EUROPEAN CENTRAL BANK

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# THE ROLE OF NON-LINEARITIES AND ASYMMETRIES

by Matthieu Bussière

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# THE ROLE OF NON-LINEARITIES AND ASYMMETRIES [1]

by Matthieu Bussière [2]


In 2007 all ECB publications feature a motif taken from the €20 banknote.



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**Abstract**

*A standard assumption in the empirical literature is that exchange rate pass-through is both linear and symmetric, implying that (a) large and small exchange rate changes and (b) appreciations and depreciations have an effect of the same magnitude, proportionally. This paper tests these assumptions for export and import prices in the G7 economies. It focuses on non-linearities in the reaction of profit margins to exchange rate movements, which may arise from the presence of price rigidities and switching costs. To this end, nonlinearities are characterised by augmenting a standard linear model with polynomial functions of the exchange rate and with interactive dummy variables. The presence of such non-linearities is confirmed by formal statistical tests. Overall, the results suggest that non-linearities and asymmetries in the exchange rate pass-through cannot be ignored, especially on the export side, although their magnitude varies noticeably across countries.*

**JEL:** C22, C51, F14, F31.

**Key Words:** Exchange Rate Pass-Through, Non-linear Model, Trade Prices.

## Non-technical summary

The relation between exchange rate movements and trade prices –both on the export and on the import side– is an issue of key policy relevance for at least three reasons. First, due to the effect of import price changes on domestic inflation, the degree of exchange-rate pass-through to import prices is an important parameter in the conduct of monetary policy. Second, the elasticity of export prices to exchange rate changes is a central element in the measurement of price competitiveness, which in turn affects net exports and real activity. Third, the reaction of trade prices to exchange rate changes also determines the reaction of trade quantities when the exchange rate fluctuates. An accurate measure of pass-through to trade prices is therefore a necessary step in understanding the build-up and the possible unwinding of global imbalances.

Accordingly, the issue of exchange rate pass-through represents an important field of investigation in academic research. The existing literature raises in particular the question why the degree of pass-through is not equal to one even in the long-run and what explains differences in the degree of pass-through across countries and over time. It is common to distinguish two strands of the theoretical literature, following Campa and Goldberg (2002): the first one follows an approach inspired by the industrial organization literature and analyzes the role of strategic interaction between firms (Dornbusch, 1987, Krugman, 1987), while the second one is concerned with the macroeconomic determinants of pass-through, related in particular to the inflationary and exchange rate regimes (Devereux and Engel, 2002, Taylor, 2000). These two approaches point to noticeably different explanatory factors for the degree of pass-through, which were subject to numerous empirical applications, both at the sectoral and at the aggregate level. Many of these studies originated from the central banking community (see for instance Anderton, 2003, Bailliu and Fujii, 2004, Campa and Goldberg, 2005, de Bandt et al., 2007, Gagnon and Ihrig, 2004, Hahn, 2003, Marazzi et al., 2005, or Warmedinger, 2004).[3]

This paper tackles the issue of exchange rate pass-through from a different angle and investigates the question whether exchange rate pass-through to export and import prices is (a) linear and (b) symmetric, as commonly assumed in the empirical literature. In other words, does a 2% appreciation have twice the impact of a 1% appreciation and does it have the same impact, with the opposite sign, as a depreciation of the same magnitude? The paper presents face value evidence why this may not necessarily be the case and formally tests whether non-linearities are present in the data, focusing on export and import prices in the G7 economies between 1980 and 2006. In spite of the policy and academic relevance of this issue, only a few papers have formally investigated the presence of non-linearities for import prices and none for export prices.

Several factors can generate asymmetries and non-linearities. An asymmetric pattern could be rationalized if prices are particularly rigid downwards and/or quantities are rigid upwards. Faced with a depreciation, exporters gain –ceteris paribus– price competitiveness: if they keep their prices

[3] See also the review of the literature in Section 2 and the detailed cross-study comparison of the results in Section 4.

unchanged in domestic currency, they can increase the quantity of exported goods. However, if they have reached full capacity or if adjustment costs are high, it may be difficult for them to adjust their production upwards and they could then decide to increase their prices instead. Conversely, faced with an appreciation, exporters would lose competitiveness and market shares if they keep their prices unchanged in domestic currency, which explains why exporters generally resort to "pricing-to-market" in an effort to partly offset the loss in competitiveness that results from an appreciation. However, if the appreciation is very large, exporters may find it increasingly difficult to lower their prices since it implies falling profit margins (beyond a certain point, lowering export prices would imply a negative mark-up). Downward price rigidities imply a lower response of export prices following an appreciation than following a depreciation, which in turn implies, for the countries on the other side of the transaction, that exchange rate pass-through is higher during depreciations than during appreciations. In such cases, export and import prices are a *convex* function of exchange rate changes, but one could also think of a *concave* function. A concave function could be rationalized in the presence of switching costs (if the elasticity of substitution between domestic and foreign goods is low for small exchange rate changes). The sign of the non-linearities is therefore not immediate: it can vary depending on the underlying microeconomic structures and needs to be formally tested.

Instead of testing for only one particular kind of non-linearity or asymmetry, the approach chosen here is as encompassing as possible and consists in systematically testing for a broad range of non-linearities. It does so by adding to a standard linear model polynomial functions of the exchange rate as well as interactive dummy variables that capture threshold effects, and by using formal non-linearity tests (Teräsvirta, 1998). The estimation is done country by country for all G7 economies, using quarterly data for export and for import prices.

The results indicate, first, that the linear version of the model yields pass-through estimates that are very much in line with the existing literature on the subject. This specification successfully passes different robustness tests, regarding in particular the use of other estimators and the possible omission of additional variables, while it also outperforms alternative specifications. Second, non-linearities/asymmetries cannot be rejected for most countries in the sample, especially on the export side, as evidenced by the enhanced model (augmenting a standard linear model with polynomial terms and interactive dummy variables) and by the non-linearity tests. The sign of the non-linearities varies noticeably across countries; for instance, the reaction of export prices to an appreciation is estimated to be convex for Italy and concave for Japan. Such convexities are related to specific microeconomic assumptions and explained, country by country.

Finally, several caveats need to be underlined before policy conclusions are derived from the present exercise: estimates of non-linearities rely on relatively few observations, given that they concern by definition extreme events. It is an open question whether such extreme events will repeat themselves in the future in a comparable way. As a consequence, non-linear results should be interpreted with caution for policy purposes.

# 1. Introduction

The aim of this paper is to investigate the question whether exchange rate pass-through to export and import prices is (a) linear and (b) symmetric, as commonly assumed in the empirical literature. In other words, does a 2% appreciation have twice the impact of a 1% appreciation and does it have the same impact, with the opposite sign, as a depreciation of the same magnitude?

The motivation for conducting this exercise stems from several episodes in recent years. For instance, the experience of euro area export and import prices since the creation of the euro provides an illustration of what seems to constitute an asymmetric pattern.[4] Since its creation in 1999, the euro experienced a depreciation followed by an appreciation of roughly the same magnitude. More precisely, between the end of 1998 to the last quarter of 2001, the euro depreciated by nearly 20% in nominal effective terms; afterwards, beginning in the second quarter of 2002, the euro started to appreciate again, and regained about 20% of its value by the end of 2004. However, neither export nor import prices reacted symmetrically to these two broadly similar exchange rate changes: during the initial depreciation, export and import prices of goods increased by around 12% and 20%, respectively; by contrast, during the subsequent appreciation, they decreased by only 4% and 5%, respectively. This simple example would suggest that appreciations and depreciations do not have the same effect – although a careful econometric analysis is of course required before one can draw any firm conclusions.[5] This paper therefore aims to test for the presence of non-linearities and asymmetries for all G7 economies, focusing on export and import prices. To reach this goal, it proceeds by adding to a standard model non-linear terms, such as polynomial functions of the exchange rate and interactive dummy variables for "large" and "small" appreciations and depreciations. Formal non-linearity tests (Teräsvirta, 1998) also confirm the presence of non-linearities.

For policy purposes, it is important to fully understand the determinants of trade prices for at least three reasons. First, due to the effect of import price changes on domestic inflation, the degree of exchange rate pass-through is of key importance for the conduct of monetary policy. Second, the elasticity of export prices to exchange rate changes is a central element in the measurement of price competitiveness, which in turn affects net exports and real activity. Third, the reaction of trade prices to the exchange rate also determines the reaction of trade quantities to the exchange rate. An accurate measure of pass-through to trade prices is therefore a necessary step in understanding global imbalances, in particular how the trade balance reacts to a change in the exchange rate. For instance, Mann (1986) attributes the lack of response of the US trade balance deficit to the depreciation of the dollar that took place in the mid-1980s to low pass-through. More recently, the depreciation of the

[4] The euro area is considered as a single entity: exports and imports refer to extra-euro area trade only. Euro area prices are here proxied by unit value indices of goods and import prices refer to manufacturing goods.

[5] This simple discussion in particular omits other factors that also play a role, such as domestic costs and oil prices, and ignores the lagged effect of past exchange rate changes. The aim of the empirical analysis is to derive estimates that take these factors into account. As testing for non-linearities requires relatively long time series (in order to have enough appreciations and depreciations episodes), the paper considers G7 economies, for which the data series are much longer than extra-euro area series.

dollar that started in 2002 did not map into a significant reduction of US imports, perhaps due to a small effect on US import prices. In turn, the weakness of the effect on import prices could be explained by the pricing behavior of foreign exporters to the US, who lowered their export prices in foreign currency terms in an effort to offset the impact of the dollar depreciation. Looking forward however, if non-linearities are strong, exporters may find it more difficult to lower their export prices when exchange rate changes are large, implying higher pass-through to US import prices than in situations when exchange rate changes are small.

In spite of its strong policy relevance, the issue of non-linearities in the degree of pass-through and pricing-to-market has received little attention so far: only a handful of papers have tested for non-linearities in this context, and those that did so focused on import prices, and for one country only (e.g. US import prices for Pollard and Coughlin, 2004, or UK import prices for Herzberg et al., 2003). There is however some value added in considering both export and import prices and in broadening the set of countries. Indeed, given that foreign export prices are also domestic import prices (once converted with the exchange rate), there is a strong connection between import and export prices. For example, the hypothesis that foreign exporters lower prices (in their currency) by a smaller amount when the exchange rate appreciates than they increase them when the exchange rate depreciates would also imply that domestic import prices (in domestic currency terms) react more to a depreciation than to an appreciation. Looking both at export and import prices, as done in this paper, therefore provides two complementary views of the issue at stake.[6]

Several factors can generate asymmetries and non-linearities. An asymmetric pattern could be rationalized if prices are particularly rigid downwards and quantities are rigid upwards. To borrow words from the title of Peltzman (2000), it seems that generally "prices rise faster than they fall" and so the same may be true for trade prices. Faced with a depreciation, exporters gain –ceteris paribus– price competitiveness: if they keep their prices unchanged in domestic currency, they can increase the quantity of exported goods. However, if they have reached full capacity or if adjustment costs are high, it may be difficult for them to adjust their production upwards, leading them to increase their prices instead.[7] Conversely, faced with an appreciation, exporters would lose competitiveness and market shares if they keep their prices unchanged in domestic currency, which explains why exporters generally resort to "pricing-to-market" in an effort to partly offset the loss in competitiveness that results from an appreciation. However, if the appreciation is very large, exporters may find it increasingly difficult to lower their prices since it implies falling profit margins (beyond a certain point, lowering export prices would imply a negative mark-up). Downward price rigidities imply a lower response of export prices following an appreciation than following a depreciation, which in turn

[6] As the existing literature has mostly focused on import prices, it tends to explain pass-through mostly with domestic factors (on the side of the importing country). Also considering export prices, as done in the present paper, highlights the complementary role of economic conditions in the exporting country.

[7] Another consideration is the uncertainty factor, as a given exchange rate movement may reverse in the future. However, as it is in practice very difficult to measure expectations, this issue is not tackled here.

implies, for the countries on the other side of the transaction, that exchange rate pass-through is higher during depreciations than during appreciations.

Testing for non-linearities involves somewhat more work than just estimating a linear model as there may be more than one non-linear functional form. For instance, in the above example, depreciations seemed to have a stronger effect than appreciations. However, in a study focusing on Japanese manufacturing export prices, Marston (1990) found the opposite results for some sectors following the 1985 yen appreciation.[8] Concerning non-linearities, export prices (and import prices) were a *convex* function of exchange rate changes in the introductory example, but one could also think of a *concave* function. A concave function could be rationalized in the presence of switching costs (if the elasticity of substitution between domestic and foreign goods is low for small exchange rate changes). Instead of testing for only one particular kind of non-linearity or asymmetry, the approach chosen here is as encompassing as possible and consists in systematically testing for a broad range of non-linearities and asymmetries.

