0.48, 2.46]
79312	-0.11	2.30	28.57 (99%) 18.21 (95%) 14.74 (90%)	0.863	[-1.60, 2.02]
84722	***1.42***	***7.32***	18.26 (99%) 11.75 (95%) 8.89 (90%)	***0.170***	[-0.44, 2.30]
89286	***0.70***	***6.28***	21.04 (99%) 14.22 (95%) 9.16 (90%)	***0.153***	[0.25, 1.49]

Notes**:** 1. This table presents the results of the bootstrap replications conducted to examine the significance of the threshold estimate, $\hat{\gamma}$, in the import price equation (Eq.43, Ch.2). Superscript "c" indicates the statistical significance of the threshold estimate at the 99% confidence level. 2. The F_1 test (Eq.28, Ch.2) represents the LR test. The null hypothesis implies no structural change in the exchange rate coefficient. This test compares the concentrated sums of squared errors from the restricted (Eq.44, Ch.2) and unrestricted (Eq.43, Ch.2) regressions of the import price. 3. Commodity codes refer to the Standard International Trade Classification presented in Table 2. 4. Asymptotic p-values for the LR F_1 test are computed by simulating the F_1 statistic (Eq.34, Ch.2) through conducting 300 repeated estimations of the unrestricted and restricted import price equations. The null hypothesis of the ERPT stability is rejected if the bootstrap p-value is smaller than the desired significance level. 5. "CV" denotes the bootstrap critical values for the LR F_1 test at the 90%, 95% and 99% confidence levels. The excess of the statistic value over the critical value implies the rejection of the null hypothesis of no structural change in the coefficient on the log-transformed exchange rate.

Table 11 - RMSFE from the PTM and non-PTM Models (Seasonally Unadjusted)

Category	Rolling		Recursive		Split		Random Walk TVP	
	PTM	Non-PTM	PTM	Non-PTM	PTM	Non-PTM	PTM	Non-PTM
Aggregate Series	**0.00586**[c]	0.00642	**0.00605**[c]	0.00630	**0.00839**[c]	0.00943	0.01047	0.01054
Food	0.00630	0.00614	0.00611	0.00596	**0.00677**[c]	0.00770	0.01085	0.01087
Chemicals	0.00586	0.00593	**0.00597**[a]	0.00609	**0.01468**[c]	0.01518	0.01113	0.01127
Machinery	**0.00699**[c]	0.00708	**0.00711**[c]	0.00712	0.02810	0.02727	0.01066	0.01055
Electric Machinery	0.00912	0.00902	0.00950	0.00929	**0.01432**[c]	0.01662	0.01273	0.01277
Clothing	**0.00890**[c]	0.00894	0.00938	0.00919	0.01446	0.01393	0.01621	0.01587
Road Vehicles	0.00555	0.00540	0.00558	0.00548	**0.00979**[c]	0.01068	0.00748	0.00797
Paper and Paperboard	0.00727	0.00699	0.00709	0.00702	0.01033	0.00987	0.01296	0.01327
Miscellaneous Metal Manufactures	**0.00627**[c]	0.00651	**0.00622**[c]	0.00645	0.00983	0.00813	0.01130	0.01146
Wood and Cork Manufactures	0.00649	0.00642	**0.00650**[c]	0.00664	**0.00751**[c]	0.01258	0.01015	0.01063
Textile Fabrics	**0.00612**[c]	0.00643	**0.00620**[c]	0.00647	**0.01509**[c]	0.01525	0.01102	0.01089

Note: see notes to Table 12

Table 12 - RMSFE from the PTM and non-PTM Models (Seasonally Adjusted)

Category	**Rolling**		**Recursive**		**Split**		**Random Walk TVP**	
	PTM	Non-PTM	PTM	Non-PTM	PTM	Non-PTM	PTM	Non-PTM
Aggregate Series	**0.64794**^{c}	0.69470	**0.62840**^{a}	0.66389	0.68950	0.70829	1.07293	1.07098
Food	0.68169	0.66156	0.65089	0.64342	**0.81381**^{c}	0.94440	1.19944	1.20634
Chemicals	**0.65695**^{b}	0.65156	**0.63529**^{b}	0.63407	**0.61388**^{c}	0.62988	1.22343	1.21829
Machinery	**0.76343**^{c}	0.78795	0.80002	0.78322	**0.87787**^{c}	1.16547	1.11280	1.11683
Electric Machinery	1.11108	1.07510	1.12171	1.12412	**1.22780**^{c}	1.35389	1.36299	1.37637
Clothing	0.93871	0.91765	**0.91567**^{b}	0.90887	**0.92493**^{c}	0.91802	1.82023	1.82302
Road Vehicles	0.56131	0.53293	0.52296	0.50120	0.58028	0.52832	0.84167	0.83227
Paper and Paperboard	0.83980	0.82650	0.82557	0.81791	**0.83583**^{c}	0.87954	1.60385	1.65217
Miscellaneous Metal Manufactures	0.90351	0.88102	**0.88094**^{b}	0.86644	1.11436	0.94783	1.48680	1.49020
Wood and Cork Manufactures	**0.71312**^{c}	0.76502	**0.72475**^{b}	0.76384	**0.81465**^{c}	0.87264	1.16943	1.20608
Textile Fabrics	**0.74716**^{c}	0.78293	**0.73787**^{c}	0.76050	0.94613	0.82146	1.41389	1.39749

Notes: 1. Tables 11 and 12 display the RMSFE (Eq.26b, Ch.3) delivered by rolling, recursive, split and RWCTVP estimation of the PTM (Eq.23a, Ch.3) and non-PTM (Eq.23b, Ch.3) models of the export price. Sample period spans the observations from January 1999 to April 2010. 2. A small RMSFE indicates a strong forecasting performance of a model and a large RMSFE reflects a poor predictive power. 3. PTM model suggests that the exchange rate has predictive power for the export price. Non-PTM model implies that the exchange rate has no predictive content for the export price. 4. TVP stands for the Time Varying Parameter estimation. 5. Aggregate series refers to the aggregate price indices of the UK trade in manufactures with the EU. 6. Symbols "c", "b" and "a" denote the statistical significance of the difference between the RMSFE of the non-PTM (Eq.23b, Ch.3) and PTM (Eq.23a, Ch.3) models at 1%, 5% and 10% levels of significance, respectively. The statistical significance of the error differential is determined using asymptotic critical values of the ENC-NEW test of forecast encompassing by Clark and McCracken (2001). These critical values are applicable only to split, rolling and recursive regressions. The null hypothesis of the ENC-NEW test suggests that $RMSFE^{Non\text{-}PTM}\text{-}RMSFE^{PTM}=0$. If the null hypothesis is rejected and $RMSFE^{Non\text{-}PTM}>RMSFE^{PTM}$, the hypothesis of PTM is adopted.

Table 12A – OLS Regression Coefficients and p-values (Eq.32, Ch.3)

Category	δ (PV) [HCPV]	β_1 (PV) [HCPV]	β_2 (PV) [HCPV]	β_3 (PV) [HCPV]	β_4 (PV) [HCPV]	β_5 (PV) [HCPV]	β_6 (PV) [HCPV]	β_7 (PV) [HCPV]	β_8 (PV) [HCPV]
AS	**0.41**	**0.45**	**0.24**	-0.03	**0.27**	**-0.26**	**0.13**	0.0001	-0.0001
	(0.097)	(0.000)	(0.037)	(0.823)	(0.090)	(0.001)	(0.101)	(0.626)	(0.519)
	[0.104]	[0.000]	[0.039]	[0.810]	[0.060]	[0.002]	[0.091]	[0.665]	[0.560]
FOOD	-0.11	**0.57**	**0.23**	**0.39**	-0.09	-0.09	0.05	0.0002	**-0.0003**
	(0.215)	(0.000)	(0.027)	(0.008)	(0.536)	(0.168)	(0.492)	(0.160)	(0.019)
	[0.219]	[0.000]	[0.030]	[0.013]	[0.570]	[0.156]	[0.475]	[0.263]	[0.052]
CHEM	**0.53**	**0.72**	-0.05	0.03	**0.18**	**-0.16**	0.03	0.0000	0.0000
	(0.040)	(0.000)	(0.661)	(0.803)	(0.087)	(0.027)	(0.724)	(0.661)	(0.729)
	[0.033]	[0.000]	[0.635]	[0.808]	[0.076]	[0.033]	[0.684]	[0.730]	[0.767]
MACH	**0.61**	**0.75**	0.06	-0.01	0.04	**-0.19**	0.05	0.0000	0.0000
	(0.092)	(0.000)	(0.611)	(0.951)	(0.849)	(0.036)	(0.563)	(0.884)	(0.667)
	[0.131]	[0.000]	[0.577]	[0.942]	[0.827]	[0.091]	[0.624]	[0.880]	[0.634]
ELEC	0.52	**0.66**	**0.22**	-0.09	0.06	-0.10	-0.02	0.0000	-0.0001
	(0.148)	(0.000)	(0.033)	(0.695)	(0.776)	(0.398)	(0.877)	(0.877)	(0.653)
	[0.206]	[0.000]	[0.057]	[0.516]	[0.627]	[0.413]	[0.871]	[0.887]	[0.633]
CLOT	0.15	**1.01**	-0.13	0.05	0.57	0.00	-0.07	0.0000	0.0001
	(0.789)	(0.000)	(0.320)	(0.886)	(0.877)	(0.971)	(0.522)	(0.808)	(0.550)
	[0.751]	[0.000]	[0.266]	[0.542]	[0.476]	[0.969]	[0.570]	[0.863]	[0.707]
ROAD	-0.16	**0.66**	**0.34**	-0.01	0.06	-0.01	0.04	0.0001	0.0000
	(0.251)	(0.000)	(0.000)	(0.947)	(0.660)	(0.814)	(0.435)	(0.580)	(0.914)
	[0.199]	[0.000]	[0.001]	[0.953]	[0.676]	[0.819]	[0.396]	[0.588]	[0.918]
PAP	**-0.50**	**0.79**	0.14	0.23	0.04	-0.10	0.15	0.0000	0.0000
	(0.015)	(0.000)	(0.200)	(0.249)	(0.813)	(0.276)	(0.128)	(0.899)	(0.979)
	[0.014]	[0.000]	[0.109]	[0.105]	[0.756]	[0.348]	[0.145]	[0.880]	[0.976]
MET	**0.29**	**0.57**	**0.19**	**0.42**	-0.20	**-0.27**	**0.16**	-0.0001	0.0001
	(0.041)	(0.000)	(0.078)	(0.001)	(0.123)	(0.000)	(0.035)	(0.394)	(0.343)
	[0.041]	[0.000]	[0.055]	[0.002]	[0.108]	[0.001]	[0.042]	[0.428]	[0.379]
WOO	**0.70**	**0.40**	**0.29**	0.12	0.01	**-0.24**	0.07	0.0001	-0.0001
	(0.023)	(0.000)	(0.009)	(0.479)	(0.960)	(0.005)	(0.430)	(0.426)	(0.416)
	[0.021]	[0.001]	[0.014]	[0.351]	[0.949]	[0.009]	[0.543]	[0.562]	[0.538]
TEXT	0.16	**0.71**	**0.27**	-0.01	0.12	**-0.23**	**0.22**	0.0001	-0.0002
	(0.342)	(0.000)	(0.023)	(0.956)	(0.551)	(0.001)	(0.002)	(0.230)	(0.155)
	[0.276]	[0.000]	[0.042]	[0.962]	[0.589]	[0.010]	[0.009]	[0.328]	[0.263]

Notes: 1. This table presents the estimated coefficients from the OLS regression of the import price (Eq.32, Ch.3) with corresponding p-values (PV) and heteroskedasticity-consistent p-values (HCPV). δ stands for constant, while other parameters are defined as follows: β_1 - coefficient on the first lag of the log of the export price, β_2 – coefficient on the second lag of the log of the export price, β_3 – coefficient on the first lag of the log of the marginal cost, β_4 – coefficient on the second lag of the log of the marginal cost, β_5 – coefficient on the first lag of the log of the exchange rate, β_6 – coefficient on the second lag of the log of the exchange rate, β_7 – coefficient on the product of the first lag of the annual average volatility of the exchange rate, σ_{t-1}, and the first lag of the log of the exchange rate, β_8 - coefficient on the product of the second lag of the annual average volatility of the exchange rate, σ_{t-2}, and the second lag of the log of the exchange rate. 2. The PTM defined as the response of the log of the export price to the log of the exchange rate is given by $[\beta_5 + \beta_7\sigma_{t-1}]$ and $[\beta_6 + \beta_8\sigma_{t-2}]$. The statistical significance of coefficients β_7 and β_8 indicates that the annual average volatility of the exchange rate causes a structural break in the PTM. 3. The expected sign of the coefficients on marginal costs is positive, i.e. $\beta_3>0$ and $\beta_4>0$. The expected signs of the remaining regression parameters are ambiguous. 4. Commodity codes represent the following industries: AS – Aggregate Series, FOOD - Food, CHEM – Chemicals, MACH – Machinery, ELEC - Electric Machinery, CLOT – Clothing, ROAD – Road Vehicles, PAP – Paper and Paperboard, MET – Miscellaneous Metal Manufactures, WOO – Wood and Cork Manufactures, TEXT – Textile Fabrics. 5. Bold type indicates the statistical significance of a coefficient estimate at the 99%, 95% or 90% confidence levels. 6. Sample period spans the observations from March 2000 to April 2010.