Of course, the example of euro area prices during one depreciation and one appreciation episode is not enough to establish evidence of non-linearities. The paper therefore investigates this issue empirically using time series for the G7 economies, which extend further back in time than for the euro area aggregate. The model is estimated with quarterly data between 1980 and 2006. The present paper is –to the best of my knowledge– the only paper that simultaneously estimates export and import price equations while looking at the issue of non-linearities and asymmetries. The data used in the paper correspond to national account export and import prices from the OECD and considers total trade of goods and services. Although the same exercise could be repeated in future research with unit value indices broken down by industry, the aim of the present exercise is to introduce various methods to test for non-linearities and asymmetries, which can be used with other datasets.

The results indicate, first, that the linear version of the model yields pass-through estimates that are very much in line with the existing literature on the subject. This specification successfully passes different robustness tests, regarding in particular the use of other estimators and the possible omission of additional variables. Second, non-linearities/asymmetries cannot be rejected for most countries in the sample, especially on the export side, as evidenced by the enhanced model (augmenting a standard linear model with polynomial terms and interactive dummy variables) and by the non-linearity tests (Teräsvirta, 1998). Interestingly, the direction of the non-linearities varies from one country to another. Such convexities are related to specific microeconomic assumptions and explained, country by country. Finally, several caveats need to be underlined before policy conclusions are derived from the present exercise: estimates of non-linearities rely on relatively few observations, given that they concern by definition extreme events. It is also an open question whether such extreme events will

[8] In a study focusing on pass-through in emerging markets (using a linear model), Frankel, Parsley and Wei (2005) also test for non-linearities. They conjecture a given direction for threshold effects (that large devaluations have a smaller effect than small devaluations) but find that "the threshold effect, while significant, goes the wrong way". The present paper provides a possible explanation for this apparently puzzling result.

repeat themselves in the future in a comparable way. As a consequence, non-linear results should be interpreted with caution for policy purposes.

Section 2 reviews the existing literature and presents the benchmark linear case. Section 3 presents the different forms of non-linearities that can be tested and relates them to specific microeconomic assumptions. Section 4 presents the empirical framework and discusses the results, including several robustness tests of the benchmark model. Finally, Section 5 concludes.

## 2. Review of the literature and benchmark case

This section first presents existing theoretical models of exchange rate pass-through and reviews selected empirical applications, focusing on the few studies that tackled the issue of non-linearities or asymmetries. Let us consider two countries, Home (the importing country) and Foreign (the exporting country), and define the following variables in Home's domestic currency (prices in foreign currency are denoted with a * sign): import prices, MP, export prices, XP*, the nominal exchange rate, ER (defined in foreign currency per unit of domestic currency, which implies that an increase represents an appreciation for Home), and finally Home and Foreign domestic prices, P and P*, respectively.

One can notice already at this stage that a simple identity relates two of the above variables. By definition (abstracting from tariffs and transportation costs):

$$MP = XP^{*} / ER \tag{1}$$

Or, taking logs and first differences:

$$\Delta\, MP = \Delta\, XP^{*} - \Delta\, ER \tag{2}$$

The existing literature models exchange rate pass-through by considering how the exporter changes export prices when the exchange rate changes. Specifically, export prices are set up as a mark-up over marginal costs. In a two country framework where Foreign is exporting to Home, the mark-up of Foreign's exporters can vary due the following elements: (a) a change in the bilateral nominal exchange rate between Home and Foreign, (b) a change in domestic prices, P, in Home, (c) a change in domestic prices, P*, in Foreign or (d) a change in domestic demand in Home. The first two elements (a) and (b) affect relative prices: an appreciation of Foreign's currency or a fall in Home's domestic prices both rise the price of Foreign's goods relative to Home's substitutes. If Foreign's exporters keep their mark-up unchanged, they may lose market share in Home (by how much depends on the price elasticity of Foreign's exports in the Home market). The third element (c) represents a rise in marginal costs for the exporter. The role of the fourth element (d) is generally found to be small, or even negligible compared to the other two elements;[9] one possible explanation is that changes in demand are reflected in prices. The theoretical reasons why exporters may change their mark-up are analyzed in section 2.1.

[9] See the results presented in Section 4.

## 2.1 Theoretical underpinnings

The literature on exchange rate pass-through is closely related to the literature on Purchasing Power Parity (PPP): if PPP held for tradable goods, pass-through would be complete. One can then draw a parallel between the failure of PPP to hold and the general finding that pass-through is incomplete (see Goldberg and Knetter, 1996, for a survey). Clearly, in a perfect competition framework with frictionless markets, pass-through would be complete because the mark-up would always be equal to zero for the exporters. Theoretical models have therefore been developed to explain why pass-through is not complete (Krugman, 1987). The key mechanism behind this result is strategic interaction between firms in an imperfect competition framework. When the exchange rate depreciates, the demand curve becomes more elastic and foreign competitors lower their price in foreign currency terms, implying that import prices increase by less than the magnitude of the exchange rate fall. In Dornbusch (1987)'s model, domestic and foreign firms engage in a Cournot type competition, which yields as equilibrium import prices a weighted average of the marginal costs of domestic and foreign firms (times the exchange rate). Froot and Klemperer (1989) introduce a dynamic model in which market shares today have an impact on profits tomorrow. During an appreciation, firms therefore face a trade-off between decreasing their profit margins now and leaving them unchanged, the latter coming at the cost of lower market shares (and therefore lower profits) tomorrow.

The degree of exchange rate pass-through can depend on several factors which can be classified into two groups (microeconomic and macroeconomic factors), following Campa and Goldberg (2002).[10] The first category of factors relates to the industrial structure of the economy. For example, in the Dornbusch (1987) paper, pass-through depends on product substitutability, market structure and the number of foreign firms respective to local firms. In the Marston (1990) model, the degree of pass-through to export prices depends on the convexity of the demand curve in the export market and changes in marginal costs resulting from changes in the output level in the exporting country. The second category of factors highlights the macroeconomic environment and in particular the role of monetary policy. One can mention in particular the contributions of Betts and Devereux (1996, 2000), who introduced pricing to market to the earlier model of Obstfeld and Rogoff (1995). The key concepts in this literature are those of local currency pricing and producer currency pricing (LCP and PCP, respectively), which refer to the case where exporters preset their prices in the currency of the importing country or in their own currency, respectively. Bacchetta and van Wincoop (2005) present a model where the invoicing choice of exporting firms depends on the market share in the importing country and on the extent to which products of domestic firms are substitutes for those of competing foreign firms. Meanwhile, the perceived decline, in the 1990s, of pass-through in industrial countries motivated a line of research that attempted to explain this phenomenon. Taylor (2000) relates the decline in pass-through to a tightening and enhanced credibility of monetary policy. Additional contributions further exploring the relation between pass-through and the inflation environment

[10] This classification is especially useful for expositional reasons. The overall objective here is not to test what factors determine pass-through elasticities but rather to test whether these elasticities themselves depend on the exchange rate.

include Choudhri and Hakura (2001), Devereux and Yetman (2002), and Devereux, Engel and Storegaard (2004). This hypothesis was empirically tested in several studies, see in particular Gagnon and Ihrig (2004) and Bailliu and Fujii (2004) and the literature therein. By contrast, Campa and Goldberg (2002, 2005) find that the decline in pass-through is better understood as a "micro" than a "macro" phenomenon: the change in the commodity composition of imports (away from goods characterised by a high pass-through) explains most of the decline in pass-through.

## 2.2 Empirical literature, linear models

The empirical literature on exchange rate pass-through often tackles two objectives. The first objective is to estimate pass-through elasticities and can constitute an end in itself. The second objective is to investigate what are the determinants of these pass-through elasticities, in which case the analysis is often split in two steps: the first step estimates elasticities across countries or across sectors, while in the second step the elasticities derived in the first step are regressed on a set of explanatory variables.

Several issues generally arise in the empirical estimation and make it necessary to depart from the theoretical model. First, the time series on trade prices, domestic prices or the exchange rate are non-stationary, which explains why the model is generally estimated in first differences. Second, many of the variables are not directly observable and need to be proxied. This is clearly the case of the marginal costs, which are often proxied by producer prices or unit labour costs. Third, although most models are static, it is unlikely that prices completely adjust within one period (especially at quarterly frequency), calling for the use of a dynamic model. Fourth, some key variables need to be added to account for idiosyncratic factors not included in the theoretical models such as dummy variables for specific political events. Given that the theoretical models do not supply a reduced form equation that can be directly tested, researchers had to find their own ways to model exchange-rate pass-through. In doing this, they opted for rather heterogeneous estimation techniques. The rest of this section turns to selected prominent papers in order to present the most common estimation techniques.

Yang (1997) presents a model where the degree of exchange rate pass-through depends on the degree of product differentiation and on the elasticity of marginal cost to output. Compared to the Dornbusch (1987) model, this model assumes in particular that marginal costs are variable rather than constant. The model is taken to the data focusing on U.S. import prices. Two sets of equations are estimated. In the first stage, exchange rate pass-through elasticities are estimated for 87 industries using the following equation for each industry k:

$$\Delta \ln(MP_t^k) = \delta_1^k \Delta \ln(MP_{t-1}^k) + \delta_2^k \Delta \ln(ER_t) + \delta_3^k \Delta \ln(P_t^k) + \varepsilon_t^k \tag{3}$$

The change in import prices is therefore regressed on its lag, on the nominal effective exchange rate and on domestic prices. In the second stage, the pass-through elasticities found in the first stage are regressed on variables that proxy product differentiation, the elasticity of marginal cost and the ratio of total imports to total supply in the economy.

Knetter (1993) is interested in cross-country differences in the degree of pricing-to-market. He focuses on export price equations where exports are broken down into 7-digit industries; prices are proxied by unit value indices. The sample covers the period 1973-1987 for the US and Japan, 1974-1987 for the UK and 1975-1987 for Germany. He estimates the following equation for each destination i:

$$\Delta \ln\left(XP_i^t\right) = \theta_t + \beta_i \Delta \ln\left(X_i^t\right) + \varepsilon_i^t \tag{4}$$

with XP for export prices and X the destination specific exchange rate (in fact, the destination specific market price level converted into domestic currency). This specification therefore excludes demand factors such as the output gap or foreign demand in the destination market. Supply factors, in particular marginal costs are captured by the time dummies, the aim of the study being not to estimate the effect of domestic prices on export prices but to measure the extent of pricing-to-market: changes in marginal costs are assumed to be common across destination markets and are captured by the time dummies.

Bailliu and Fujii (2004) show evidence that exchange rate pass-through to domestic prices (import, producer and consumer prices) has declined over time and that this decline resulted from a transition to a low-inflation environment, itself induced by a shift in monetary policy. To this aim, they estimate for a panel of 11 industrialized countries i the following equation with annual data in first log differences:

$$\begin{aligned} \Delta P_i^t &= \alpha_i + \delta_t + \sum_{j=1}^{2} \phi_j \Delta P_{i,t-j} + \lambda\, \Delta ER_{i,t} + \lambda_{reg\_80}\left(\Delta ER_{i,t} * REG80_{i,t}\right) \\ &+ \lambda_{reg\_90}\left(\Delta ER_{i,t} * REG90_{i,t}\right) + \tau\, \Delta\, ulc\_row_{i,t} + \delta\, gap_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{5}$$

The above equation is estimated with a generalized method of moments for three different dependent variables: import prices, producer prices and consumer prices. Prices are therefore regressed on their lags, on country and time dummy variables ($\alpha_i$ and $\delta_t$), on the nominal effective exchange rate, on the exchange rate interacted with two policy dummy variables indicating shifts in the inflation environment in the 1980s and 1990s, respectively, on the change in foreign producer costs ulc_row and on the output gap. The variable ulc_row is constructed from the real effective exchange rate deflated by unit labor costs (subtracting the domestic unit labor costs and the nominal exchange rate). The results indicate that the decline in pass-through over time was brought about by the inflation stabilization episodes that took place in the 1990s, but not in the 1980s.

Gagnon and Ihrig (2004) investigate the link between monetary policy and exchange rate pass-through. They develop a theoretical model relating the fall in the degree of pass-through to increased emphasis on inflation stabilization by the central banks. Using quarterly data covering the period 1971-2003, they estimate for 20 industrialized countries the following equation in first log differences:

$$\begin{aligned} \Delta \ln(P_t) &= \delta_0 + \delta_1 \Delta \ln(P_{t-1}) + \delta_2 \Delta\left(\ln(P_t^*) - \ln(ER_t)\right) + \delta_3 \Delta\left(\ln(P_{t-1}^*) - \ln(ER_{t-1})\right) \\ &+ \delta_4 \Delta\left(\ln(P_{t-2}^*) - \ln(ER_{t-2})\right) \end{aligned} \tag{6}$$

This equation therefore relates CPI inflation to its lag and three lags of competitor's prices in domestic currency. This equation is then estimated on two subsamples, disentangling for each country two sub-periods corresponding to high- and low-inflation. Results indicate that pass-through is higher in the high inflation period. Finally, they regress, across countries, the degree of pass-through on the mean and on the standard deviation of the inflation rate (in two separate regressions to avoid multi-colinearity problems) Results all point to a substantial link between pass-through and inflation.