Table 12B – First-Differenced Data on UK Export Prices, PPI and Exchange Rate

Date	EPI	PPI	BSEERI
February 1999	0.000	0.000	0.004
March 1999	-0.004	0.002	0.007
April 1999	-0.004	0.002	0.000
May 1999	0.000	0.000	0.004
June 1999	0.000	0.000	0.000
July 1999	0.000	0.000	-0.005
August 1999	-0.004	0.000	0.002
September 1999	-0.004	0.001	0.006
October 1999	0.000	0.000	0.004
November 1999	-0.004	0.000	0.000
December 1999	0.000	0.000	0.003
January 2000	-0.009	0.000	0.007
February 2000	0.004	0.000	-0.002
March 2000	0.000	0.001	-0.001
April 2000	-0.004	0.002	0.006
May 2000	0.000	0.000	-0.008
June 2000	0.004	0.001	-0.013
July 2000	0.000	0.000	0.004
August 2000	0.000	-0.001	0.004
September 2000	-0.004	0.001	-0.006
October 2000	-0.004	0.001	0.011
November 2000	0.004	0.000	-0.007
December 2000	0.000	-0.001	-0.001
January 2001	0.000	-0.002	-0.005
February 2001	0.000	-0.001	-0.002
March 2001	0.000	0.000	0.004
April 2001	0.000	0.000	0.004
May 2001	-0.004	0.001	0.001
June 2001	0.000	0.000	0.000
July 2001	-0.004	-0.001	0.003
August 2001	0.000	-0.001	-0.005
September 2001	-0.009	0.000	0.005
October 2001	0.005	0.000	-0.001
November 2001	-0.005	-0.003	0.000
December 2001	0.014	0.000	0.002
January 2002	0.000	0.001	0.001
February 2002	0.000	0.000	0.001
March 2002	0.004	0.001	-0.003
April 2002	-0.004	0.002	0.003
May 2002	-0.004	0.001	-0.006
June 2002	0.004	0.000	-0.004
July 2002	0.000	0.000	0.010

Notes: This table presents first-differenced data on the UK trade in manufactures with the EU. Data on the aggregate Export Price Index (EPI) was obtained from the *Monthly Review of External Trade Statistics* provided by the Office for National Statistics. Data on the Producer Price Index (PPI) for the output of manufactured goods was retrieved from the *PPI First Release 2005=100* by the Office for National Statistics.

BSEERI denotes Broad Sterling Effective Exchange Rate Index from the *Financial Statistics Freestanding* release by the Office for National Statistics. All variables have been log-transformed.

Table 13 - PTM and ERPT in the LCP and PCP (Ch. 4)

Case	PTM	ERPT
PCP with no subsistence absorption	$\frac{\partial\left(MC_{it}^{f}\vartheta\right)}{\partial e_t}\frac{e_t}{MC_{it}^{f}\vartheta}=0$	$\frac{\partial\left(MC_{it}^{f}\vartheta e_t\right)}{\partial e_t}\frac{e_t}{MC_{it}^{f}\vartheta e_t}=1$
PCP with subsistence absorption	$\frac{\partial\left(MC_{it}^{f}\mu_3\right)}{\partial e_t}\frac{e_t}{MC_{it}^{f}\mu_3}=\frac{\partial\mu_3}{\partial e_t}\frac{e_t}{\mu_3}$	$\frac{\partial\left(MC_{it}^{f}\mu_3 e_t\right)}{\partial e_t}\frac{e_t}{MC_{it}^{f}\mu_3 e_t}=1+\frac{\partial\mu_3}{\partial e_t}\frac{e_t}{\mu_3}$
LCP with no subsistence absorption	$\frac{\partial\left(\frac{q_{it}^{f}}{e_t}\right)}{\partial e_t}\frac{e_t}{q_{it}^{f}/e_t}=-1$	$\frac{\partial\left(MC_{it}^{f}\vartheta\right)}{\partial e_t}\frac{e_t}{MC_{it}^{f}\vartheta}=0$
LCP with subsistence absorption	$\frac{\partial\left(\frac{MC_{it}^{f}\mu_2}{e_t}\right)}{\partial e_t}\frac{e_t}{MC_{it}^{f}\mu_2/e_t}=$ $=\frac{\partial\mu_2}{\partial e_t}\frac{e_t}{\mu_2}-1<0$	$\frac{\partial\left(\mu_2 MC_{it}^{f}\right)}{\partial e_t}\frac{e_t}{\mu_2 MC_{it}^{f}}=\frac{\partial\mu_2}{\partial e_t}\frac{e_t}{\mu_2}<0$

Notes: 1. This table displays the degrees of PTM and ERPT for two types of firm (i.e. Producer Currency Pricing and Local Currency Pricing) and two types of demand function, namely the demand with subsistence absorption (Eq.4, Ch.4) and the demand with no subsistence absorption. 2. PTM is computed as the elasticity of the export price with respect to the exchange rate, i.e. percentage change in the export price divided by the percentage change in the exchange rate. The ERPT represents the elasticity of the import price with respect to the exchange rate, i.e. proportionate change of the import price divided by the proportionate change of the exchange rate. 3. The functional forms of the export and import prices are derived using the optimal price mark-ups given in equations (39), (40) and (48) from Chapter 4. The optimal mark-ups of price over the marginal cost are found by solving the firms' profit maximization problems.

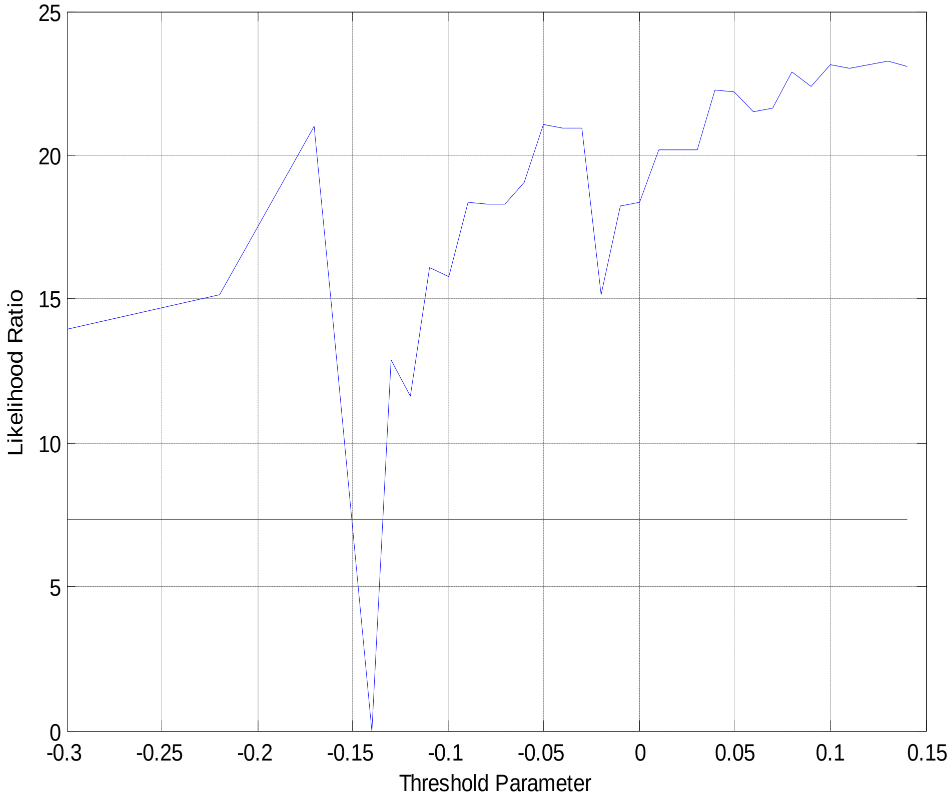
Table 14 – Calibration of the DSGE Model from Ch. 4

Parameter	Interpretation	Value
$\boldsymbol{\beta}$	Subjective factor for discounting future utility	**0.9902**
$\boldsymbol{\delta}$	Intertemporal elasticity of substitution in consumption	**2**
$\boldsymbol{h}$	Steady state share of time spent at work	**0.2**
$\boldsymbol{c^*, c^{*f}}$	Domestic and foreign subsistence consumption	**0.064**
$\boldsymbol{i^*, i^{*f}}$	Domestic and foreign subsistence investment	**0.016**
$\boldsymbol{\eta}$	Elasticity of substitution across differentiated goods	**5.3**
$\boldsymbol{\sigma}$	Quarterly depreciation rate of capital	**0.01**
$\boldsymbol{\alpha}$	Elasticity of output with respect to capital	**0.25**
$\boldsymbol{(c^*+i^*)/(c+i)}$	Domestic ratio of the aggregate subsistence demand to the aggregate demand	**0.3**
$\boldsymbol{(c^{*f}+i^{*f})/(c^f+i^f)}$	Foreign ratio of the aggregate subsistence demand to the aggregate demand	**0.3**

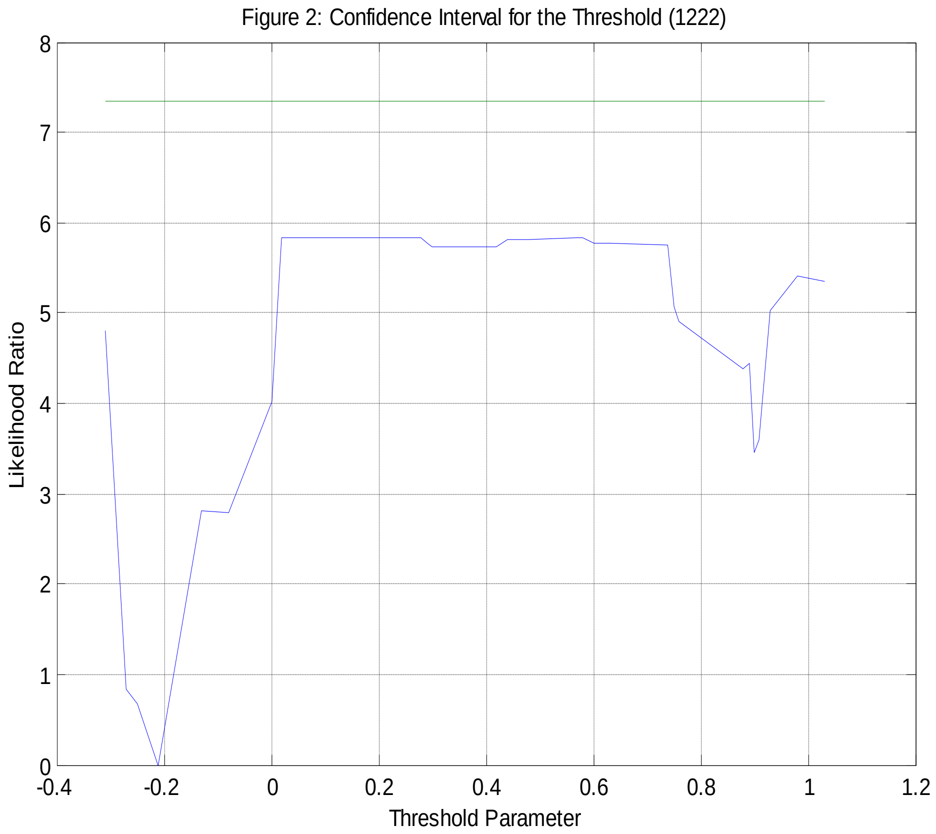
Notes**:** This table summarizes the calibration of the parameters from the DSGE model of the time varying PTM and ERPT, which is derived in Chapter 4. It presents the values assigned to the parameters of the utility (Eq.1, Ch.4) and production (Eq.24, Ch.4) functions. These parameter values are used to simulate the response of the PCP and LCP mark-ups (Figures 26-29) to positive shocks to technology and preferences. Parameter calibration follows Ravn et al. (2006).

6.3 Figures

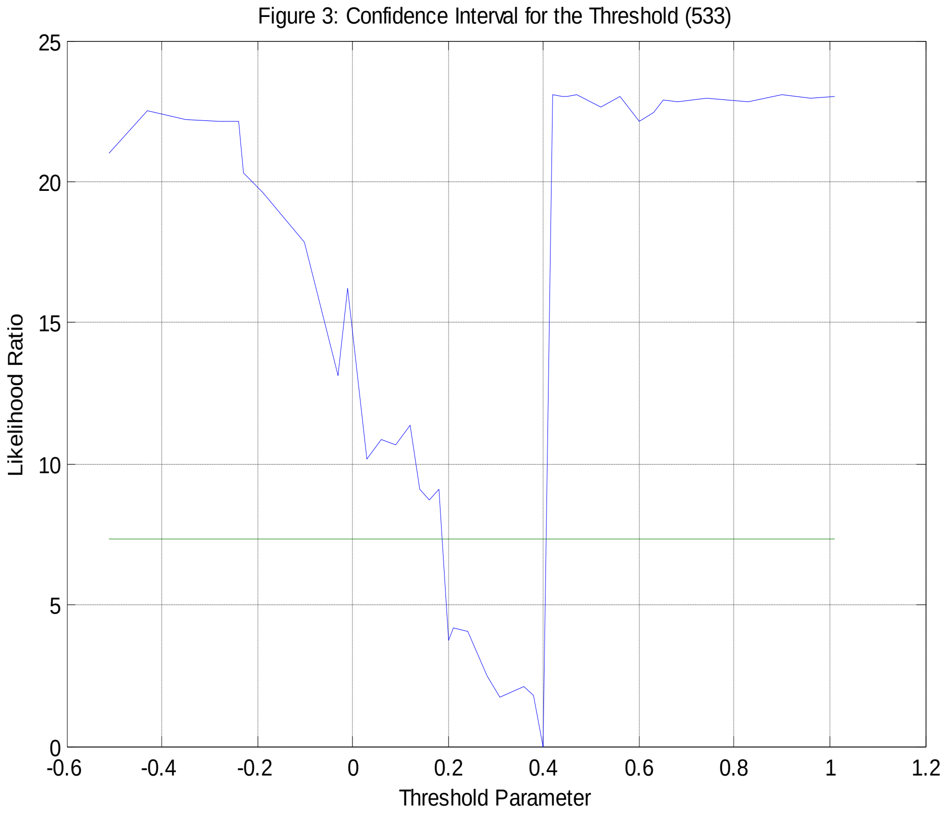
Figure 1: Confidence Interval for the Threshold (1124)



Notes: 1. This figure plots the $F_2(\gamma)$ LR statistic (Eq.35, Ch.2) testing the null hypothesis that the observed threshold parameter value equals the true threshold. The excess of the statistic value over the critical value implies the rejection of the null hypothesis. 2. Commodity code 1124 denotes “Spirits (other than 51216); liqueurs” in the Standard International Trade Classification. 3. Commodity code 51216 refers to “Ethyl alcohol and other spirits, denatured” in the Standard International Trade Classification. 4. The horizontal line corresponds to the critical value for the $F_2(\gamma)$ statistic at the 0.05 significance level. The set of $F_2(\gamma)$ values lying above the horizontal line represents the asymptotic confidence interval for the threshold, i.e. the “no-rejection” region containing all threshold values that satisfy the null hypothesis.

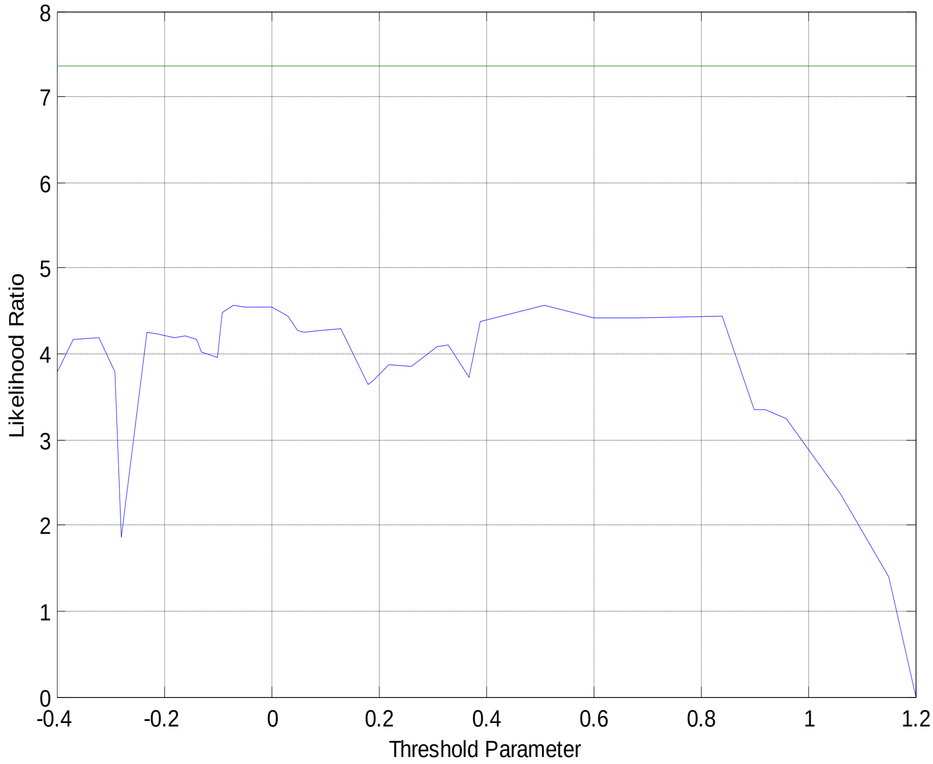


Notes: 1. This figure plots the $F_2(\gamma)$ LR statistic (Eq.35, Ch.2) testing the null hypothesis that the observed threshold parameter value equals the true threshold. The excess of the statistic value over the critical value implies the rejection of the null hypothesis. 2. Commodity code 1222 denotes "Cigarettes containing tobacco" in the Standard International Trade Classification. 3. The horizontal line corresponds to the critical value for the $F_2(\gamma)$ statistic at the 0.05 significance level. The set of $F_2(\gamma)$ values lying above the horizontal line represents the asymptotic confidence interval for the threshold, i.e. the "no-rejection" region containing all threshold values that satisfy the null hypothesis.



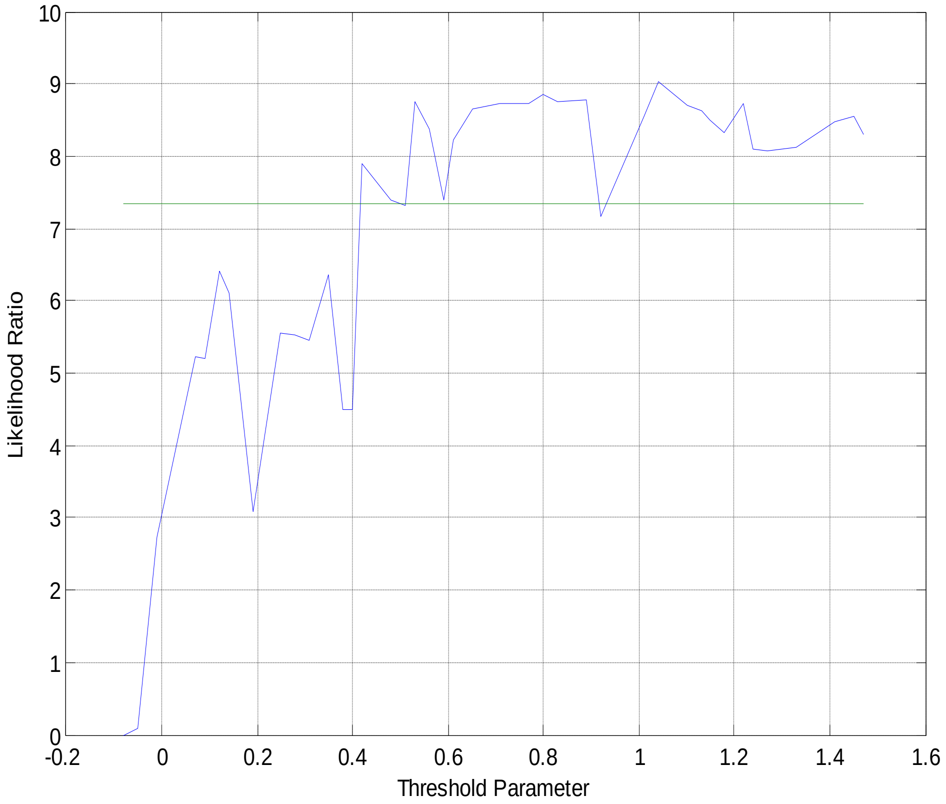
Notes: 1. This figure plots the $F_2(\gamma)$ LR statistic (Eq.35, Ch.2) testing the null hypothesis that the observed threshold parameter value equals the true threshold. The excess of the statistic value over the critical value implies the rejection of the null hypothesis. 2. Commodity code 533 denotes "Pigments, paints, varnishes and related materials" in the Standard International Trade Classification. 3. The horizontal line corresponds to the critical value for the $F_2(\gamma)$ statistic at the 0.05 significance level. The set of $F_2(\gamma)$ values lying above the horizontal line represents the asymptotic confidence interval for the threshold, i.e. the "no-rejection" region containing all threshold values that satisfy the null hypothesis.

Figure 4: Confidence Interval for the Threshold (6123)

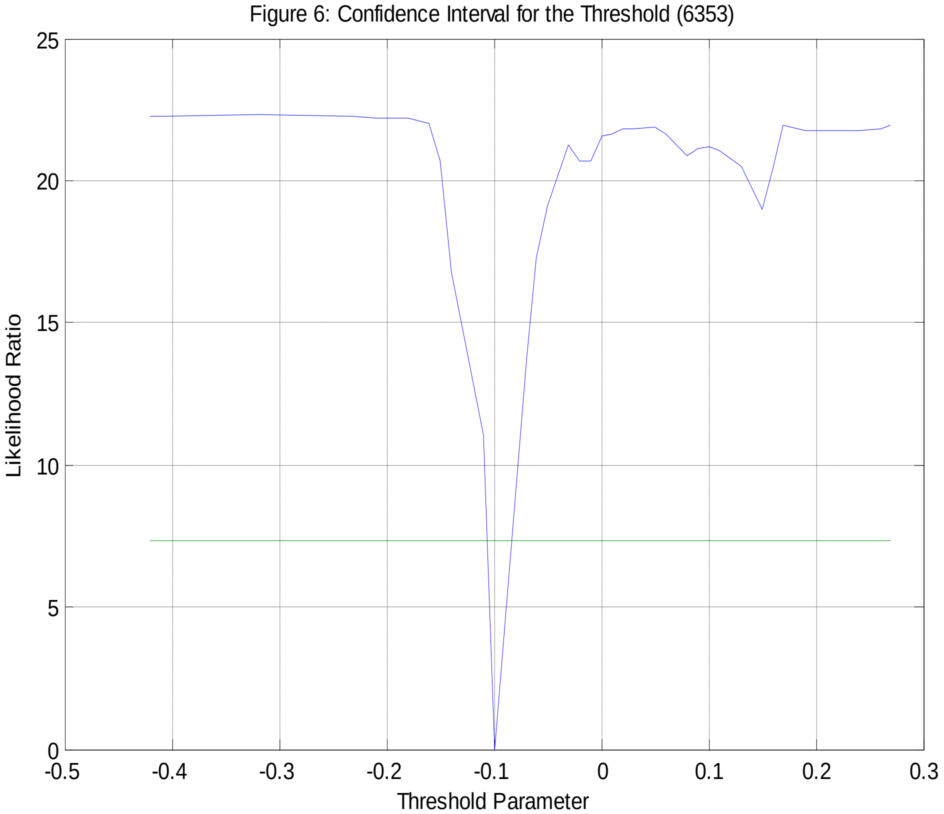


Notes: 1. This figure plots the $F_2(\gamma)$ LR statistic (Eq.35, Ch.2) testing the null hypothesis that the observed threshold parameter value equals the true threshold. The excess of the statistic value over the critical value implies the rejection of the null hypothesis. 2. Commodity code 6123 denotes "Parts of footwear" in the Standard International Trade Classification. 3. The horizontal line corresponds to the critical value for the $F_2(\gamma)$ statistic at the 0.05 significance level. The set of $F_2(\gamma)$ values lying above the horizontal line represents the asymptotic confidence interval for the threshold, i.e. the "no-rejection" region containing all threshold values that satisfy the null hypothesis.

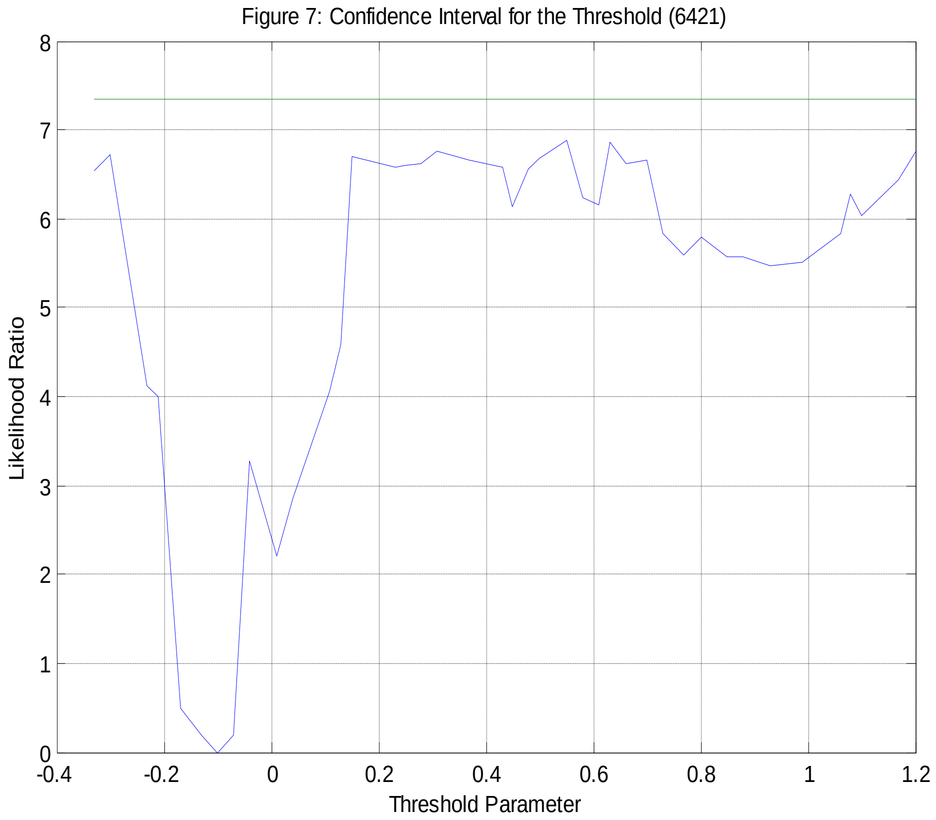
Figure 5: Confidence Interval for the Threshold (621)



Notes: 1. This figure plots the $F_2(\gamma)$ LR statistic (Eq.35, Ch.2) testing the null hypothesis that the observed threshold parameter value equals the true threshold. The excess of the statistic value over the critical value implies the rejection of the null hypothesis. 2. Commodity code 621 denotes "Materials of rubber (pastes, plates, sheets, etc.)" in the Standard International Trade Classification. 3. The horizontal line corresponds to the critical value for the $F_2(\gamma)$ statistic at the 0.05 significance level. The set of $F_2(\gamma)$ values lying above the horizontal line represents the asymptotic confidence interval for the threshold, i.e. the "no-rejection" region containing all threshold values that satisfy the null hypothesis.