Finally, some papers have estimated VAR models to account for potential exogeneity problems, see in particular, McCarthy (2000), Hahn (2003) and Shambaugh (2006). The latter aims at identifying the effect of different shocks and concludes that "the measure of the import price pass-through ratio does not vary substantially across shocks" (whereas pass-through to domestic prices does). First differenced VAR models applied to exchange-rate pass-through are however not without caveat, as noted for instance by Bache (2007). One important consideration is the possibility that some of the variables in the system cointegrate with each other. This issue is addressed in de Bandt et al. (2007), who estimate an error correction model. It seems however that the question whether the variables cointegrate is very dataset-specific: Campa and Goldberg (2005) report that their variables do not cointegrate, and the tests presented in Table A1 in the present paper also point to the same result (see discussion in Section 4). This non-exhaustive review of the literature has shown the heterogeneity in existing empirical applications. Let us now turn to the (thinner) literature on non-linearities.

## 2.3 Empirical literature, non-linear and/or asymmetric models

The empirical literature that considered the possibility of either non-linear or asymmetric responses is to date relatively scarce, although some papers actually indicate that this constitutes an important extension to look for.[11] Pollard and Coughlin (2004) analyze exchange rate pass-through to U.S. import prices for 30 industries and test whether the direction and the size of exchange rate changes affect pass-through. They test such effects using interactive dummy variables; starting from the following (linear) specification:

$$\Delta \ln(MP_t^i) = \beta_1^i \,\Delta \ln(ER_t^i) + \beta_2^i \,\Delta \ln(P_t^i) + \beta_3^i \,\Delta \ln(P_t^{*i}) + \beta_4^i \,\Delta \ln(DD_t^i) + quarterly\, dummies \qquad (7)$$

where DD refers to domestic demand and P and P* refer to the domestic and foreign marginal costs, respectively, proxied by domestic and foreign PPI. All variables, including the exchange rate, are sector specific. Next, they create two sets of dummy variables that they introduce to the above equation:

$$A_t = \begin{cases} 1 \; if \;\; \Delta \ln(ER_t^i) > 0 \\ 0 \; otherwise \end{cases}, \quad D_t = \begin{cases} 1 \; if \;\; \Delta \ln(ER_t^i) < 0 \\ 0 \; otherwise \end{cases} \qquad (8)$$

[11] See for instance Frankel, Parsley and Wei (2005), p. 16-17. The authors are interested in pass-through to emerging markets and use panel data estimation. They find strong evidence in favour of asymmetries, reporting that they "cannot reject the hypothesis that appreciation is not passed through at all, suggesting downward price rigidity". They also test for non-linearities. Interestingly they conclude that "the threshold effect, while significant, goes the wrong way" (they indeed expected that large devaluations have a smaller proportionate effect on prices). Section 3.1 reviews the factors that may explain this result.

$$L_t = \begin{cases} 1 \; if \; |\Delta \ln(ER_t^i)| > 3\% \\ 0 \; otherwise \end{cases}, \quad S_t = \begin{cases} 1 \; if \; |\Delta \ln(ER_t^i)| < 3\% \\ 0 \; otherwise \end{cases}$$

replacing $\beta_1\Delta\ln(ER^i_t)$ first by $\beta_{1A}A^i_t\Delta\ln(ER^i_t)+\beta_{1D}D^i_t\Delta\ln(ER^i_t)$ and second by $\beta_{1L}L^i_t\Delta\ln(ER^i_t)+\beta_{1S}S^i_t\Delta\ln(ER^i_t)$. Their results indicate that more than half of the industries respond asymmetrically to appreciations and depreciations, although the direction of the asymmetry varies by industry. In addition, they find substantial non-linearities, the magnitude of the import price response being positively associated with the size of the exchange rate shock. Overall, they also conclude that the size effect is more important than the direction effect. More recently, Yang (2007) is interested in the possible asymmetry in pass-through to US import prices, at a disaggregated level. Specifically, he introduces to the specification of Yang (1997) an interactive dummy variable equal to 1 after March 1985 (when the dollar reached a peak) and zero otherwise. The results vary depending on the level of disaggregation: the interacted dummy variable is not significant in all but one sector at the two-digit level, it is significant in a few more sectors with a finer breakdown. Overall, the author concludes that "a few industries (…) did show increasing exchange rate pass-through as the dollar depreciated, while a few other industries demonstrated decreasing exchange rate pass-through as the dollar depreciated", confirming that the direction of the asymmetry is not obvious ex ante and needs to be tested. However, he also concludes that "there is some evidence that the exchange rate pass-through for US import price for all commodities increased when the dollar depreciated during the latter part of the 1980s, but the evidence is not robust.". By contrast, Swamy and Thurman (1994), who also test for asymmetries in the elasticity of US import prices using a so-called Swamy-Tinsley time varying estimator covering the period 1972Q4 to 1988Q2, conclude that depreciations are characterised by higher pass-through. Turning to Japan, Marston (1990) tests for asymmetries (but not for non-linearities) in the elasticity of Japanese export prices for 17 products, with a sample of monthly data between 1980 and 1987 (a relatively short time span including only one appreciation episode). He uses interactive dummy variables and finds that appreciations have a larger effect for five sectors.

Not all studies looking at this issue have detected significant non-linearities or asymmetries. Focusing on the UK, Herzberg, Kapetanios and Price (2003) test for but reject non-linearities.[12] In a study on pass-through to import prices of manufactured goods in Japan, Wickremasinghe and Silvapulle (2004) find an estimated pass-through coefficient of 98% for appreciations and 83% for depreciations, based on the methodology of Enders and Granger (1998). Finally, the literature on non-linearities can also be related to studies testing for non-linearities in the Purchasing Power Parity relation. Although there is no space here for a detailed review of this literature, one can refer in particular to Imbs et al. (2003), Sarno et al. (2004), Schnatz (2006) and Nikolaou (2006) for recent applications.

To conclude, although some papers have considered non-linearities of one particular kind (and for one given country), the present study is the only one that systematically tests for different types of non-

[12] Specifically, they use three different tests: a threshold model, a spline model that allows for asymmetry but no threshold, and a quadratic-logistic STAR model. They conclude that the model is linear (this is also the conclusion I reach for UK import prices).

linearities across a broad set of systemically important economies. It is also the only one doing it for *both* export and import prices.

# 3. Different types of non-linearities and how they relate to microeconomic assumptions on the pricing behaviour of exporting firms

## 3.1 Microeconomic assumptions

A convenient way to represent linear models is to consider that foreign competitors try to offset a fraction $\alpha$ ($0 \leq \alpha \leq 1$) of exchange rate movements in foreign currency terms. Using first (log) differences:

$$\Delta XP^* = - \alpha \Delta ER^* \tag{9}$$

In that case, using (2) and remembering that $\Delta ER = - \Delta ER^*$, the impact of exchange rate changes on import prices is simply:

$$\Delta MP = - (1 - \alpha) \Delta ER \tag{10}$$

Under the assumption that $0 \leq \alpha \leq 1$, an appreciation (an increase in ER) therefore results in a less than proportional fall in MP. Figure 1 shows the reaction function of (Foreign) export prices (in Foreign currency) in Panel A and the reaction of (Domestic) import prices (in Domestic currency). The dotted line in Panel B represents the 45 degree line (full pass-through). It is clear that if $\alpha$ is the reaction of export prices to exchange rate changes, $(1 - \alpha)$ is the degree of pass-through to import prices. The coefficient $\alpha$ can be read in panel A as the angle between the horizontal line and the XP* (red) line; it can also be read in panel B as the angle between the 45 degree line and the MP (blue) line. If exporters keep their price unchanged in their domestic currency ($\alpha = 0$), the red line in Panel A coincides with the horizontal line while the blue line in Panel B coincides with the 45 degree line (there is full pass-through to import prices). If, on the other hand, foreign exporters always fully offset exchange rate changes by adjusting their export prices ($\alpha = 1$), the red line in Panel A coincides with the 45 degree line, whereas the blue line in Panel B coincides with the horizontal axis (full pricing-to-market).

None of the two cases described above is realistic in practice. Instead, one might expect (and empirical results generally indicate) that pass-through is somewhere between 0 and 1 (strictly). However, the assumption that exchange-rate pass-through is linear and symmetric is also not realistic. A number of microeconomic assumptions would justify a non-linear relationship between the exchange rate and trade prices. The rest of this section reviews these various assumptions and their implication for the concavity of the curves relating the exchange-rate and trade prices.

<u>Assumption 1:</u> export prices are rigid downwards. According to a growing body of the empirical literature, prices are rigid in the short-run, particularly on the downside. To borrow the title from Peltzman (2000), “prices rise faster than they fall”. This implies that when the exchange rate

depreciates, exporters increase their export prices by a larger extent than they decrease them when the exchange rate appreciates (in other words, they may be more prone to increase their mark-up than to decrease it). Another implication is that depreciations also have a larger effect than appreciations on import prices. This can be seen formally in Section 3.2 using as example a quadratic function. The intuition is that a depreciation for Home is an appreciation for Foreign. Downward price rigidity for foreign exporters means that they can offset a smaller extent of the exchange rate appreciation, implying more pass-through for Home. Assumption 1 rationalises the result of Frankel et al. (2005) discussed in Section 2.3. A large devaluation for the importing country indeed represents a large appreciation for the exporting countries. According to Assumption 1, foreign exporters will not be able to offset as much of this large appreciation as in the case of a smaller appreciation, implying larger pass-through in the importing country.

Assumption 2: export quantities are rigid upwards. When exporting firms are already at full capacity, it is reasonable to assume that export prices will react more during a depreciation than during an appreciation: faced with a depreciation, exporters would need to increase production capacities if they decide to keep their export prices constant in their currency (implying lower prices in importer's currency). Yet, opening new plants or hiring new workers may take time. In the short-run, exporters may therefore be tempted to increase their mark-up instead of using the gain in price competitiveness to increase market share. While the first and second assumptions have a clear implication concerning the asymmetric effect of exchange rate changes, they also have implications for possible non-linearities and threshold effects. In particular, it seems clear that a large depreciation may lead exporters to build up capacities and increase quantities instead of prices (with a moderate depreciation, the investment cost required to build new capacities may be higher than the extra profit). In any case, assumption 1 and 2 have the same implication for what regards asymmetries: depreciations should have a larger effect than appreciations on export and on import prices.

Assumption 3: the market share concerned exporting firm. The degree of pricing-to-market (and, therefore, the degree of pass-through) is often related to competitiveness. However, the relation between pricing-to-market and competitiveness depends on the direction of the exchange rate. Indeed, an exporting firm that shows a high elasticity of export prices to exchange rate changes is more competitive than a firm with a low elasticity when the exchange rate appreciates (in that case, the former loses price competitiveness to a lesser extent than the latter). However, faced with a depreciation, it is the opposite: the firm with high elasticity does not gain as much price competitiveness than the firm with low elasticity. A firm that decides to gain competitiveness will therefore adjust its export prices more during appreciations than during depreciations, as conjectured by Marston (1990, p. 232). This pricing behavior could also arise if a gain in market share today implies higher profits tomorrow. In turn, for the importing country, this means that depreciations have a lower effect (on import prices) than appreciations. Assumption 3 therefore implies a very different type of asymmetry than assumption 1 and 2.

Assumption 4: menu costs and switching costs. The presence of menu costs or switching costs are both common microeconomic assumptions. With menu costs, exporters may leave their price unchanged if exchange rate changes are small, and change their prices only when the exchange rate change is above a given threshold. With switching costs, exporters can keep their prices unchanged in their currency as long as the price of their goods in local currency does not vary beyond a given limit (consumers will switch to a different brand only if the import price change is above the cost of switching to a different product). Assumption 4 implies a non-linear, but symmetric effect on export and import prices.

Assumption 5: a decline in exchange rate pass-through over time. It is often asserted that exchange pass-through has declined in developed countries in the past two decades (see for instance Taylor, 2000). If a decline in pass-through did happen on the import price side, it is interesting to cross-check this with estimation on the export side and test whether the elasticity of export prices to exchange rate changes has increased over time. Evidence suggests a fall in the average long-run pass-through coefficient for import prices over time (it averaged to 63% in the 1980s, against 53% for the whole sample, see Section 4). There is however no corresponding increase in the elasticity of export prices, which remained broadly constant around 25%. This implies that other countries, not included in the sample, have seen a rise in the elasticity of export prices over time. Alternatively, the share – in total imports from the G7 countries – of countries with a high export prices elasticity may have risen over time. It is however difficult to combine a test of this last assumption with the issue of non-linearities: indeed, testing for non-linearities implies to go sufficiently far in time to be able to rely on enough appreciation and depreciation episodes. It is observationally very difficult to distinguish between the hypothesis that the data generating process has changed over time and the hypothesis that the same – complex– data generating process is actually revealed over time.