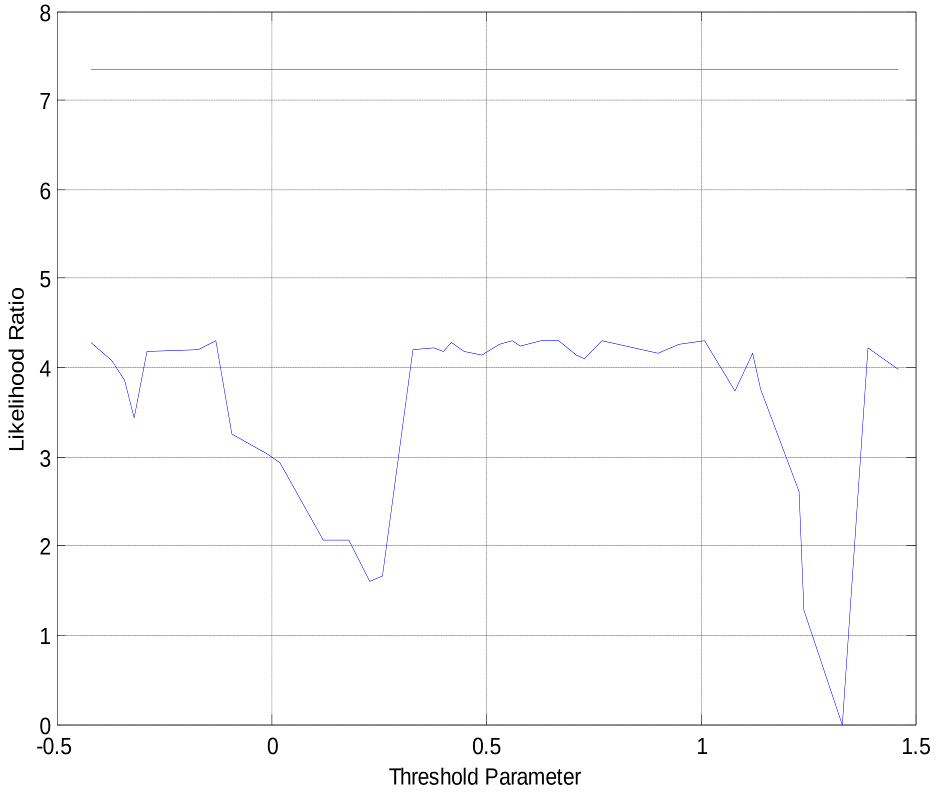


Notes: 1. This figure plots the $F_2(\gamma)$ LR statistic (Eq.35, Ch.2) testing the null hypothesis that the observed threshold parameter value equals the true threshold. The excess of the statistic value over the critical value implies the rejection of the null hypothesis. 2. Commodity code 6353 denotes "Builders' joinery and carpentry of wood" in the Standard International Trade Classification. 3. The horizontal line corresponds to the critical value for the $F_2(\gamma)$ statistic at the 0.05 significance level. The set of $F_2(\gamma)$ values lying above the horizontal line represents the asymptotic confidence interval for the threshold, i.e. the "no-rejection" region containing all threshold values that satisfy the null hypothesis.



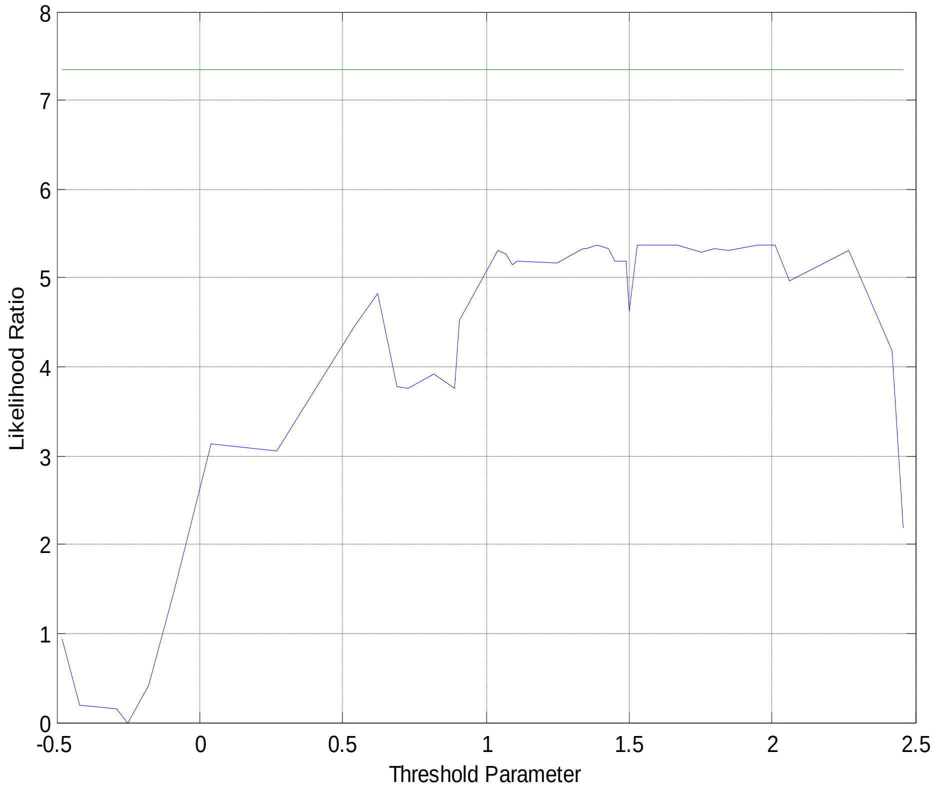
Notes: 1. This figure plots the $F_2(\gamma)$ LR statistic (Eq.35, Ch.2) testing the null hypothesis that the observed threshold parameter value equals the true threshold. The excess of the statistic value over the critical value implies the rejection of the null hypothesis. 2. Commodity code 6421 denotes "Cartons, bags, other containers, of paper, paperback, etc." in the Standard International Trade Classification. 3. The horizontal line corresponds to the critical value for the $F_2(\gamma)$ statistic at the 0.05 significance level. The set of $F_2(\gamma)$ values lying above the horizontal line represents the asymptotic confidence interval for the threshold, i.e. the "no-rejection" region containing all threshold values that satisfy the null hypothesis.

Figure 8: Confidence Interval for the Threshold (678)



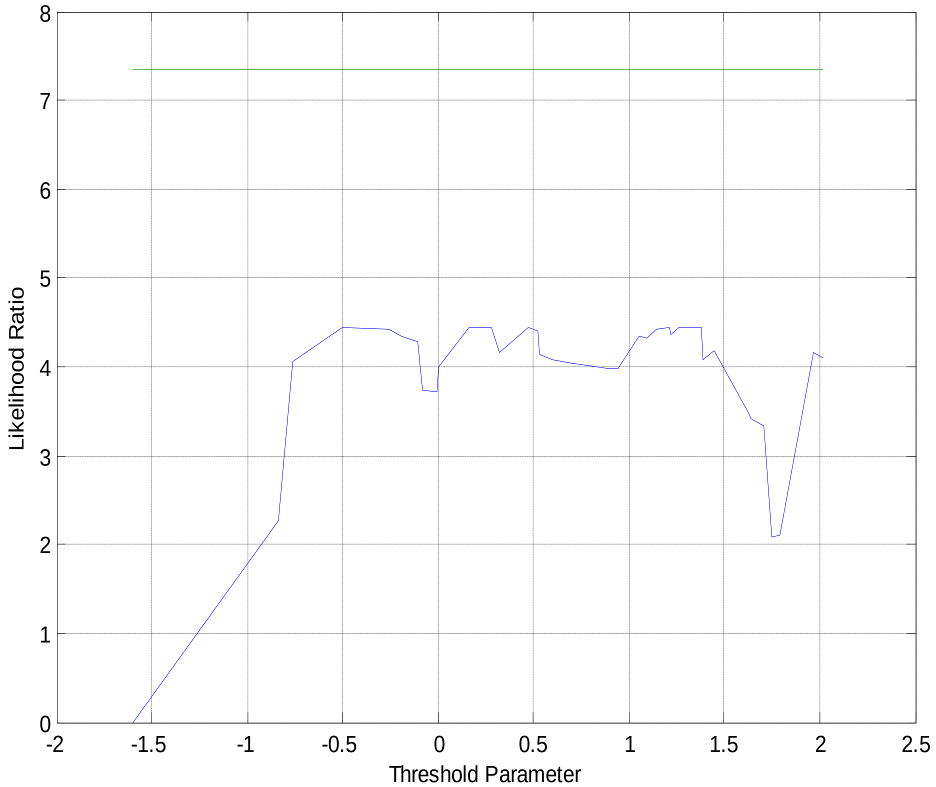
Notes: 1. This figure plots the $F_2(\gamma)$ LR statistic (Eq.35, Ch.2) testing the null hypothesis that the observed threshold parameter value equals the true threshold. The excess of the statistic value over the critical value implies the rejection of the null hypothesis. 2. Commodity code 678 denotes "Tubes, pipes and fittings, of iron or steel" in the Standard International Trade Classification. 3. The horizontal line corresponds to the critical value for the $F_2(\gamma)$ statistic at the 0.05 significance level. The set of $F_2(\gamma)$ values lying above the horizontal line represents the asymptotic confidence interval for the threshold, i.e. the "no-rejection" region containing all threshold values that satisfy the null hypothesis.

Figure 9: Confidence Interval for the Threshold (7525)



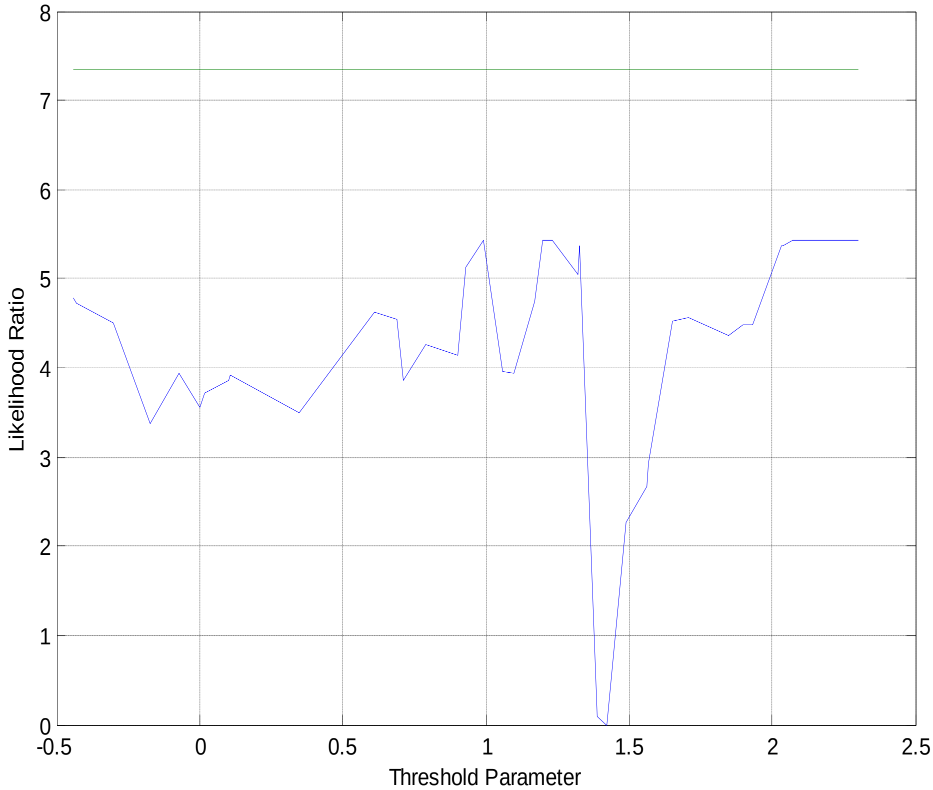
Notes: 1. This figure plots the $F_2(\gamma)$ LR statistic (Eq.35, Ch.2) testing the null hypothesis that the observed threshold parameter value equals the true threshold. The excess of the statistic value over the critical value implies the rejection of the null hypothesis. 2. Commodity code 7525 denotes "Peripheral units, including control and adapting units" in the Standard International Trade Classification. 3. The horizontal line corresponds to the critical value for the $F_2(\gamma)$ statistic at the 0.05 significance level. The set of $F_2(\gamma)$ values lying above the horizontal line represents the asymptotic confidence interval for the threshold, i.e. the "no-rejection" region containing all threshold values that satisfy the null hypothesis.