## 3.2 Different functional forms

This section presents various functional forms that depart from the linear case. Instead of being linear for positive and negative values of the change in the exchange rate, the curve relating the change in the exchange rate and the change in trade prices can be either linear with a different slope for positive and negative values, or convex/concave for positive or negative values. Polynomial functions are a convenient way to capture these different cases. The rest of this section reviews how these various functional forms can be related to the micro-assumptions described in the previous section.

**Quadratic case.** Exporters try to offset a fraction of exchange rate movements, but –unlike in equation (1)– this fraction varies with the magnitude of the exchange rate changes:

$$\Delta\, XP^{*} = -\,(\alpha - \beta\, \Delta\, ER^{*})\, \Delta\, ER^{*} \qquad (11)$$

In that case, the impact of exchange rate changes on import prices can be derived as in (10):

$$\Delta\, MP = -\,(1 - \alpha)\, \Delta\, ER + \beta\, (\Delta\, ER)^{2} \qquad (12)$$

The quadratic case is presented in Figure 2a and 2b, with respectively $\beta > 0$ and $\beta < 0$. The case $\beta > 0$ defines a convex reaction function: for a larger exchange rate appreciation, the reaction of export prices decreases (e.g., because prices are rigid downwards, consistent with Assumption 1 in Section 3.1), while for a large depreciation, the reaction of export prices increases upwards (e.g., because of capacity constraints, exporters prefer to increase export prices rather than quantities, consistent with Assumption 2 in Section 3.1). The case $\beta < 0$ defines a concave function: as the exchange rate appreciates, the exporters lower they prices by a larger amount (e.g., because firms are afraid to lose market shares, consistent with Assumption 3 in Section 3.1).

**Cubic case.** The quadratic functional forms are both non-linear and asymmetric. Another interesting functional form arises with a cubic function, which is non-linear but symmetric (Figure 3a and 3b). It is a mixed case: the sign of the convexity varies for positive and negative values.

$$\Delta\, XP^* = - (\alpha - \beta\, (\Delta\, ER^*)^2)\, \Delta\, ER^* \tag{13}$$

$$\Delta\, MP = - (1 - \alpha)\, \Delta\, ER + \beta\, (\Delta\, ER)^3 \tag{14}$$

The two different cases $\beta < 0$ and $\beta > 0$ account for the presence of menu costs on the exporter and on the importer side, respectively (consistent with Assumption 4 in Section 3.1). When $\beta < 0$ (Figure 3a), exporters do not change much export prices in their currency for small exchange rate changes, they let exchange rate changes "pass through" to import prices (menu costs are on the exporter side). When $\beta>0$, by contrast, they offset small exchange rate movements by adjusting their export prices, attenuating the effect of exchange rate changes on import prices (menu costs are on the importer side).

In practice, in order to estimate the degree of convexity/concavity of the response to exchange rate changes, one needs to separate the appreciations and the depreciations episodes. Indeed, there is no reason why the same convexity should prevail on both sides of the vertical axis in Figure 1-3. This can be done by creating quadratic functions of the exchange rate on positive values only, and on negative values only.[13] When testing for such variables, one also needs to include simple dummy variables for appreciations and depreciations in order to allow for different intercepts.

**Interactive terms.** The last functional form considered introduces an interactive term which itself is a (logistic) function of the deviation of the exchange rate level from its long-term value (c). However, for a reasonable range of parameters, this function is hard to distinguish from other, more simple functional forms (see Figure 4). In addition, the selection of parameter c is unclear (the assumptions explained in Section 3.1 relate to the change in the exchange rate, not the level).

$$\Delta\, XP^* = - (\alpha - \beta\, \gamma_t\, )\, \Delta\, ER^* \tag{15}$$

$$\Delta\, MP = - (1 - \alpha)\, \Delta\, ER - \beta\, (\gamma_t\, \Delta\, ER) \tag{16}$$

$$\text{With } \gamma_t = \frac{1}{1+e^{\gamma(ER_t - c)}} - \frac{1}{2} \tag{16'}$$

[13] The cubic and quadratic polynomial functions can be tested against each other for the broad range of exchange rate changes (i.e. including both ap- and depreciations), but not if one looks at ap- and depreciations separately.

**Thresholds.** The above example features a smooth transition from low to high pass-through (polynomial functions are continuous). An alternative is to use thresholds. The key question in this case is how to determine the value of this threshold[14]. In the absence of a clear theoretical guideline, I empirically defined the value of this threshold as being equal to one standard deviation of the (first differenced) exchange rate, quarter on quarter. This allows to make it vary across countries and accounts for the fact that exchange rate changes may be more volatile is some countries than others. Separating exchange rate changes into appreciations and depreciations gives roughly a 50% split across all countries over the sample, the share of appreciations ranging from 42% (Italy) to 56% (Germany). The threshold for "high" exchange rate changes selects around 30% of the episodes, with however marked differences between Japan (24%) and the US (36%). Future research may more thoroughly do a grid search in order to select the appropriate threshold.

Finally, one may note the difficulty in precisely measuring non-linearities, which by definition depend on a small number of observations. This is illustrated in Figure 5, which plots hypothetical linear and non-linear elasticities and their corresponding confidence intervals. The two confidence intervals coincide until point A: for all points situated left of point A, the two models are not significantly different from each other. If most observations are located in this range, the linear model is a good approximation of the "true" elasticity. The relevance of the non-linear model therefore crucially depends on the share of observations beyond point A.

## 4. Empirical Results

**Data and specification**

The following models were estimated in log differences, country by country, with quarterly data. For export prices:

$$\Delta XP_t = \alpha_0 + \alpha_1 \Delta XP_{t-1} + \alpha_2 \Delta ER_t + \alpha_3 \Delta PPI_t + (\text{other controls}) + \beta(\text{non-linear terms}) + \varepsilon_{X,t} \quad (17)$$

and for import prices:

$$\Delta MP_t = \alpha'_0 + \alpha'_1 \Delta MP_{t-1} + \alpha'_2 \Delta ER_t + \alpha'_3 \Delta PPI_t + (\text{other controls}) + \beta'(\text{non-linear terms}) + \varepsilon_{M,t} \quad (18)$$

These models are therefore simple dynamic linear models augmented with non-linear terms. As the full model encompasses a linear and a non-linear part, one specification can be tested against the other. The linear version of the model relates the change in the logs of export and import prices (for equation (17) and (18), respectively) to two key explanatory variables: foreign prices converted in national currency terms (ER) and the producer price index (PPI). Both equations are dynamic: they include the lagged dependent variable, in order to account for lagged effects of the explanatory variables, similar to Yang (1997). In the dynamic specifications (17) and (18), the immediate effect of the exchange rate is given by the coefficient $\alpha_2$ and $\alpha'_2$, whereas the long-run effect is given by $\alpha_2/(1- \alpha_1)$ and $\alpha'_2/(1- \alpha'_1)$,

[14] Pollard and Coughlin (2004) choose a common threshold for all sectors, equal to 3%.

respectively. Other models (e.g. Marazzi et al., 2005) do not include the lagged dependent variable but include more lags of the explanatory variables instead.[15]

The fact that foreign prices and the nominal effective exchange rate have the same coefficient follows from the underlying theoretical framework (see Hooper and Mann, 1989 or Barhoumi, 2006 for a discussion). Barhoumi (2006) considers the following equation for import prices of the importing country: $MP_t = (1\text{-}\alpha)\ E_t + (1\text{-}\alpha)\ c^*_t + \alpha\ PPI_t + \beta\ Y_t$ where $E_t$ is the nominal exchange rate, $c^*_t$ foreign prices and $Y_t$ domestic demand (all variables are in logs). Given that export and import prices are related by a simple identity ($MP_t = E_t + XP_t$), the corresponding equation for export prices (of the exporting country) is therefore: $XP_t = -\alpha\ E_t + (1\text{-}\alpha)\ c^*_t + \alpha\ PPI_t + \beta\ Y_t$. Remembering that $E_t =- E^*_t$ and that for the exporting country, $c^*_t$ corresponds to *domestic* prices and $PPI_t$ to *foreign* prices, it follows that for export prices, too, the nominal exchange rate and foreign prices should have the same coefficient. This calls for using competitor's prices converted into domestic currency (variable ER). This model also suggests that one should use a measure of demand in the import and in the export price equations. However, in practice, demand terms often appear to be insignificant.[16]

The quarterly series for trade prices come from the OECD Economic Outlook for total exports and imports of goods and services (codes PXGS and PMGS). Producer price indices come from the OECD MEI (code PPI). Competitors prices converted in domestic currency (ER) are obtained by dividing the real effective exchange rate by PPI, as standard in the literature (see for instance Gagnon and Ihrig, 2004). All variables are seasonally adjusted and in first differences. Stationarity tests clearly reject the presence of a unit root in the first differences of the dependent and independent variables for these countries, while the series do not appear to cointegrate (see results in Table A1 in the Table Appendix).[17] The set of "other controls" includes quarterly dummy variables, oil prices, and, for Germany, a dummy variable for the 1991 unification. Oil prices entered the export price equation significantly only for Canada and the UK, whereas their coefficient was significant for all seven countries in the import price equation. Oil prices were defined here in dollar terms, in order to avoid multicollinearity issues with the ER variable. The set of additional controls could be extended to variables that directly capture the effect of shift in demand, such as the output gap, GDP, or domestic demand. However, this effect is most likely going to be reflected in changes in domestic prices (if one follows the argument that higher domestic demand, for instance, would tend to raise domestic and import prices). In fact, the robustness tests presented below show that the coefficients of these additional variables are insignificant for nearly all countries.

[15] I also estimated a specification with up to three lags for ER and PPI (and no lagged dependent variables); the results for the long-run effect of the exchange rate were very similar. In some cases the goodness-of-fit, measured by the adjusted $R^2$, fell slightly. The highest fall was registered for US export prices (from 70% to 64%), due to the large coefficient of lagged export prices in the US model.

[16] The presence of the demand term is formally tested –and rejected– below, using three different variables as proxy. A likely explanation is that the effect of demand is already captured by the other variables.

[17] Campa and Goldberg (2005) also note (p. 682, footnote 11) that the series in level are nonstationary and that they do not cointegrate with each other.

**Results from the linear specification**

Before turning to the non-linear results, I consider the results of the linear model, i.e. when the non-linear terms are not included in (17) and (18), and compare this with results from the existing literature. Table 1 reports the short- and long-run effect of exchange rate changes on export and import prices, as well as the goodness-of-fit of the model. These estimates can be compared with existing results for G7 countries by Marazzi et al. (2005, henceforth MSV), by Ihrig et al. (2006, henceforth IMR), by Campa and Goldberg (2005, henceforth CG) and by Warmedinger (2004, henceforth TW).[18]

Overall, the results from the linear specification are consistent with the literature. Estimates of the long-run elasticity of export prices to exchange rate changes appear to be rather low for Germany (8%) and the US (16%), very much in line with MSV (3% and 12%, respectively). Results are also similar for the UK (27% against 33%), while they are somewhat smaller for Japan (34% against 47%) and for Canada (19% against 36%). The discrepancy observed for Japan seems to be partly related to the fact that the lagged dependent variable for Japan is negative (whereas it is positive for all other countries), such that the long-run effect is smaller –in absolute value– than the short-run effect (39%).

For Italy and especially France, the elasticity of export prices is found to be substantially higher than for Germany, at 28% and 39%, respectively. One potential explanation can be related to the fact that Germany exports a higher share of capital and intermediate goods than France and Italy, given that the demand elasticity of these goods is generally admitted to be lower than that of consumer goods. Finally, goodness-of-fit appears to be rather high, with all $R^2$ statistics being above 50%, while the residuals pass most standard tests. In particular, the residuals are found to be stationary and to have low serial correlation.

**Table 1: Exchange Rate Elasticity of Export and Import Prices for the G7 Economies, Linear Specification.**

| | Canada | Germany | France | Italy | Japan | UK | US |
|---|---|---|---|---|---|---|---|
| **Exports** | | | | | | | |
| Short-run | -0.17 | -0.08 | -0.32 | -0.24 | -0.39 | -0.23 | -0.08 |
| Long-run | -0.19 | -0.08 | -0.39 | -0.28 | -0.34 | -0.27 | -0.16 |
| $R^2$ | 0.64 | 0.87 | 0.75 | 0.55 | 0.76 | 0.50 | 0.70 |
| **Imports** | | | | | | | |
| Short-run | -0.45 | -0.33 | -0.52 | -0.56 | -0.58 | -0.39 | -0.23 |
| Long-run | -0.49 | -0.36 | -0.76 | -0.72 | -0.63 | -0.48 | -0.29 |
| $R^2$ | 0.75 | 0.77 | 0.78 | 0.65 | 0.70 | 0.69 | 0.80 |

*Note: the full results are presented in the Table Appendix (Table A2, panel a and b) and correspond to equations (17) and (18), respectively, where the non-linear terms are excluded. The estimation period corresponds to 1980Q1-2006Q4, except Italy (starting 1981Q2). Negative coefficients indicate that an appreciation implies a fall in export and import prices (as expected).*

[18] One caveat for this comparison is of course that the sample periods do not always coincide perfectly.

On the import side, the average elasticity to exchange rate changes appears to be larger (around 55% for the G7 countries) than for export prices (around 25%).[19] In line with the predictions of the Dornbusch (1987) model, pass-through is found to be lower for the larger countries:[20] 29% for the US, and 36% for Germany. For the US, the pass-through coefficient presented here is close to IMR (32%) and somewhat lower than CG (42%). For Germany by contrast, the estimate presented in Table 1 is between IMR (around 30%) and TW (48%). For Canada, the present estimate (49%) is below CG (65%) and much below IMR (89%); for Japan it is the opposite, the present estimate (63%) being closer to IMR (61%) than that of CG (113%), which appears to be unrealistically high[21]. For the UK all three studies provide estimates in the same ballpark of around 50% to 60%. For France the present estimate is found to be relatively high, at nearly 76%, largely driven by the sharp depreciation of the early 1980s. Although CG find an even higher estimate (98%), this contrasts with TW (73%) and especially IMR (16%). Finally, for Italy, the present estimate (slightly below 72%) is somewhat higher than in the other studies (around 50% for TW and IMR, 35% for CG).

**Robustness tests**

Five types of robustness tests are conducted. First, as the present specification is taken from the reduced form of a theoretical model, it is useful to test whether the parameters fulfill the restrictions imposed in the model. In particular, price homogeneity cannot be rejected for most countries, which is another indication that the model is very satisfying (see full results of the Wald tests in the addendum to Table A2a and to Table A2b in the Table Appendix). The fact that price homogeneity is rejected for Japan is due to the 1985-1986 appreciation episode (between the third quarter of 1985 and the third quarter of 1986, the yen appreciated by 35%): once this episode is dummied out, the homogeneity restriction is accepted.

Second, one may question the proxies used in the benchmark specification. In particular, as argued in Section 2, the literature is undecided about which variable should be used as a proxy for domestic prices, some papers using producer price indices and others unit labor costs (ULC). To test whether ULC would give different results, the same specification is estimated with ULC replacing PPI (Table A3a).[22] The results indicate that ULC does not work as well as PPI, the coefficient of the variable being noticeably lower than PPI (implying a failure of the price homogeneity restriction) and not significantly different from zero on the import side in all cases except Canada. Third, a possible question is whether the results are sensitive to the type of estimator used in the benchmark specification, concerning in particular the exogeneity of domestic prices. However, the use of an instrumental variable estimator (Table A3b) shows that the results are by and large similar. The

[19] In theory the two elasticities should sum up to 100% if there were no other countries. The results are broadly consistent with Goldberg and Tille (2006), who find that invoicing in domestic currency is more prevalent on the export than on the import side. The low elasticity estimated here for US export and import prices could be related to the overwhelming use of the dollar as invoicing currency (with the caveat that invoicing and pricing do not always coincide).
[20] Interestingly, Feenstra, Gagnon and Knetter (1996) find a nonlinear relation between market share and pass-through: "pass-through rises with market shares at an increasing rate as share becomes large" (p. 189).
[21] However, Wickremasinghe and Silvapulle (2004) also find estimates in the ballpark of 90% for Japanese import prices.
[22] Data are missing for Italy for this series.

correlation between the long-run elasticities obtained with the benchmark model and the IV estimator is above 90% both for export and import prices.

Fourth, the choice of the specification – which does not include a separate variable for demand – can also be tested, by adding to the benchmark case a variable capturing domestic demand. Three proxies have been tested here: a measure of the output gap, the growth rate of domestic demand and the growth rate of real GDP (see results in Table A4-a, b, and c, respectively).[23] The output gap is insignificant for all countries, domestic demand is significant only for France and the growth rate of real GDP only for the UK, but in both cases it does not affect the other coefficients significantly.[24]

Finally, a recurrent question in the literature is whether the degree of pass-through has changed over time (Taylor, 2000). As noted in Section 3.1, it is difficult to test this hypothesis in combination with the issue of non-linearities, which requires pooling together a high number of episodes. Suggestive evidence (Table A5a and A5b) based on the estimation of the benchmark model over a subperiod (restricted to the 1980s) shows that for most countries the elasticity of export prices has remained broadly similar since the 1980s, except for Italy. On the import price side, the decline is more pronounced, especially for Germany, France and Japan.

Overall, the results are therefore in the ballpark of previous empirical work published on the subject and successfully pass several robustness tests. This standard linear model can therefore constitute an appropriate framework in which to test for non-linearities.

**Results from the non-linear specification**

The next step introduces into the above specification additional terms that capture non-linearities and asymmetries. These terms are added rather than substituted in order to really test for the significance of the non-linearities; they include the polynomial functions defined in Section 3.2 as well as dummy variables interacted with the exchange rate. Specifically, equation (17) and (18) take the following form for quadratic terms. For export prices:

$$\Delta XP_t = \alpha_0 + \alpha_1 \Delta XP_{t-1} + \alpha_2 \Delta ER_t + \alpha_3 \Delta PPI_t + (\text{other controls}) + \beta_2 D^{ap} (\Delta ER_t)^2 + \beta_3 D^{ap} + \varepsilon_{X,t} \qquad (19)$$

Where $D^{ap}$ is a dummy variable equal to 1 for appreciations, 0 otherwise. Similarly, for import prices:

$$\Delta MP_t = \alpha'_0 + \alpha'_1 \Delta MP_{t-1} + \alpha'_2 \Delta ER_t + \alpha'_3 \Delta PPI_t + (\text{other controls}) + \beta'_2 D^{ap} (\Delta ER_t)^2 + \beta'_3 D^{ap} + \varepsilon_{M,t} \quad (20)$$

In this case, the coefficients of interest are $\beta_2$ and $\beta'_2$. The same equations are also estimated with a dummy variable for depreciations, $D^{dep}$. The use of two separate regressions with $D^{ap}$ and $D^{dep}$ is preferable to just adding the (non-interacted) polynomial term, which would impose the same slope for

[23] All three variables are taken from the OECD with codes GAP, FDDV and GDPV, respectively.

[24] The demand terms were here added in the import price equation, as in Bailliu and Fujii (2004). When they are added in the export price equation, as suggested by Hooper and Mann (1989), the results were similar (i.e., their coefficient is insignificant in most cases, and even when it is, it does not affect the other coefficients).

the non-linearities on positive and negative values of the exchange rate.[25] Finally, I also estimated similar threshold models as in Coughlin and Pollard (2004), in which case (17) and (18) become:

$$\Delta XP_t = \alpha_0 + \alpha_1 \Delta XP_{t-1} + \alpha_2 \Delta ER_t + \alpha_3 \Delta PPI_t + (\text{other controls}) + \beta_2\, D\, \Delta ER_t + \beta_3\, D + \varepsilon_{X,t} \quad (21)$$

$$\Delta MP_t = \alpha'_0 + \alpha'_1 \Delta MP_{t-1} + \alpha'_2 \Delta ER_t + \alpha'_3 \Delta PPI_t + (\text{other controls}) + \beta'_2\, D\, \Delta ER_t + \beta'_3\, D + \varepsilon_{M,t} \quad (22)$$

The dummy variable D is chosen in the set $\{D^{highap}, D^{lowap}, D^{highdep}, D^{lowep}\}$, corresponding to high appreciations, low appreciations, high depreciations and low depreciations, respectively (the choice of the threshold is explained in Section 3.2). The results are summarized in Table 2 and the full results are presented the Table Appendix. Using both threshold dummy variables and polynomial functions allows to compare and complement the different approaches.

**Table 2: Summary Results for the Non-Linear Specification.**

| | Canada | Germany | France | Italy | Japan | UK | US |
|---|---|---|---|---|---|---|---|
| **Exports** | | | | | | | |
| 1. Linear impact | -0.17 | -0.08 | -0.32 | -0.24 | -0.39 | -0.23 | -0.08 |
| 2. Quadratic ($D^{ap}$) | | | | >0 | <0 | | <0 |
| 3. Quadratic ($D^{dep}$) | | | >0 | | | | <0 |
| 4. High appreciation | | | | 0.72 | -0.31 | | -0.39 |
| 5. Low appreciation | | | | | 0.23 | | |
| 6. High depreciation | | | | -0.31 | | 0.21 | 0.19 |
| 7. Low depreciation | | 0.15 | | | | | |
| 8. F-test | 0.02 | 0.00 | 0.74 | 0.09 | 0.02 | 0.25 | 0.03 |
| **Imports** | | | | | | | |
| 1. Linear impact | -0.45 | -0.33 | -0.52 | -0.56 | -0.58 | -0.39 | -0.23 |
| 2. Quadratic ($D^{ap}$) | | | | | | | |
| 3. Quadratic ($D^{dep}$) | | | | | | | |
| 4. High appreciation | | 0.75 | | | -0.59 | | |
| 5. Low appreciation | | | 2.10 | | | | |
| 6. High depreciation | | | -0.41 | | | | |
| 7. Low depreciation | | | | | | | |
| 8. F-test | 0.35 | 0.03 | 0.16 | 0.19 | 0.67 | 0.22 | 0.81 |

*Note: The estimation results in row 1 correspond to the coefficient of ER in equation (17) and (18). Rows 2 and 3 report the coefficient of interest ($\beta_2$ for export prices and $\beta'_2$ for import prices) in equation (19) and (20); rows 4-7 correspond to equation (21) and (22). The full results are presented in Table 3 for the specifications in rows 2 and 3, and in the Table Appendix for the results in rows 4-7 (Table A6, panel a-d). Only significant coefficients are reported in Table 2; a positive coefficient for the dummy variables (rows 4-7) indicates a less than proportional response. The p-values of the different F-tests are reported in Table A7.*

[25] Equations (19) and (20) also include non-interacted dummies to allow for possibly different intercepts between ap- and depreciations, but in practice these variables do not play a role (the coefficients $\beta_3$ and $\beta'_3$ are usually not significantly different from zero – when they are, they are very small in absolute value).

Starting with export prices, non-linearities of some form can be detected for all countries, although the nature of these non-linearities and their importance vary considerably across countries. For Italy, the quadratic term enters the specification with a positive sign during appreciation episodes, indicating that appreciations may trigger a smaller reaction than depreciations, and that "large" appreciations have a less than proportional effect compared to small appreciations. This is confirmed by the fact that the individual dummy variable for large appreciations has a positive sign (implying a less than proportional effect) and the dummy for large depreciations a negative sign; this is also confirmed by the formal F-test.

This result could be consistent with the presence of downward price rigidities in the case of Italy's export prices (Assumption 1), resulting in the finding that large appreciations are associated with less than proportional decreases in export prices. Meanwhile, the fact that the coefficient $\beta_2$ of the dummy variable for large depreciations is significant and equal to -0.31 (as can be seen in row 6) indicates that large depreciations have a more than proportional response, consistent with Assumption 2. In the case of Germany, by contrast, depreciations tend to have a less than proportional effect on export prices, as evidenced by the positive sign of the low depreciation dummy, which is consistent with Assumption 3. This is confirmed by the F-tests; however, the fact that none of the quadratic terms is significant in the case of Germany suggests that the difference between the linear and the non-linear model may not be very large. For France, evidence is mixed. On the one hand, the quadratic term for depreciations is positive (the p-value for this term is actually very close to 10%), indicating that large depreciations have a more than proportional effect.[26] On the other hand, this is not confirmed by the interactive dummy variables and by the F-test.

In the case of Japanese export prices, there seems to be strong non-linearities for appreciations, with high appreciations having a more than proportional (downward) impact, consistent with Assumption 3.[27] This results comes out very clearly from the fact that the quadratic term has a negative sign (row 2), from the sign of the individual dummies (row 4 and 5) and from the F-test. One possible interpretation is that Japanese exports are subject to high switching costs: Japanese exporters could let exchange rate changes be passed-through as long as they are small; yet, faced with larger appreciations, they may intensify their effort to offset the loss in competitiveness stemming from the appreciation. The presence of switching costs in Japanese exports may in turn be explained by the high share of investment goods in total Japanese exports, which are traditionally less price elastic than consumer goods. However, one does not observe a similar type of non-linearity on the depreciation side (row 6 and 7), such that the argument along the line of Assumption 3 seems preferable.

[26] This result is very sensitive to the depreciation of the early 1980s, which was associated with a large rise in export prices.
[27] This is consistent with some of the results presented by Marston (1990), who concludes that appreciations have a stronger effect on export prices for 5 sectors out of 17.