Figure 10: Confidence Interval for the Threshold (79312)



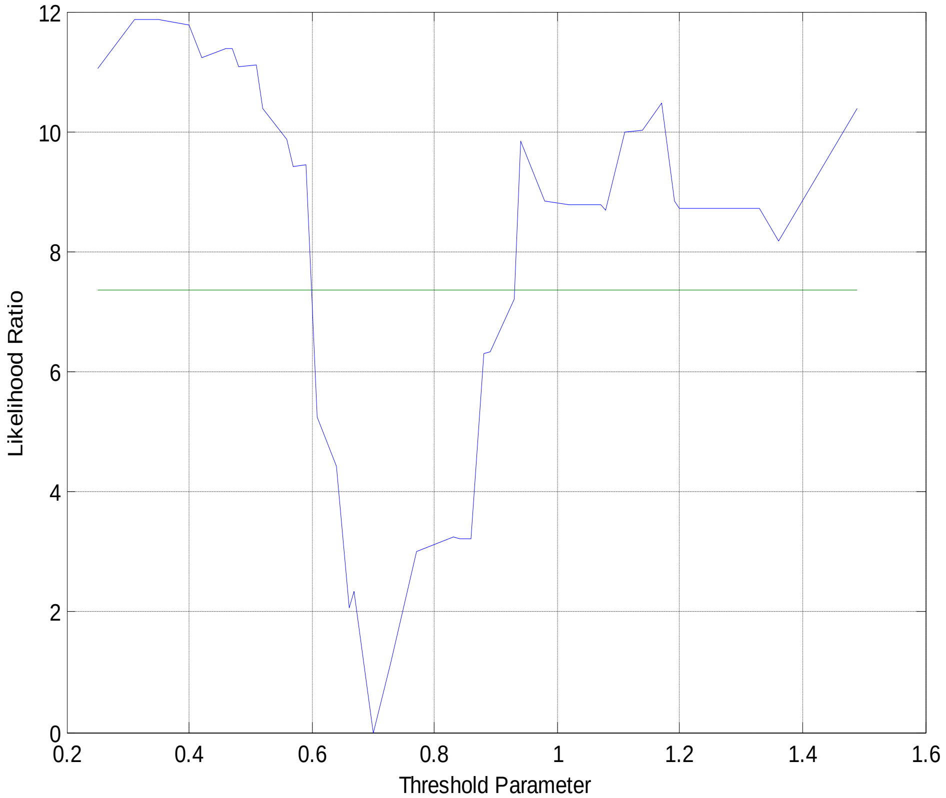
Notes: 1. This figure plots the $F_2(\gamma)$ LR statistic (Eq.35, Ch.2) testing the null hypothesis that the observed threshold parameter value equals the true threshold. The excess of the statistic value over the critical value implies the rejection of the null hypothesis. 2. Commodity code 79312 denotes “Sailboats, not inflatable, with auxiliary motor or not“ in the Standard International Trade Classification. 3. The horizontal line corresponds to the critical value for the $F_2(\gamma)$ statistic at the 0.05 significance level. The set of $F_2(\gamma)$ values lying above the horizontal line represents the asymptotic confidence interval for the threshold, i.e. the “no-rejection” region containing all threshold values that satisfy the null hypothesis.

Figure 11: Confidence Interval for the Threshold (84722)



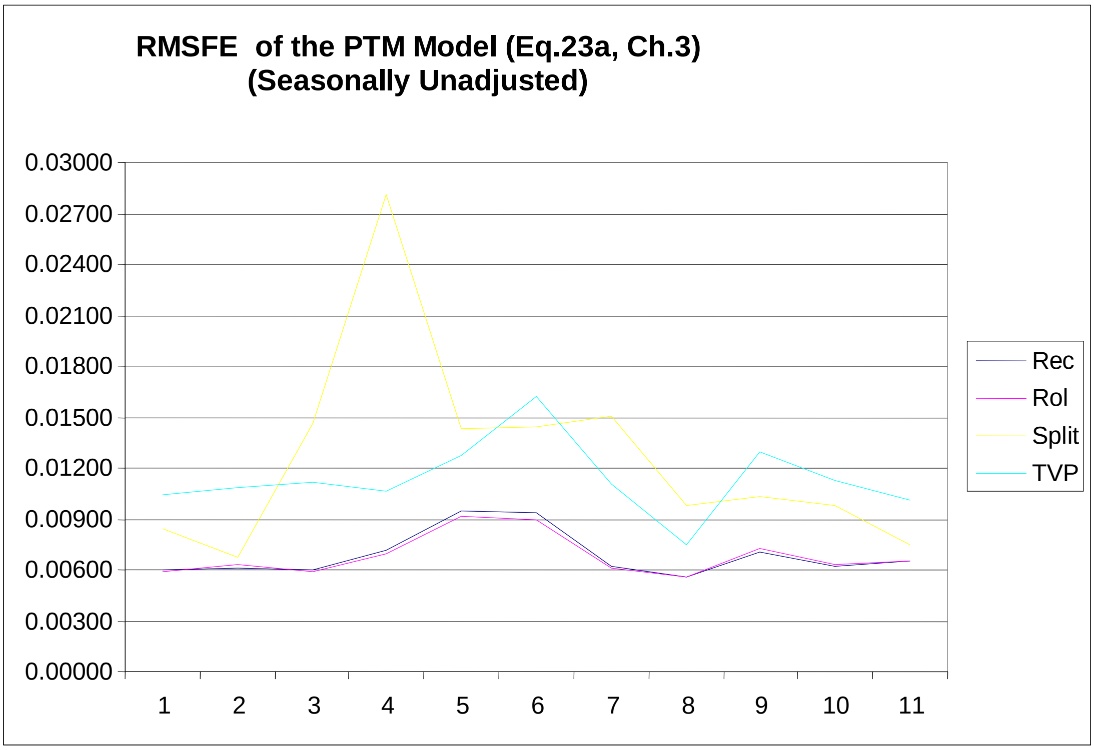
Notes: 1. This figure plots the $F_2(\gamma)$ LR statistic (Eq.35, Ch.2) testing the null hypothesis that the observed threshold parameter value equals the true threshold. The excess of the statistic value over the critical value implies the rejection of the null hypothesis. 2. Commodity code 84722 denotes "Stockings, ankle-socks and the like" in the Standard International Trade Classification. 3. The horizontal line corresponds to the critical value for the $F_2(\gamma)$ statistic at the 0.05 significance level. The set of $F_2(\gamma)$ values lying above the horizontal line represents the asymptotic confidence interval for the threshold, i.e. the "no-rejection" region containing all threshold values that satisfy the null hypothesis.

Figure 12: Confidence Interval for the Threshold (89286)



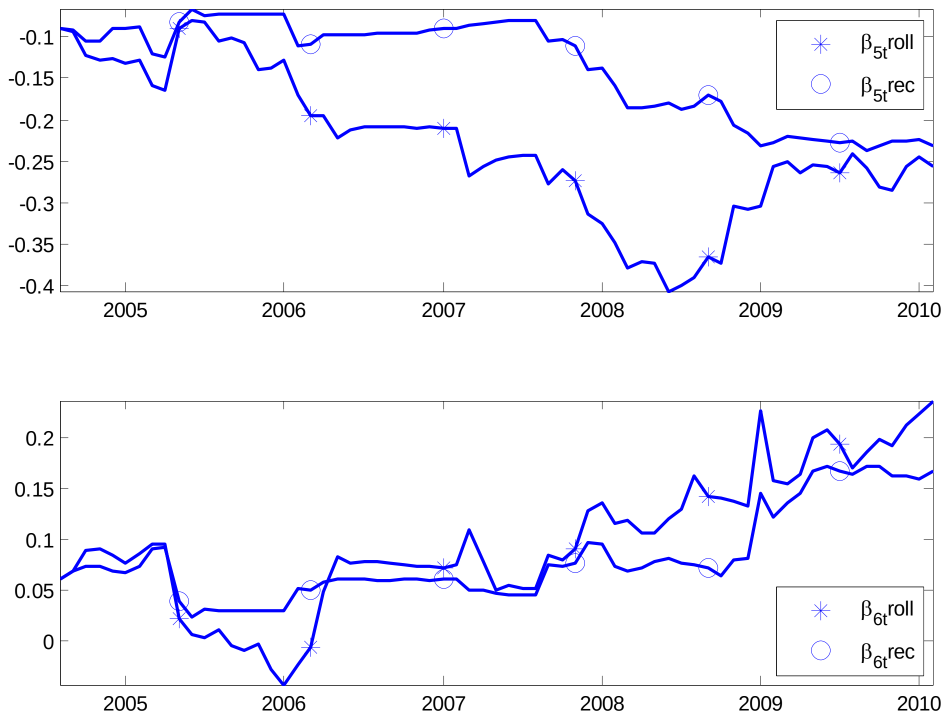
Notes: 1. This figure plots the $F_2(\gamma)$ LR statistic (Eq.35, Ch.2) testing the null hypothesis that the observed threshold parameter value equals the true threshold. The excess of the statistic value over the critical value implies the rejection of the null hypothesis. 2. Commodity code 89286 denotes "Trade advertising material, commercial catalogues, etc." in the Standard International Trade Classification. 3. The horizontal line corresponds to the critical value for the $F_2(\gamma)$ statistic at the 0.05 significance level. The set of $F_2(\gamma)$ values lying above the horizontal line represents the asymptotic confidence interval for the threshold, i.e. the "no-rejection" region containing all threshold values that satisfy the null hypothesis.

Figure 13



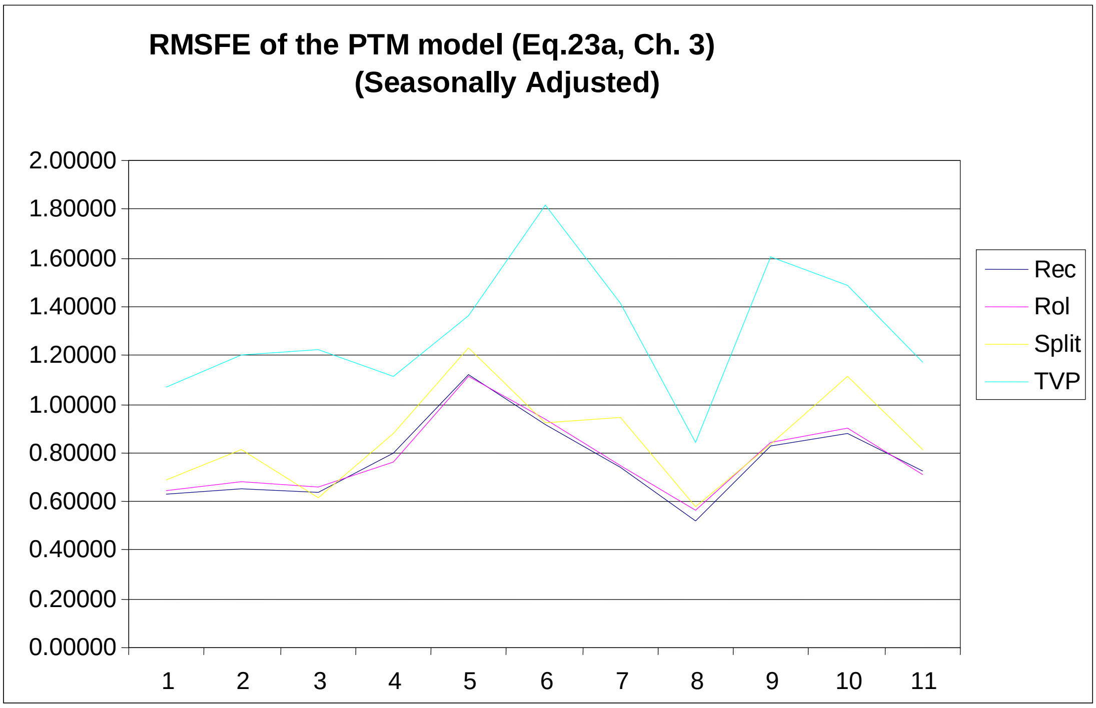
Notes: 1. This figure displays the RMSFE (Eq.26b, Ch.3) from estimating the PTM model (Eq.23a, Ch.3) using split, rolling (Rol), recursive (Rec) and RWCTVP (TVP) regressions. A low RMSFE indicates a strong predictive power of a model. 2. The sample spans the period from January 1999 to April 2010. 3. Numbers along the horizontal axis indicate the level of product disaggregation as follows: 1 - Aggregate Series (total Manufactures), 2 - Food, 3 - Chemicals, 4 - Machinery, 5 - Electric Machinery, 6 - Clothing, 7 - Textile Fabrics, 8 - Road Vehicles, 9 - Paper and Paperboard, 10 - Miscellaneous Metal Manufactures, 11 - Wood and Cork Manufactures.

Figure 14 - Estimates of the PTM Parameters for Aggregate Series (Seasonally Unadjusted)



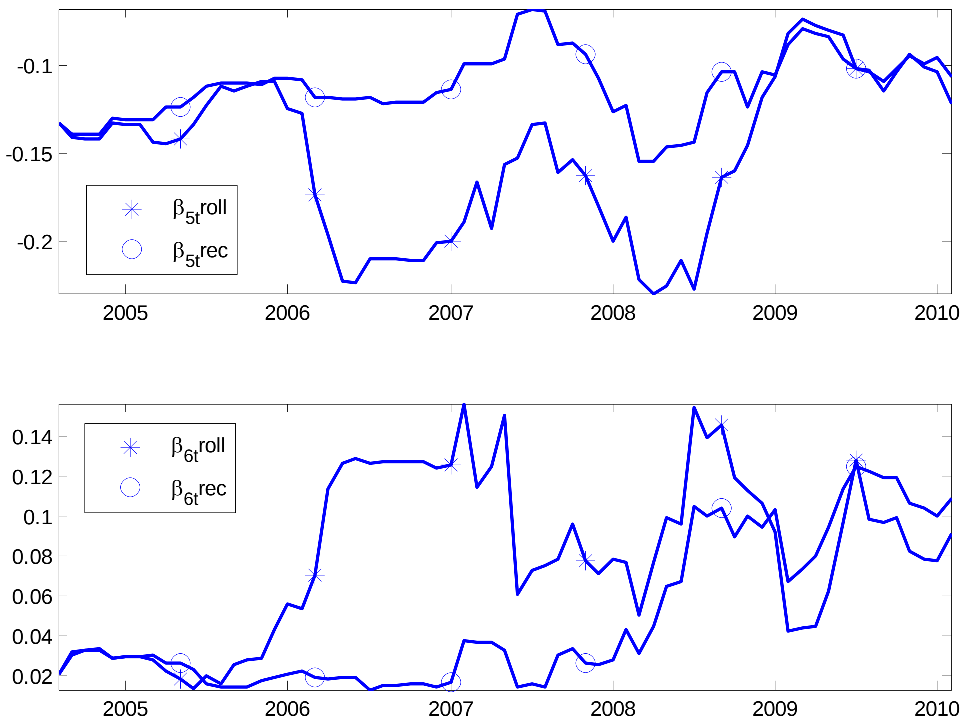
Notes: 1. This figure plots the coefficients on the past exchange rates, β_{5t} and $\beta_{6t,}$ from the PTM model (Eq.23a, Ch.3). 2. The UK data on aggregate price indices of manufactured exports to the EU spans the period from January 1999 to April 2010. 3. First, the PTM coefficients are estimated using the first half of the sample. Second, the coefficients are updated for each subsequent period through a re-estimation using rolling (roll) and recursive (rec) regressions.

Figure 15



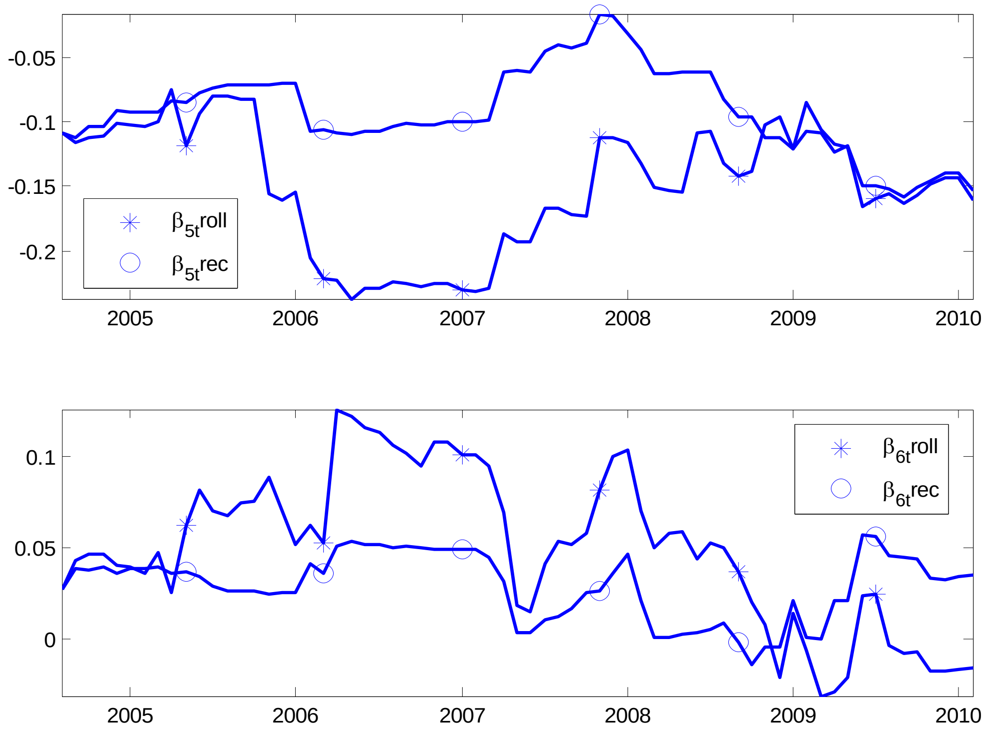
Notes: 1. This figure displays the RMSFE (Eq.26b, Ch.3) from estimating the PTM model (Eq.23a, Ch.3) using split, rolling (rol), recursive (rec) and random walk coefficient time varying parameter (TVP) regressions. A low RMSFE indicates a strong predictive power of the model. 2**.** Data on the UK export price indices has been seasonally adjusted according to the equation (30) from Chapter 3. The sample spans the period from January 1999 to April 2010. 3**.** Numbers along the horizontal axis indicate the level of product disaggregation as follows: 1 - Aggregate Series (total of Manufactures), 2 - Food, 3 - Chemicals, 4 - Machinery, 5 - Electric Machinery, 6 - Clothing, 7 - Textile Fabrics, 8 - Road Vehicles, 9 - Paper and Paperboard, 10 - Miscellaneous Metal Manufactures, 11 - Wood and Cork Manufactures.

Figure 16 - Estimates of the PTM Parameters for Food (Seasonally Unadjusted)



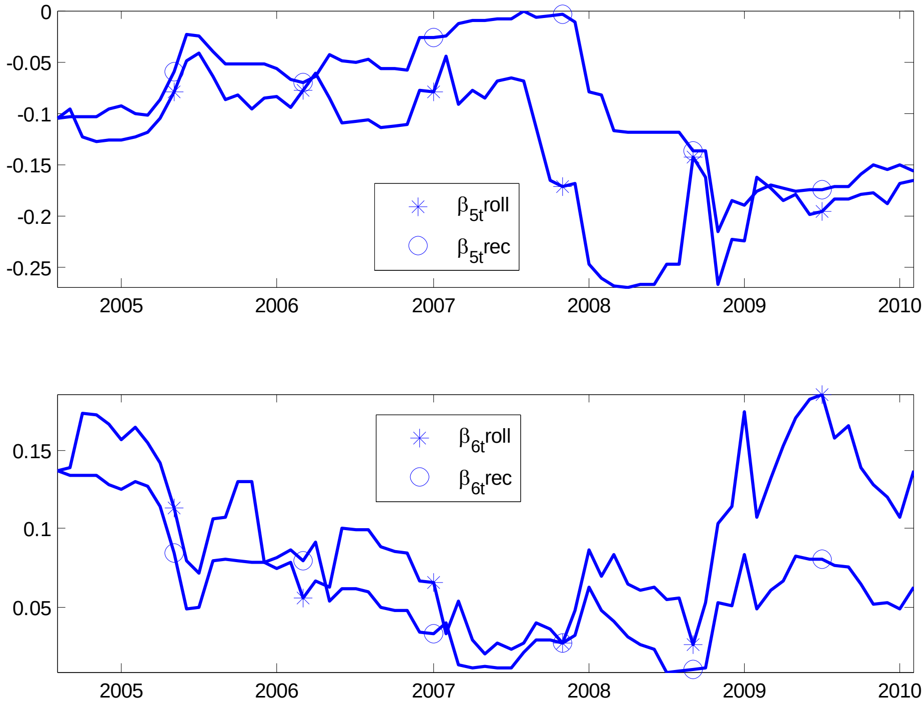
Note: see note to Figure 25.

Figure 17 - Estimates of the PTM Parameters for Chemicals (Seasonally Unadjusted)



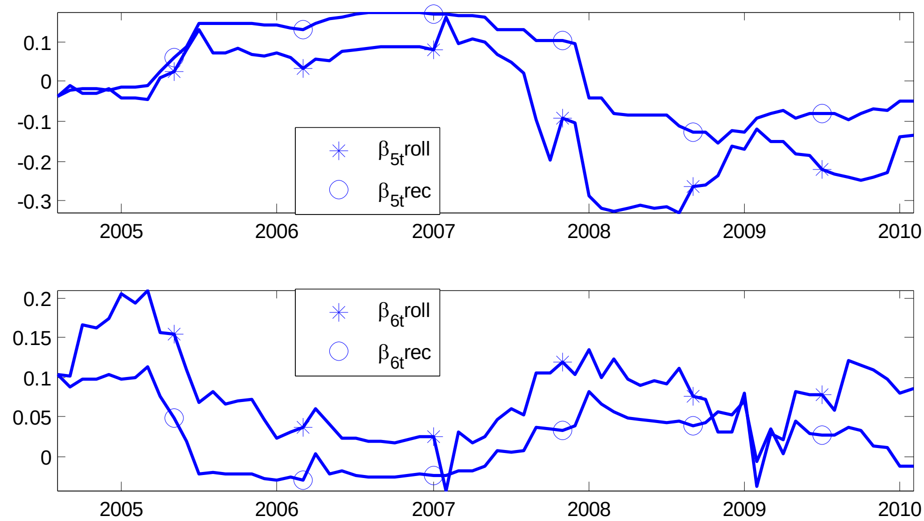
Note: see note to Figure 25.

Figure 18 - Estimates of the PTM Parameters for Machinery (Seasonally Unadjusted)



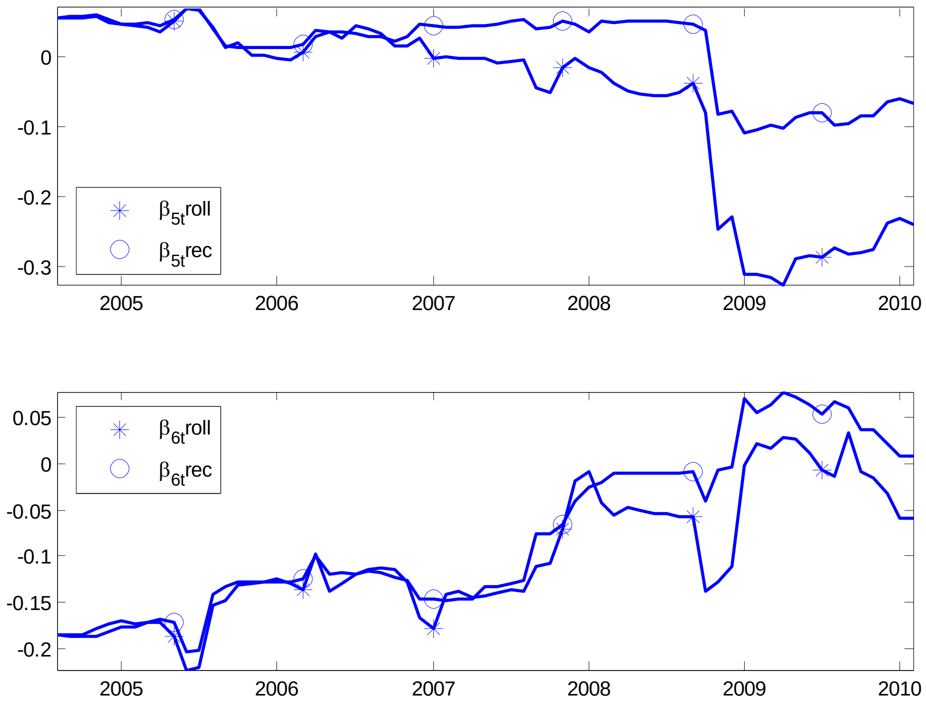
Note: see note to Figure 25.

Figure 19 - Estimates of the PTM Parameters for Electric Machinery (Seasonally Unadjusted)



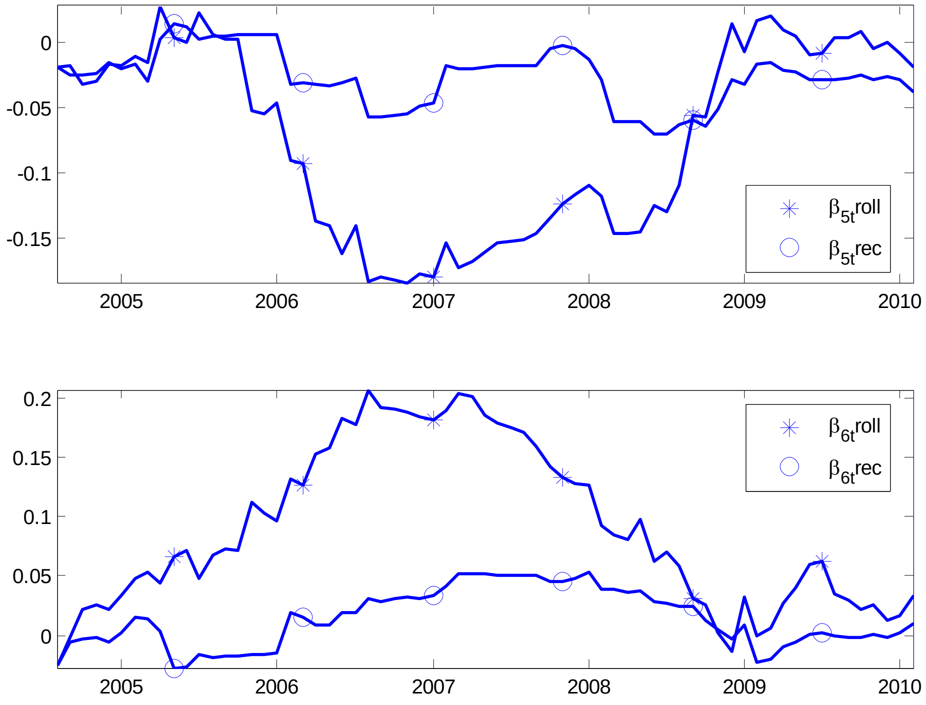
Note: see note to Figure 25.

Figure 20 - Estimates of the PTM Parameters for Clothing (Seasonally Unadjusted)



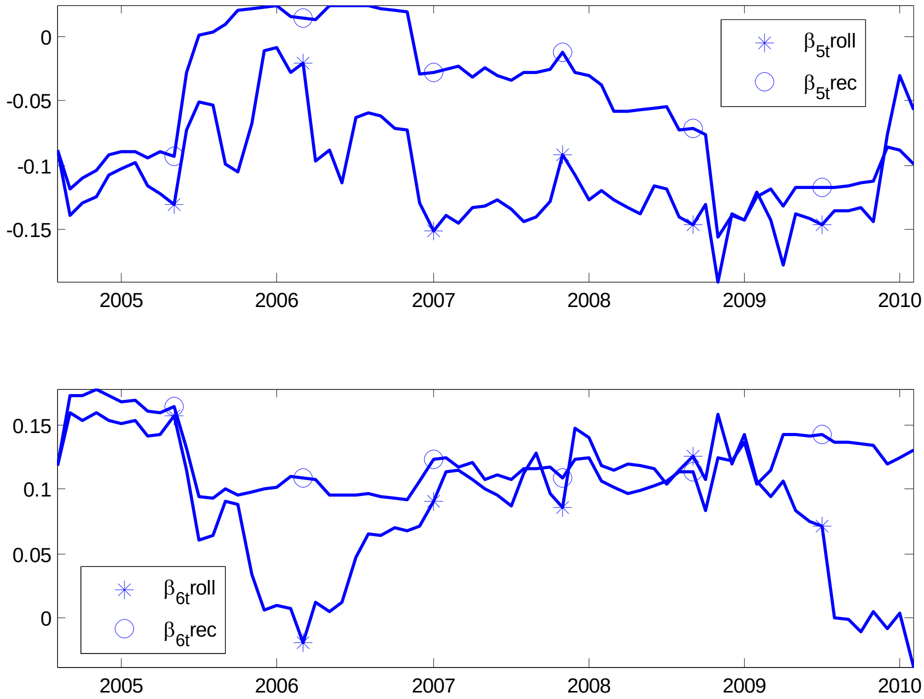
Note: see note to Figure 25.