## Table 3: Adding Polynomial Functions to the Benchmark Model.

### Table 3a: Quadratic Terms, Appreciations.

| Export Prices | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Export prices (t-1) | 0.0993 | 0.0526 | 0.1592** | 0.1148 | -0.1437*** | 0.1618* | 0.4950*** |
| | [0.0643] | [0.0434] | [0.0784] | [0.0830] | [0.0538] | [0.0844] | [0.0673] |
| ER(t) | -0.1752* | -0.0740** | -0.3174*** | -0.3509*** | -0.3241*** | -0.1895*** | -0.0244 |
| | [0.0895] | [0.0327] | [0.0552] | [0.0624] | [0.0534] | [0.0655] | [0.0311] |
| PPI (t) | 0.7676*** | 0.7083*** | 0.4450*** | 0.6085*** | 0.3673*** | 0.7508*** | 0.3799*** |
| | [0.1166] | [0.0679] | [0.0851] | [0.1336] | [0.1345] | [0.1782] | [0.0810] |
| Oil prices (t), $ | 0.0279*** | -0.0138*** | 0.0001 | 0.0086 | -0.0160** | 0.0259** | -0.0045 |
| | [0.0078] | [0.0026] | [0.0047] | [0.0080] | [0.0072] | [0.0101] | [0.0047] |
| $D^{ap}(t) * ER(t)^2$ | -0.376 | 0.6544 | 3.8709 | 7.4227* | -1.6040** | -2.9149 | -4.2780*** |
| | [2.4447] | [1.3922] | [6.6788] | [3.8925] | [0.6672] | [2.2743] | [1.5133] |
| $D^{ap}(t)$ | 0.0005 | -0.0006 | -0.0012 | 0.0056* | -0.0005 | -0.0004 | -0.0009 |
| | [0.0034] | [0.0011] | [0.0020] | [0.0032] | [0.0033] | [0.0037] | [0.0015] |
| Constant | -0.0016 | 0.001 | 0.0012 | -0.0024 | 0.0033 | -0.0006 | -0.0002 |
| | [0.0027] | [0.0009] | [0.0016] | [0.0030] | [0.0028] | [0.0035] | [0.0014] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.64 | 0.88 | 0.76 | 0.58 | 0.78 | 0.51 | 0.72 |

| Import Prices | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Import prices (t-1) | 0.069 | 0.0965 | 0.3266*** | 0.2291*** | 0.0786 | 0.1944*** | 0.1978*** |
| | [0.0535] | [0.0609] | [0.0593] | [0.0771] | [0.0666] | [0.0619] | [0.0482] |
| ER(t) | -0.4770*** | -0.2902*** | -0.6325*** | -0.5688*** | -0.4871*** | -0.3379*** | -0.2675*** |
| | [0.0788] | [0.0928] | [0.0758] | [0.0961] | [0.1133] | [0.0533] | [0.0506] |
| PPI (t) | 0.5984*** | 1.3679*** | 0.2316** | 0.3687* | 0.9155*** | 0.5726*** | 0.7849*** |
| | [0.0998] | [0.2014] | [0.1104] | [0.2024] | [0.3426] | [0.1438] | [0.1208] |
| Oil prices (t), $ | 0.0046 | 0.0032 | 0.0551*** | 0.0493*** | 0.0721*** | 0.0271*** | 0.0348*** |
| | [0.0070] | [0.0073] | [0.0067] | [0.0122] | [0.0155] | [0.0083] | [0.0078] |
| $D^{ap}(t) * ER(t)^2$ | 1.242 | 5.6924 | 13.1628 | -0.7639 | -1.5493 | -2.8013 | -0.3415 |
| | [2.0908] | [3.9571] | [9.4679] | [6.0017] | [1.4344] | [1.8635] | [2.4737] |
| $D^{ap}(t)$ | 0.0004 | -0.0046 | 0.0039 | 0.0013 | -0.0031 | -0.0017 | 0.0025 |
| | [0.0030] | [0.0030] | [0.0028] | [0.0049] | [0.0071] | [0.0030] | [0.0024] |
| Constant | -0.0042* | 0.002 | -0.003 | -0.0092** | 0.0077 | -0.0037 | -0.0065*** |
| | [0.0024] | [0.0026] | [0.0023] | [0.0046] | [0.0059] | [0.0028] | [0.0023] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.76 | 0.79 | 0.79 | 0.65 | 0.7 | 0.7 | 0.81 |

### Table 3b: Quadratic Terms, Depreciations.

| Export Prices | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Export prices (t-1) | 0.0858 | 0.0526 | 0.1595** | 0.1391* | -0.1497*** | 0.1605* | 0.4808*** |
| | [0.0628] | [0.0434] | [0.0775] | [0.0832] | [0.0553] | [0.0843] | [0.0680] |
| ER(t) | -0.0779 | -0.0555 | -0.174 | -0.4091*** | -0.4450*** | -0.3304*** | -0.1789*** |
| | [0.1235] | [0.0452] | [0.1061] | [0.1240] | [0.0493] | [0.1030] | [0.0497] |
| PPI (t) | 0.8103*** | 0.7092*** | 0.4647*** | 0.6033*** | 0.3940*** | 0.7317*** | 0.3880*** |
| | [0.1163] | [0.0680] | [0.0855] | [0.1366] | [0.1376] | [0.1782] | [0.0820] |
| Oil prices (t), $ | 0.0279*** | -0.0138*** | 0.0002 | 0.0074 | -0.0150** | 0.0267** | -0.005 |
| | [0.0077] | [0.0026] | [0.0047] | [0.0081] | [0.0074] | [0.0102] | [0.0048] |
| $D^{dep}(t) * ER(t)^2$ | 2.8916 | 0.3109 | 2.3297* | -1.0212 | -0.7649 | -1.2804 | -2.5349*** |
| | [2.6605] | [1.0336] | [1.5816] | [1.1773] | [0.8001] | [0.9827] | [0.9392] |
| $D^{dep}(t)$ | 0.0013 | 0.0009 | 0.0031 | -0.0087** | -0.0031 | -0.0023 | -0.0013 |
| | [0.0038] | [0.0012] | [0.0024] | [0.0040] | [0.0033] | [0.0043] | [0.0017] |
| Constant | -0.0031 | 0.0003 | -0.0007 | 0.0051* | 0.0034 | -0.0002 | -0.0003 |
| | [0.0033] | [0.0008] | [0.0018] | [0.0029] | [0.0029] | [0.0036] | [0.0014] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.64 | 0.88 | 0.76 | 0.57 | 0.77 | 0.51 | 0.72 |

| Import Prices | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Import prices (t-1) | 0.0694 | 0.0978 | 0.3285*** | 0.2348*** | 0.0766 | 0.1917*** | 0.2000*** |
| | [0.0536] | [0.0615] | [0.0594] | [0.0759] | [0.0669] | [0.0627] | [0.0484] |
| ER(t) | -0.4211*** | -0.1635 | -0.4380*** | -0.7038*** | -0.6142*** | -0.4041*** | -0.2555*** |
| | [0.1080] | [0.1300] | [0.1517] | [0.1872] | [0.1015] | [0.0853] | [0.0812] |
| PPI (t) | 0.5959*** | 1.3810*** | 0.2538** | 0.3359 | 0.9358*** | 0.5619*** | 0.7748*** |
| | [0.1007] | [0.2040] | [0.1127] | [0.2056] | [0.3434] | [0.1451] | [0.1213] |
| Oil prices (t), $ | 0.0043 | 0.0028 | 0.0549*** | 0.0494*** | 0.0726*** | 0.0264*** | 0.0355*** |
| | [0.0070] | [0.0074] | [0.0067] | [0.0121] | [0.0156] | [0.0084] | [0.0078] |
| $D^{dep}(t) * ER(t)^2$ | 0.9348 | 1.6987 | 2.9015 | -1.4302 | -1.0326 | -0.4127 | 0.3443 |
| | [2.3301] | [2.9655] | [2.2701] | [1.7842] | [1.6823] | [0.8165] | [1.5275] |
| $D^{dep}(t)$ | 0.0005 | 0.0062* | -0.0023 | -0.0042 | -0.0007 | 0.0009 | -0.0022 |
| | [0.0033] | [0.0035] | [0.0035] | [0.0060] | [0.0069] | [0.0036] | [0.0027] |
| Constant | -0.0041 | -0.003 | 0.0008 | -0.0064 | 0.0056 | -0.0058* | -0.0043* |
| | [0.0030] | [0.0023] | [0.0025] | [0.0044] | [0.0061] | [0.0029] | [0.0022] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.76 | 0.78 | 0.79 | 0.65 | 0.7 | 0.7 | 0.81 |

*Notes: Standard errors in brackets; *, ** and *** indicate significance at 10%, 5% and 1% respectively. All variables are defined in first (log) differences. All regressions include quarterly time dummies. Regressions for Germany include dummies for the 1991 unification. Acronyms refer to Canada (CN), Germany (DE), France (FR), Italy (IT), Japan (JP), the United Kingdom (UK) and the United States (US). The results correspond to equation (19) for export prices and (20) for import prices. Panel a reports the results of equations (19) and (20) with the dummy variable $D^{ap}$; panel b reports the results of the same specifications using dummy variable $D^{dep}$ instead of $D^{ap}$.*

Turning to the UK, non-linearities seem to be detected in the data in the form of an asymmetry between appreciations and depreciations, but this is only evidenced through the F-tests and the dummy variable for high depreciations, which implies a less than proportional impact. This result seems to come predominantly from the 1992 strong depreciation of the sterling, which was associated with a relatively moderate increase in UK export prices. Meanwhile, significant non-linearities can be detected for US export prices, confirmed by the quadratic terms, the interactive dummies and the F-test. Large appreciations seem to have a more than proportional effect (as for Japan), while large depreciations seem to have a less than proportional effect (as for the UK). As a final comment on non-linear results for export prices, one needs to underline that the improvement in terms of goodness-of-fit is relatively modest (the R-squared are higher only by a few percentage points in the non-linear specifications), implying that linear models are a good first order approximation over the long-run. This is not surprising given that most observations correspond to "normal" times. However, during specific episodes, the difference between linear and non-linear models can be relatively substantial.[28]

On the import side, non-linearities are not as frequently detected as for exports. For France the dummy variable for strong depreciations is significant and negative, implying a more than proportional impact on import prices. This result seems to be largely driven by the depreciation episode of the early 1980s. For the other countries, evidence is more mixed. For Italy, the dummy variable for large depreciations was close to the significance level, but this result must be contrasted with the fact that the quadratic terms are not significant. For Germany results from the F-test and from the interactive dummy variables suggest that large appreciations have a less than proportional effect. For Japan this result is reversed: large appreciations tend to have a more than proportional effect (based on the interactive dummy variable), but this is confirmed neither by the F-test nor by the polynomial terms.

The fact that non-linearities are more clearly detected for export than for import prices may be explained by two factors. First, total imports of the G7 economies include a much higher share of oil and non-oil commodities that exports. As oil and non-oil commodities are generally characterized by higher pass-through, this could somewhat blur the picture, even though oil prices have been added as an explanatory variable. It could therefore be a possible extension for future research to repeat the exercise at a disaggregated level; however, Yang (2007) does not find robust evidence of asymmetries even at the four digit level for US import prices. A second, more likely factor, is related to the fact that the signs of the convexity varies across countries for export prices (e.g., between Italy and Japan). This may result in non-linearities canceling each other when considering total imports. In addition, one may note that failing to detect non-linearities in the data does not imply that non-linearities will never arise. Indeed, if most data are to be found on the left-hand side of point A in Figure 5, the non-linear model will not be significantly different from the linear model: the two models can only be disentangled beyond point A. If exchange rate realizations beyond point A materialize, it may therefore be that the reaction of trade prices starts to be non-linear, even though this has never been detected so far.

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[28] Taking the example of Italian export prices during the 1995-1996 appreciation, the predicted change was closer to the actual figure (6.7%) for the quadratic and threshold models (6.7% and 6.0%, resp.) than with the linear model (4.4%).

# 5. Conclusion

This paper has examined the case of possible non-linearities and asymmetries in the reaction of export and import prices to changes in the exchange rate, using quarterly data from 1980 to 2006. The empirical exercise was conducted with total export and import prices for all G7 countries. The methodology consisted in adding to a standard linear single equation framework additional terms to account for possible non-linearities or asymmetries, such as polynomial terms and interactive dummy variables, and in using formal non-linearity tests.

The results indicate first, that the linear version of the model is very much in line with existing estimates from the literature, and second, that non-linear effects cannot be neglected, although the direction of the asymmetries and the magnitude of the non-linearities vary across countries. For instance, large appreciations have a less than proportional effect on export prices in the case Italy, but a more than proportional effect for Japan and the US. Such cross-country differences can be related to microeconomic assumptions on price rigidity and on demand elasticity. Explicitly considering non-linearities and asymmetries yields a more accurate understanding of exchange rate pass-through and its connection to competitiveness. For instance, in a situation where linear results indicate that export prices strongly react to exchange rate changes, the interpretation of the average coefficient varies with the direction of the change: while this would imply stronger competitiveness during an appreciation, it actually implies lower competitiveness during a depreciation (compared with a lower absolute response).