Figure 21 - Estimates of the PTM Parameters for Road Vehicles (Seasonally Unadjusted)



Note: see note to Figure 25.

Figure 22 - Estimates of the PTM Parameters for Paper and Paperboard (Seasonally Unadjusted)

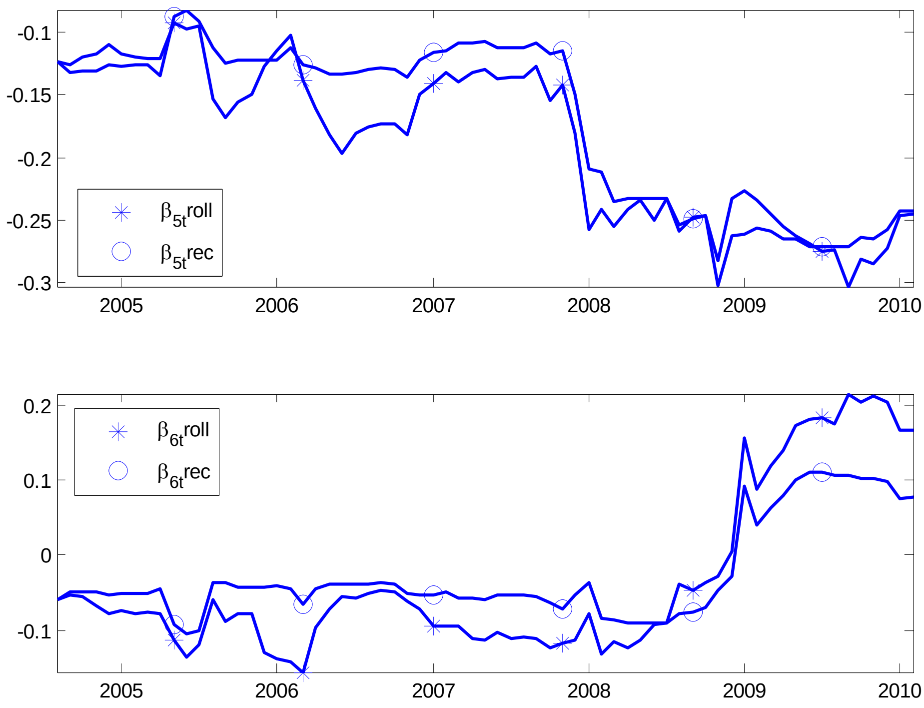


Note: see note to Figure 25.

Figure 23 - Estimates of the PTM Parameters for Miscellaneous Metal Manufactures (Seasonally Unadjusted)

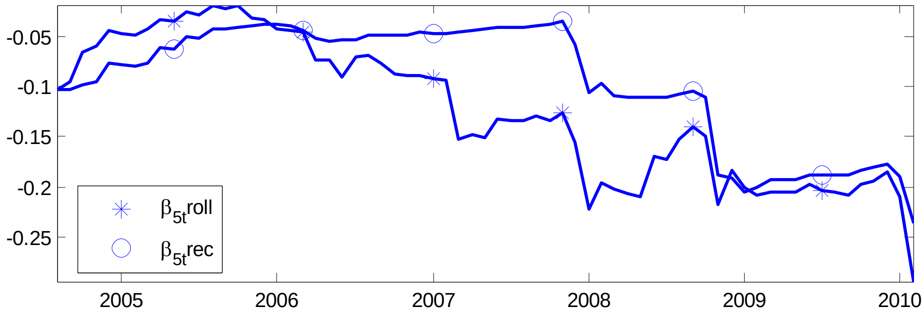
Note: see note to Figure 25.

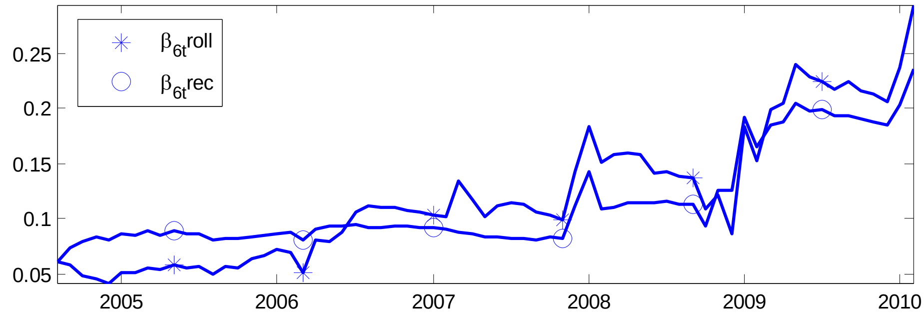
Figure 24 - Estimates of the PTM Parameters for Wood and Cork Manufactures (Seasonally Unadjusted)



Note: see note to Figure 25.

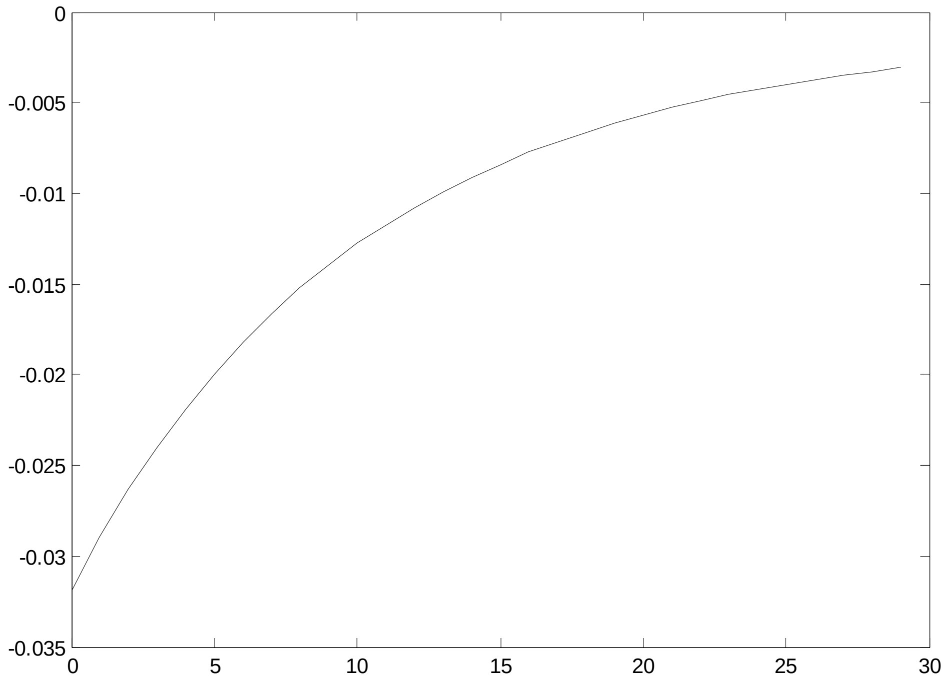
Figure 25 - Estimates of the PTM Parameters for Textile Fabrics (Seasonally Unadjusted)





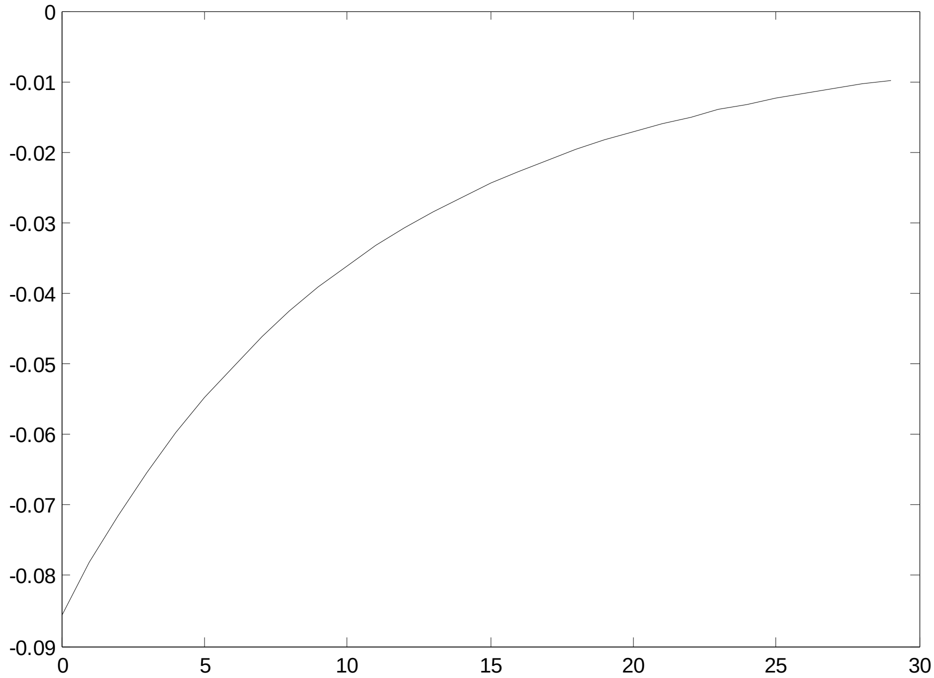
Notes: 1. Figures 16-25 plot the estimated coefficients on the past exchange rates, β_{5t} and β_{6t}, from the PTM model (Eq.23a, Ch.3). 2. Data on the UK export price indices for trade with the EU is disaggregated by product category and spans the period from January 1999 to April 2010. 3. First, the PTM parameters are estimated on the first half of the data sample. Second, the coefficients are updated for each subsequent period through a re-estimation using rolling (roll) and recursive (rec) regressions.

Figure 26 - Impulse Response of the Domestic LCP Mark-up to a Positive Shock to Domestic and Foreign Preferences



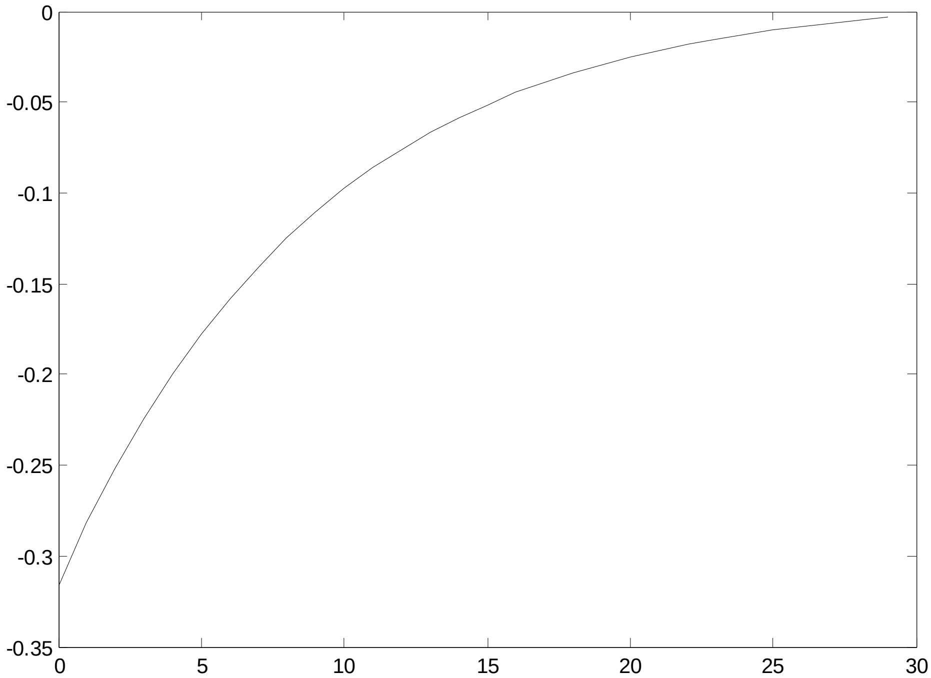
Notes: 1. Horizontal axis measures time in quarters. 2. Impulse responses represent percent deviations from steady state. 3. LCP mark-up (Eq.40, Ch.4) denotes the mark-up of price over the marginal cost under the local currency pricing. 4. Preference shock (Eq.1a, Ch.4) is modelled as a first-order autoregressive process with a persistence parameter of 0.9.