While this paper was purely empirical and primarily aimed at testing for non-linearities, future research may also seek to more systematically explore what explains cross-country differences in the convexity of pass-through. This can be done in a set of second stage regressions, similar to the approach proposed by Yang (1997) at the sectoral level and Gagnon and Ihrig (2004) at the country level. In the present case, one would need to derive a measure of convexity and regress it, in a second stage, on explanatory variables.[29] The sectoral composition of trade flows, differences in market power, and proxies for price rigidities constitute potential candidates for this second stage regression. However, one would need to extend the dataset to more countries and/or different sectors in order to estimate such regression. Meanwhile, the intended contribution of the present paper was to investigate, for the first time, the issue of non-linearities in a systematic way for export and import prices of all G7 countries and to relate the results to possible microeconomic assumptions. The fact that non-linearities can be detected at the aggregate level is a noteworthy result, which has implications for balance of payment adjustment. Finally, a word of caution should be added: although the results are robust to a variety of tests, they are very sensitive to specific historical episodes. For instance, the depreciation of the French Franc in the early 1980s triggered a significant increase in trade prices. The question is therefore whether this episode is best considered as a one-off event, or whether it is representative of what happens in case of a large depreciation: this is still an open debate.

[29] In his study of price asymmetries, Peltzman (2000) proposes such extension but he finds very mixed results.

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## Table Appendix

**Table A1: Stationarity Tests for the Main Series (Dickey-Fuller and Philips-Perron Test Statistics).**

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| **Panel A: variables in first differences** | | | | | | | |
| Export Prices | -8.151 *** | -7.327 *** | -4.583 *** | -6.088 *** | -8.949 *** | -7.168 *** | -4.997 *** |
| | -8.014 *** | -7.467 *** | -4.416 *** | -6.186 *** | -9.020 *** | -7.135 *** | -4.886 *** |
| Import Prices | -7.808 *** | -6.283 *** | -5.570 *** | -6.112 *** | -7.745 *** | -6.682 *** | -8.069 *** |
| | -7.771 *** | -6.366 *** | -5.565 *** | -6.043 *** | -7.860 *** | -6.644 *** | -8.055 *** |
| PPI | -7.742 *** | -5.634 *** | -3.519 *** | -5.030 *** | -7.189 *** | -5.865 *** | -6.938 *** |
| | -7.488 *** | -5.635 *** | -3.478 ** | -4.950 *** | -7.289 *** | -5.837 *** | -6.906 *** |
| NEER | -7.613 *** | -7.412 *** | -7.433 *** | -7.107 *** | -7.890 *** | -8.341 *** | -7.875 *** |
| | -7.664 *** | -7.545 *** | -7.546 *** | -7.125 *** | -7.944 *** | -8.192 *** | -7.989 *** |
| ER | -7.371 *** | -7.869 *** | -6.415 *** | -6.830 *** | -7.802 *** | -8.283 *** | -8.280 *** |
| | -7.373 *** | -7.870 *** | -6.535 *** | -6.887 *** | -7.822 *** | -8.204 *** | -8.332 *** |
| **Panel B: cointegration tests** | | | | | | | |
| Export Price Equation | | | | | | | |
| | -2.001 | 0.531 | 0.321 | -0.109 | -0.249 | -0.797 | -0.676 |
| | -2.005 | 0.302 | -0.013 | -0.104 | -0.167 | -0.938 | -0.688 |
| Import Price Equation | | | | | | | |
| | -0.476 | -0.857 | -0.355 | 0.612 | -2.186 | -0.874 | -1.364 |
| | -0.843 | -0.995 | -0.805 | -0.083 | -2.028 | -1.165 | -1.351 |

*Country acronyms refer to Canada (CN), Germany (DE), France (FR), Italy (IT), Japan (JP), the United Kingdom (UK) and the United States (US).*

*Panel A presents the stationarity tests for the variables in first differences for the Dickey-Fuller and for the Philips-Perron statistics (first and second row, respectively). Variables are described in the beginning of Section 4. *** denotes rejection of the null hypothesis of the presence of a unit root.*

*Panel B presents stationarity tests for the residuals of the regression of export prices and of import prices on variables PPI and ER. The same notes as in panel A apply (the absence of * indicates that none of the residuals is stationary, implying that the variables do not cointegrate).*

**Table A2a: Export Price Equation, Linear Specification.**

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Export prices (t-1) | 0.0967 | 0.0488 | 0.1627** | 0.1365 | -0.1414** | 0.1614* | 0.5034*** |
| | [0.0618] | [0.0427] | [0.0776] | [0.0845] | [0.0547] | [0.0835] | [0.0694] |
| Exchange rate (t) | -0.1711*** | -0.0805*** | -0.3248*** | -0.2407*** | -0.3936*** | -0.2288*** | -0.0797*** |
| | [0.0504] | [0.0181] | [0.0416] | [0.0494] | [0.0237] | [0.0420] | [0.0171] |
| PPI (t) | 0.7767*** | 0.7155*** | 0.4376*** | 0.5721*** | 0.4134*** | 0.7363*** | 0.3373*** |
| | [0.1085] | [0.0669] | [0.0837] | [0.1359] | [0.1362] | [0.1742] | [0.0821] |
| Oil prices (t), $ | 0.0278*** | -0.0139*** | 0.0001 | 0.005 | -0.0142* | 0.0250** | -0.0015 |
| | [0.0076] | [0.0025] | [0.0046] | [0.0081] | [0.0074] | [0.0097] | [0.0048] |
| Constant | -0.0015 | 0.0007 | 0.0009 | 0.0015 | 0.001 | -0.0018 | -0.0015 |
| | [0.0020] | [0.0006] | [0.0013] | [0.0024] | [0.0020] | [0.0028] | [0.0011] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.64 | 0.87 | 0.75 | 0.55 | 0.76 | 0.5 | 0.7 |

**Addendum to Table A2a: Wald Test for the Long-Run Restrictions of Price Homogeneity**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Wald test | 0.22 | 8.69 | 1.79 | 0.24 | 8.84 | 0.76 | 1.42 |
| *p-value* | 0.64 | 0.00 | 0.18 | 0.62 | 0.01 | 0.39 | 0.24 |

**Table A2b: Import Price Equation, Linear Specification.**

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Import prices (t-1) | 0.0689 | 0.0891 | 0.3182*** | 0.2269*** | 0.0788 | 0.1941*** | 0.1979*** |
| | [0.0531] | [0.0618] | [0.0598] | [0.0748] | [0.0663] | [0.0621] | [0.0477] |
| Exchange rate (t) | -0.4518*** | -0.3289*** | -0.5201*** | -0.5586*** | -0.5784*** | -0.3902*** | -0.2350*** |
| | [0.0443] | [0.0526] | [0.0579] | [0.0728] | [0.0484] | [0.0345] | [0.0271] |
| PPI (t) | 0.5870*** | 1.4174*** | 0.2662** | 0.3593* | 0.9532*** | 0.5508*** | 0.7828*** |
| | [0.0951] | [0.2034] | [0.1099] | [0.1975] | [0.3386] | [0.1429] | [0.1173] |
| Oil prices (t), $ | 0.0042 | 0.0026 | 0.0531*** | 0.0489*** | 0.0739*** | 0.0271*** | 0.0348*** |
| | [0.0069] | [0.0074] | [0.0068] | [0.0119] | [0.0154] | [0.0080] | [0.0075] |
| Constant | -0.0035* | -0.0005 | -0.0003 | -0.0084** | 0.0043 | -0.0055** | -0.0050*** |
| | [0.0018] | [0.0018] | [0.0018] | [0.0035] | [0.0041] | [0.0023] | [0.0017] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.75 | 0.77 | 0.78 | 0.65 | 0.7 | 0.69 | 0.8 |

*Notes: Standard errors in brackets; *, ** and *** indicate significance at 10%, 5% and 1% respectively. All variables are defined in first (log) differences.*
*All regressions include quarterly time dummies. Regressions for Germany include dummies for the 1991 unification.*
*Acronyms refer to Canada (CN), Germany (DE), France (FR), Italy (IT), Japan (JP), the United Kingdom (UK) and the United States (US).*

**Addendum to Table A2b: Wald Test for the Long-Run Restrictions of Price Homogeneity**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Wald test | 1.68 | 29.92 | 1.65 | 0.90 | 4.59 | 1.27 | 4.26 |
| *p-value* | 0.20 | 0.00 | 0.20 | 0.34 | 0.03 | 0.26 | 0.04 |

## Table A3: Robustness Tests, Alternative Proxy for Domestic Prices and Alternative Estimator

## Table A3a: Linear Specification, Alternative Proxy for Domestic Costs.

Panel A: Export Prices

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Export prices (t-1) | 0.2278*** | 0.2701*** | 0.3382*** | 0.3416*** | -0.1139** | 0.2988*** | 0.6846*** |
| | [0.0727] | [0.0542] | [0.0702] | [0.0778] | [0.0537] | [0.0801] | [0.0615] |
| Exchange rate (t) | -0.3536*** | -0.1678*** | -0.3274*** | -0.3500*** | -0.4094*** | -0.2686*** | -0.0787*** |
| | [0.0534] | [0.0230] | [0.0455] | [0.0573] | [0.0243] | [0.0440] | [0.0185] |
| ULC (t) | 0.145 | 0.1048** | 0.2768*** | 0 | 0.2802** | 0.2487* | -0.0109 |
| | [0.1328] | [0.0406] | [0.0930] | [0.0000] | [0.1155] | [0.1337] | [0.0597] |
| Oil prices (t), $ | 0.0467*** | 0 | 0.0031 | 0.015 | -0.007 | 0.0312*** | 0.0123*** |
| | [0.0089] | [0.0032] | [0.0051] | [0.0100] | [0.0076] | [0.0103] | [0.0037] |
| Constant | -0.001 | 0.0021** | -0.001 | 0.0022 | 0.0005 | -0.0006 | 0.001 |
| | [0.0026] | [0.0008] | [0.0015] | [0.0030] | [0.0020] | [0.0032] | [0.0011] |
| Observations | 107 | 106 | 106 | 106 | 106 | 107 | 106 |
| R-squared | 0.46 | 0.74 | 0.71 | 0.46 | 0.75 | 0.43 | 0.64 |

Panel B: Import Prices

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Import prices (t-1) | 0.1530** | 0.3314*** | 0.3965*** | 0.2978*** | 0.1848*** | 0.3146*** | 0.3437*** |
| | [0.0593] | [0.0638] | [0.0577] | [0.0638] | [0.0552] | [0.0590] | [0.0505] |
| Exchange rate (t) | -0.5821*** | -0.4725*** | -0.5629*** | -0.6415*** | -0.5929*** | -0.4123*** | -0.2209*** |
| | [0.0456] | [0.0583] | [0.0590] | [0.0723] | [0.0505] | [0.0366] | [0.0323] |
| ULC (t) | 0.1938* | 0.1604 | 0.0208 | 0 | 0.2309 | 0.0284 | 0.1422 |
| | [0.1105] | [0.1003] | [0.1302] | [0.0000] | [0.2436] | [0.1086] | [0.1018] |
| Oil prices (t), $ | 0.0205*** | 0.0295*** | 0.0538*** | 0.0552*** | 0.0840*** | 0.0332*** | 0.0689*** |
| | [0.0074] | [0.0078] | [0.0070] | [0.0124] | [0.0160] | [0.0084] | [0.0065] |
| Constant | -0.0036 | 0.0033 | -0.0002 | -0.0058 | 0.0036 | -0.0031 | -0.0002 |
| | [0.0022] | [0.0020] | [0.0021] | [0.0035] | [0.0042] | [0.0026] | [0.0019] |
| Observations | 107 | 106 | 106 | 106 | 106 | 107 | 106 |
| R-squared | 0.67 | 0.67 | 0.76 | 0.64 | 0.68 | 0.65 | 0.72 |