Figure 27 - Impulse Response of the Domestic PCP Mark-up to a Positive Shock to Foreign and Domestic Preferences



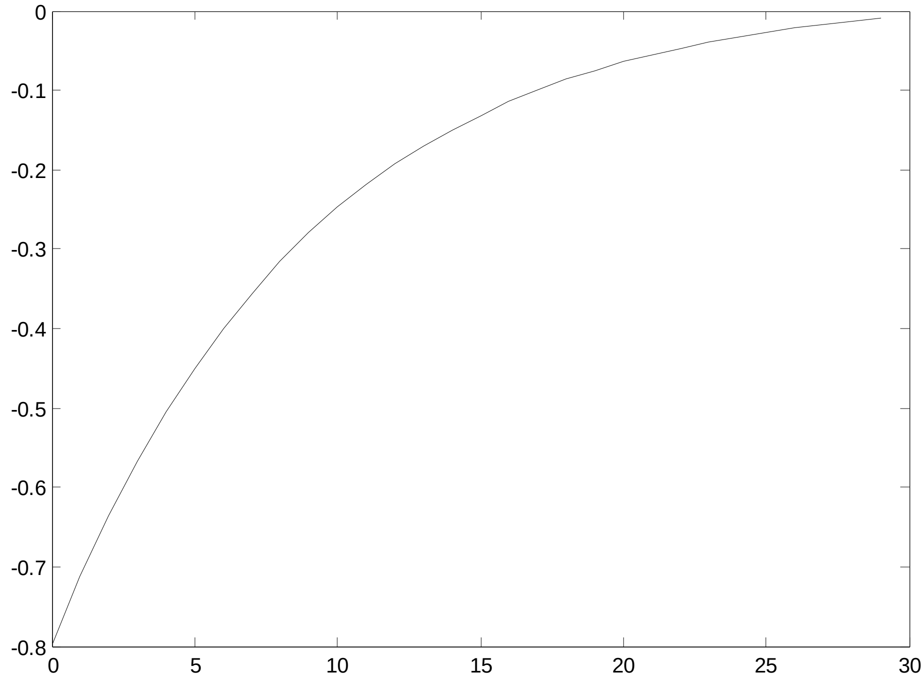
Notes: 1. Horizontal axis measures time in quarters. 2. Impulse responses represent percent deviations from steady state. 3. PCP mark-up (Eq.48, Ch.4) denotes the mark-up of price over the marginal cost under the producer currency pricing. 4. Preference shock (Eq.1a, Ch.4) is modelled as a first-order autoregressive process with a persistence parameter of 0.9.

Figure 28 - Impulse Response of the Domestic LCP Mark-up to a Positive Shock to Domestic and Foreign Technologies



Notes: 1**.** Horizontal axis measures time in quarters. 2. Impulse responses represent percent deviations from steady state. 3. LCP mark-up (Eq.40, Ch.4) denotes the mark-up of price over the marginal cost under the local currency pricing. 4. The logarithm of the technology shock, log A_t, is modelled as a first-order autoregressive process with a persistence parameter of 0.9.

Figure 29 - Impulse Response of the Domestic PCP Mark-up to a Positive Shock to Domestic and Foreign Technologies



Notes: 1. Horizontal axis measures time in quarters. 2. Impulse responses represent percent deviations from steady state. 3. PCP mark-up (Eq.48, Ch.4) denotes the mark-up of price over the marginal cost under the producer currency pricing. 4. The logarithm of the technology shock, log A_t, is modelled as a first-order autoregressive process with a persistence parameter of 0.9.

List of references

Ashley, R., Granger, C.W.J., Schmalensee, R., 1980. Advertising and Aggregate Consumption: an Analysis of Causality. Econometrica 48, 1149-1167.

Aw, B., 1993. Price Discrimination and Markups in Export Markets. Journal of Development Economics 42, 315-336.

Bacchetta, P., Wincoop, E., 2003. Why Do Consumer Prices React Less than Import Prices to Exchange Rates? Journal of the European Economic Association 1, 662-670.

Belsley, D.A., 1976. Multicollinearity: Diagnosing its Presence and Assessing the Potential Damage it Causes Least Squares Estimation. NBER Working Paper No. 154.

Benigno, P., Faia, E., 2010. Globalization, Pass-Through and Inflation Dynamic. Kiel Working Paper No. 1604.

Berthou, A., Emlinger, C., 2011. The Trade Unit Values Database. CEPII Working Paper No. 2011 – 10.

Betts, C., Devereux, M.B., 1996. The Exchange Rate in a Model of Pricing-to-Market. European Economic Review 40, 1007-1021.

Bils, M., Klenow, P.J., 2004. Some Evidence on the Importance of Sticky Prices. Journal of Political Economy 112, 947-985.

Bulow, J.I., Geanakoplos, J.D., Klemperer, P.D., 1985. Multimarket Oligopoly: Strategic Substitutes and Complements. Journal of Political Economy 93, 488-511.

Bussière, M., Peltonen, T., 2008. Exchange Rate Pass-through in the Global Economy: the Role of Emerging Market Economies. ECB Working Paper No. 951.

Byrne, J.P., Kortava, E., MacDonald, R., 2013. A New Approach to Tests of Pricing-to-Market. Journal of International Money and Finance 32, 654-667.

Campa, J.M., Goldberg, L.S., 2002. Exchange Rate Pass-through into Import Prices: a Macro or Micro Phenomenon? NBER Working Paper No. 8934.

Cavaliere, G., Phillips, P.C.B., Smeekes, S., Taylor, A.M.R., 2012. Lag Length Selection for Unit Root Tests in the Presence of Nonstationary Volatility. Cowles Foundation Discussion Paper No. 1844.

Chan, K.S., 1993. Consistency and Limiting Distribution of the Least Squares Estimator of a Threshold Autoregressive Model. The Annals of Statistics 21, 520-533.

Chari, V., Kehoe, P., McGrattan, E., 2002. Can Sticky Price Models Generate Volatile and Persistent Exchange Rates? Review of Economic Studies 69, 533-563.

Clark, T.E., McCracken, M.W., 2001. Tests of Equal Forecast Accuracy and Encompassing for Nested Models. Journal of Econometrics 105, 85-110.

Correa, A.S., Minella, A., 2006. Non-linear Mechanisms of the Exchange Rate Pass-through: a Phillips Curve Model with Threshold for Brazil. Central Bank of Brazil Working Paper No. 122.

Corsetti, G., Dedola, L., 2005. A Macroeconomic Model of International Price Discrimination. Journal of International Economics 67, 129-155.

Devereux, M.B., Engel, C., 2003. Monetary Policy in the Open Economy Revisited: Price Setting and Exchange-Rate Flexibility. Review of Economic Studies 70, 765-783.

Devereux, M.B., Yetman, J., 2002. Price-Setting and Exchange Rate Pass-Through: Theory and Evidence. HKIMR Working Paper No. 222002.

Diebold, F.X., Mariano, R.S., 1995. Comparing Predictive Accuracy. Journal of Business and Economic Statistics 13, 253-263.

Diebold, F.X., Nerlove, M., 1989. The Dynamics of Exchange Rate Volatility: A Multivariate Latent Factor Arch Model. Journal of Applied Econometrics 4, 1-21.

Eichenbaum, M., Jaimovich, N., Rebelo, S., 2011. Reference Prices, Costs, and Nominal Rigidities. American Economic Review 101, 234-262.

Engel, C., 2000. Optimal Exchange Rate Policy: The Influence of Price Setting and Asset Markets. NBER Working Paper No. 7889.

Erceg, C.J., Guerrieri, L., Gust, C., 2006. SIGMA: A New Open Economy Model for Policy Analysis. International Journal of Central Banking 2, 111-144.

Feenstra, R.C., Gagnon, J.E., Knetter, M.M., 1996. Market Share and Exchange Rate Pass-through in World Automobile Trade. Journal of International Economics 40, 187-207.

Frankel, J., Parsley, D., Wei, S-J., 2012. Slow Pass-through Around the World: A New Import for Developing Countries? Open Economies Review 23, 213-251.

Froot, K., Klemperer, P., 1989. Exchange Rate Pass-though when Market Share Matters. American Economic Review 79, 637-653.

Gagnon, J.E., Knetter, M.M., 1995. Markup Adjustment and Exchange Rate Fluctuations: Evidence from Panel Data on Automobile Exports. Journal of International Money and Finance 14, 289-310.

Gamble, J.A., LeSage, J.P., 1993. A Monte Carlo Comparison of Time Varying Parameter and Multiprocess Mixture Models in the Presence of Structural Shifts and Outliers. The Review of Economics and Statistics 75, 515-19.

Garbade, K., 1977. Two Methods for Examining the Stability of Regression Coefficients. Journal of the American Statistical Association 72, 54-63.

Gervais, J-P., Larue, B., 2009. A Joint Test of Price Discrimination, Menu Costs and Currency Invoicing. Agricultural Economics 40, 29-41.

Goldberg, P.K., Knetter, M.M., 1997. Goods Prices and Exchange Rates: What Have We Learned? Journal of Economic Literature 35, 1243-1272.

Gopinath, G., Itskhoki, O., Rigobon, R., 2010. Currency Choice and Exchange Rate Pass-Through. American Economic Review 100, 304-336.

Gross, D.M., Schmitt, N., 2000. Exchange Rate Pass-through and Dynamic Oligopoly: an Empirical Investigation. Journal of International Economics 52, 89-112.

Hamilton, J.D., 1989. A New Approach to the Economic Analysis of Nonstationary Time Series and the Business Cycle. Econometrica 57, 357-384.

Hansen, B.E., 1996. Inference when a Nuisance Parameter is not Identified under the Null Hypothesis. Econometrica 64, 413-430.

Hansen, B.E., 1999. Threshold Effects in Non-dynamic Panels: Estimation, Testing, and Inference. Journal of Econometrics 93, 345-368.

Hansen, B.E, 2000. Sample Splitting and Threshold Estimation. Econometrica 68, 575-603.

Hausman, J.A., Taylor, W.E., 1981. Panel Data and Unobservable Individual Effects. Econometrica 49, 1377-1398.

Kasa, K., 1989. Solution and Estimation of a Bivariate Interdependent Adjustment Cost Model. Economics Letters 31, 225-230.

Kenen, P.B., 2000. Fixed versus Floating Exchange Rates. Cato Journal 20, 109-113.

Klemperer, P., 1987. Markets with Consumer Switching Costs. The Quarterly Journal of Economics 102, 375-394.

Klemperer, P., 1987. The Competitiveness of Markets with Switching Costs. Rand Journal of Economics 18, 138-150.

Knetter, M.M., 1989. Price Discrimination by U.S. and German Exporters. The American Economic Review 79, 198-210.

Knetter, M.M., 1995. Pricing to Market in Response to Unobservable and Observable Shocks. International Economic Journal 9, 1-25.

Krugman, P., 1986. Pricing to Market when the Exchange Rate Changes. NBER Working Paper No. 1926.

Levy-Yeyati, E., Sturzenegger, F., 2003. To Float or to Fix: Evidence on the Impact of Exchange Rate Regimes on Growth. American Economic Review 93, 1173–1193.

Lutkepohl, H., 2005. New Introduction to Multiple Time Series Analysis. Springer, Dordrecht.

Lynch, B., Whitaker, S., 2004. The New Sterling ERI. Bank of England Quarterly Bulletin 44, 429-441.

MacDonald, R., 1995. Long-Run Exchange Rate Modelling: A Survey of the Recent Evidence. International Monetary Fund Working Paper No. 95/14.

MacDonald, R., 1996. Panel Unit Root Tests and Real Exchange Rates. Economics Letters 50, 7-11.

Mankiw, N.G., Summers, L.H., 1986. Money Demand and the Effects of Fiscal Policies. Journal of Money, Credit and Banking 18, 415-429.

Marston, R.C., 1990. Pricing to Market in Japanese Manufacturing. Journal of International Economics 29, 217-236.

McCracken, M.W., 2007. Asymptotics for Out of Sample Tests of Granger Causality. Journal of Econometrics 140, 719-752.

Nogueira, R.P., Leon-Ledesma, M., 2011. Does Exchange Rate Pass-Through Respond to Measures of Macroeconomic Instability? Journal of Applied Economics 14, 167-180.

Obstfeld, M., 2001. Beyond the Mundell-Fleming Model. NBER Working Paper No. 8369.

Obstfeld, M., 2006. Pricing-to-market, the Interest-rate Rule, and the Exchange Rate. NBER Working Paper No. 12699.

Obstfeld, M., Rogoff, K., 1995. Exchange Rate Dynamics Redux. Journal of Political Economy 103, 624-660.

Parsley, D.C., 1993. Exchange Rate Pass-through: Evidence from Aggregate Japanese Exports. Southern Economic Journal 60, 454-462.

Rangan, S., Lawrence, R.Z., 1993. The Responses of U.S. Firms to Exchange Rate Fluctuations: Piercing the Corporate Veil. Brookings Papers on Economic Activity 24, 341-379.

Ravn, M., Schmitt-Grohe, S., Uribe, M., 2006. Deep Habits. Review of Economic Studies 73, 195-218.

Ravn, M., Schmitt-Grohe, S., Uribe, M., 2008. Macroeconomics of Subsistence Points. Macroeconomic Dynamics 12, 136-147.

Rogoff, K., 1996. The Purchasing Power Parity Puzzle? Journal of Economic Literature 34, 647-68.

Rossi, B., 2006. Are Exchange Rates Really Random Walks? Some Evidence Robust to Parameter Instability. Macroeconomic Dynamics 10, 20-38.

Rotemberg, J.J., Woodford, M., 1997. An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy. NBER Macroeconomics Annual 12, 297-346.

Rowntree, R.H., 1941. Note on Constant Marginal Cost. The American Economic Review 31, 335-338.

Smets, F., Wouters, R., 2002. Openness, Imperfect Exchange Rate Pass-through and Monetary Policy. Journal of Monetary Economics 49, 947-981.

Stock, J.H., Watson, M.W., 1994. Evidence on Structural Instability in Macroeconomic Time Series Relations. NBER Technical Working Paper No. 164.

Taylor, J.B., 2000. Low Inflation, Pass-through and the Pricing Power of Firms. European Economic Review 44, 1389-1408.

Vigfusson, R.J., Sheets, N., Gagnon, J., 2007. Exchange Rate Pass-Through to Export Prices: Assessing Some Cross-Country Evidence. Board of Governors of the Federal Reserve System International Finance Discussion Paper No. 902.

Walsh, C.E., 2003. Monetary Theory and Policy. MIT Press, Cambridge, Massachusetts.

Wong, C.S, Lee, W.K., 2001. On a Logistic Mixture Autoregressive Model. Biometrika 88, 833-846.