## Table A3b: Linear Specification, Instrumental Variable Estimator.

Panel A: Export Prices

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Export prices (t-1) | 0.0948 | 0.035 | 0.2276*** | 0.1169 | -0.1335** | 0.1984** | 0.6555*** |
| | [0.1094] | [0.0569] | [0.0818] | [0.0939] | [0.0551] | [0.0912] | [0.0816] |
| Exchange rate (t) | -0.1922* | -0.0589** | -0.3066*** | -0.1950*** | -0.3896*** | -0.2368*** | -0.0763*** |
| | [0.1044] | [0.0256] | [0.0452] | [0.0574] | [0.0241] | [0.0441] | [0.0192] |
| PPI (t) | 0.7193* | 0.8085*** | 0.4154*** | 0.7300*** | 0.5029*** | 0.6937*** | 0.0761 |
| | [0.4055] | [0.1194] | [0.1098] | [0.2242] | [0.1912] | [0.2470] | [0.1677] |
| Oil prices (t), $ | 0.0452*** | -0.002 | 0.0017 | 0.0169** | -0.0099 | 0.0333*** | 0.0124*** |
| | [0.0087] | [0.0027] | [0.0049] | [0.0082] | [0.0074] | [0.0101] | [0.0037] |
| Constant | -0.0014 | 0.0005 | 0.0007 | 0.001 | 0.0011 | -0.0017 | 0.0004 |
| | [0.0026] | [0.0008] | [0.0013] | [0.0026] | [0.0020] | [0.0031] | [0.0015] |
| Observations | 107 | 106 | 106 | 101 | 106 | 107 | 106 |
| R-squared | 0.47 | 0.81 | 0.73 | 0.49 | 0.76 | 0.45 | 0.65 |

Panel B: Import Prices

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Import prices (t-1) | 0.0164 | 0.0169 | 0.3436*** | 0.2616*** | 0.1971*** | 0.2788*** | 0.3592*** |
| | [0.0822] | [0.0880] | [0.0592] | [0.0775] | [0.0654] | [0.0667] | [0.0794] |
| Exchange rate (t) | -0.4126*** | -0.2763*** | -0.5173*** | -0.5630*** | -0.5874*** | -0.4043*** | -0.2218*** |
| | [0.0772] | [0.0695] | [0.0618] | [0.0827] | [0.0508] | [0.0369] | [0.0331] |
| PPI (t) | 0.8155** | 1.7731*** | 0.2407* | 0.214 | -0.0827 | 0.2243 | 0.0085 |
| | [0.3105] | [0.3876] | [0.1354] | [0.3027] | [0.4658] | [0.1993] | [0.3385] |
| Oil prices (t), $ | 0.0162** | 0.0259*** | 0.0540*** | 0.0549*** | 0.0808*** | 0.0334*** | 0.0697*** |
| | [0.0074] | [0.0072] | [0.0069] | [0.0120] | [0.0158] | [0.0083] | [0.0065] |
| Constant | -0.0041* | -0.0015 | -0.0004 | -0.0075* | 0.0036 | -0.004 | 0.0009 |
| | [0.0021] | [0.0021] | [0.0019] | [0.0038] | [0.0043] | [0.0025] | [0.0030] |
| Observations | 107 | 106 | 106 | 101 | 106 | 107 | 106 |
| R-squared | 0.68 | 0.72 | 0.77 | 0.62 | 0.68 | 0.65 | 0.71 |

*Notes: Standard errors in brackets; *, ** and *** indicate significance at 10%, 5% and 1% respectively. All variables are defined in first (log) differences.*
*All regressions include quarterly time dummies. Regressions for Germany include dummies for the 1991 unification.*
*Acronyms refer to Canada (CN), Germany (DE), France (FR), Italy (IT), Japan (JP), the United Kingdom (UK) and the United States (US). In Table A3a, data are missing for Italy.*

## Table A4: Robustness Tests (Continued), Additional Explanatory Variables.

### Table A4a: with Output Gap

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Import prices (t-1) | 0.0694 | 0.0892 | 0.3097*** | 0.1977** | 0.0774 | 0.1937*** | 0.1796*** |
| | [0.0533] | [0.0621] | [0.0609] | [0.0763] | [0.0667] | [0.0622] | [0.0487] |
| Exchange rate (t) | -0.4561*** | -0.3293*** | -0.5201*** | -0.5776*** | -0.5769*** | -0.3950*** | -0.2312*** |
| | [0.0453] | [0.0529] | [0.0580] | [0.0731] | [0.0489] | [0.0350] | [0.0270] |
| PPI (t) | 0.5830*** | 1.4073*** | 0.2778** | 0.4432** | 0.9396*** | 0.5977*** | 0.8042*** |
| | [0.0959] | [0.2057] | [0.1112] | [0.2023] | [0.3427] | [0.1524] | [0.1170] |
| Oil prices (t), $ | 0.0038 | 0.0023 | 0.0525*** | 0.0452*** | 0.0742*** | 0.0258*** | 0.0325*** |
| | [0.0070] | [0.0075] | [0.0068] | [0.0120] | [0.0155] | [0.0081] | [0.0076] |
| GAP (t) | 0.0002 | 0.0002 | 0.0005 | 0.0016 | 0.0003 | 0.0004 | 0.0006 |
| | [0.0003] | [0.0004] | [0.0006] | [0.0010] | [0.0010] | [0.0005] | [0.0004] |
| Constant | -0.0034* | -0.0004 | 0.0002 | -0.0077** | 0.0043 | -0.0054** | -0.0045** |
| | [0.0018] | [0.0018] | [0.0020] | [0.0035] | [0.0041] | [0.0023] | [0.0017] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.76 | 0.77 | 0.78 | 0.66 | 0.7 | 0.7 | 0.81 |

### Table A4b: with Domestic Demand (Growth Rate)

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Import prices (t-1) | 0.0724 | 0.0901 | 0.2891*** | 0.2306*** | 0.0738 | 0.1958*** | 0.2084*** |
| | [0.0529] | [0.0624] | [0.0579] | [0.0763] | [0.0660] | [0.0626] | [0.0488] |
| Exchange rate (t) | -0.4429*** | -0.3284*** | -0.5090*** | -0.5631*** | -0.5850*** | -0.3916*** | -0.2377*** |
| | [0.0446] | [0.0530] | [0.0555] | [0.0748] | [0.0484] | [0.0349] | [0.0272] |
| PPI (t) | 0.5773*** | 1.4211*** | 0.3115*** | 0.3544* | 0.9295*** | 0.5292*** | 0.7986*** |
| | [0.0951] | [0.2056] | [0.1061] | [0.1991] | [0.3372] | [0.1552] | [0.1183] |
| Oil prices (t), $ | 0.006 | 0.0026 | 0.0534*** | 0.0493*** | 0.0767*** | 0.0266*** | 0.0342*** |
| | [0.0070] | [0.0075] | [0.0065] | [0.0120] | [0.0154] | [0.0081] | [0.0075] |
| Dom. Demand (t) | -0.1079 | 0.0152 | -0.5019*** | 0.0529 | -0.3373 | -0.0507 | 0.0929 |
| | [0.0822] | [0.0896] | [0.1578] | [0.1821] | [0.2355] | [0.1388] | [0.0913] |
| Constant | -0.0026 | -0.0006 | 0.0021 | -0.0087** | 0.0063 | -0.0051** | -0.0060*** |
| | [0.0019] | [0.0018] | [0.0019] | [0.0037] | [0.0043] | [0.0026] | [0.0020] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.76 | 0.77 | 0.8 | 0.65 | 0.71 | 0.69 | 0.81 |

### Table A4c: with Real Domestic Output (Growth Rate)

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Import prices (t-1) | 0.0689 | 0.0877 | 0.3046*** | 0.2261*** | 0.0758 | 0.1748*** | 0.2037*** |
| | [0.0533] | [0.0621] | [0.0604] | [0.0753] | [0.0663] | [0.0619] | [0.0479] |
| Exchange rate (t) | -0.4518*** | -0.3277*** | -0.5229*** | -0.5587*** | -0.5849*** | -0.3760*** | -0.2361*** |
| | [0.0445] | [0.0529] | [0.0577] | [0.0732] | [0.0488] | [0.0348] | [0.0271] |
| PPI (t) | 0.5869*** | 1.4218*** | 0.2906** | 0.3583* | 0.9530*** | 0.7092*** | 0.8019*** |
| | [0.0960] | [0.2043] | [0.1110] | [0.1986] | [0.3384] | [0.1612] | [0.1183] |
| Oil prices (t), $ | 0.0042 | 0.0022 | 0.0545*** | 0.0491*** | 0.0759*** | 0.0284*** | 0.0339*** |
| | [0.0070] | [0.0075] | [0.0068] | [0.0120] | [0.0155] | [0.0079] | [0.0075] |
| Output growth (t) | 0.0017 | 0.0578 | -0.2813 | 0.0505 | -0.2664 | 0.3905** | 0.1173 |
| | [0.1179] | [0.1028] | [0.2139] | [0.2886] | [0.2521] | [0.1939] | [0.1019] |
| Constant | -0.0035* | -0.0008 | 0.0009 | -0.0086** | 0.0061 | -0.0086*** | -0.0061*** |
| | [0.0019] | [0.0019] | [0.0021] | [0.0037] | [0.0044] | [0.0027] | [0.0020] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.75 | 0.77 | 0.78 | 0.65 | 0.7 | 0.71 | 0.81 |

*Notes: Standard errors in brackets; *, ** and *** indicate significance at 10%, 5% and 1% respectively. All variables are defined in first (log) differences except the output gap. All regressions include quarterly time dummies. Regressions for Germany include dummies for the 1991 unification. Acronyms refer to Canada (CN), Germany (DE), France (FR), Italy (IT), Japan (JP), the United Kingdom (UK) and the United States (US).*

## Table A5: Robustness Tests (Continued), Testing on Sub-periods.

### Table A5a: Export Prices, Sample Restricted to the 1980s.

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Export prices (t-1) | 0.1035 | 0.2181*** | 0.0149 | -0.2547* | -0.0207 | 0.3005** | 0.4603*** |
| | [0.1113] | [0.0753] | [0.1380] | [0.1473] | [0.1111] | [0.1109] | [0.1615] |
| Exchange rate (t) | -0.1612** | -0.0637** | -0.3464*** | -0.5411*** | -0.3967*** | -0.2504*** | -0.0804** |
| | [0.0737] | [0.0250] | [0.0699] | [0.1754] | [0.0458] | [0.0515] | [0.0393] |
| PPI (t) | 0.7049*** | 0.5393*** | 0.6414*** | 1.0588*** | 0.2005 | 0.7256*** | 0.3992* |
| | [0.1599] | [0.0867] | [0.1684] | [0.2739] | [0.1869] | [0.2481] | [0.2097] |
| Oil prices (t), $ | 0.0244** | -0.0113*** | 0.0133 | 0.0006 | -0.0122 | 0.0642*** | -0.0045 |
| | [0.0116] | [0.0031] | [0.0102] | [0.0171] | [0.0146] | [0.0162] | [0.0130] |
| Constant | -0.0034 | 0.001 | 0.0018 | -0.0052 | 0.002 | -0.0044 | -0.002 |
| | [0.0030] | [0.0007] | [0.0026] | [0.0048] | [0.0032] | [0.0044] | [0.0033] |
| Observations | 40 | 40 | 39 | 35 | 39 | 40 | 39 |
| R-squared | 0.65 | 0.92 | 0.81 | 0.73 | 0.78 | 0.75 | 0.61 |
| Long-run effects, 1980s: | -0.18 | -0.08 | -0.35 | -0.43 | -0.39 | -0.36 | -0.15 |
| Memo: full sample: | -0.19 | -0.08 | -0.39 | -0.28 | -0.34 | -0.27 | -0.16 |

### Table A5b: Import Prices, Sample Restricted to the 1980s.

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Import prices (t-1) | 0.2909** | 0.1305 | 0.3188*** | 0.095 | 0.1304 | 0.1852* | 0.1492 |
| | [0.1147] | [0.0921] | [0.0958] | [0.1588] | [0.1222] | [0.1057] | [0.0909] |
| Exchange rate (t) | -0.3428*** | -0.4287*** | -0.6935*** | -0.6227* | -0.7924*** | -0.4049*** | -0.2838*** |
| | [0.0849] | [0.1121] | [0.0970] | [0.3173] | [0.1212] | [0.0565] | [0.0471] |
| PPI (t) | 0.5475*** | 1.2327*** | 0.1787 | 0.9448* | 0.4446 | 0.6250** | 0.8973*** |
| | [0.1873] | [0.3595] | [0.2194] | [0.4772] | [0.6202] | [0.2742] | [0.2101] |
| Oil prices (t), $ | 0.0156 | 0.016 | 0.0694*** | 0.0601* | 0.0578 | 0.0455** | 0.0209 |
| | [0.0134] | [0.0137] | [0.0146] | [0.0309] | [0.0393] | [0.0181] | [0.0146] |
| Constant | -0.0066* | -0.0031 | -0.0029 | -0.0182* | 0.0031 | -0.0115** | -0.0105** |
| | [0.0035] | [0.0031] | [0.0036] | [0.0089] | [0.0087] | [0.0049] | [0.0040] |
| Observations | 40 | 40 | 39 | 35 | 39 | 40 | 39 |
| R-squared | 0.69 | 0.86 | 0.87 | 0.66 | 0.74 | 0.73 | 0.78 |
| Long-run effects, 1980s: | -0.48 | -0.49 | -1.02 | -0.69 | -0.91 | -0.50 | -0.33 |
| Memo: full sample: | -0.49 | -0.36 | -0.76 | -0.72 | -0.63 | -0.48 | -0.29 |

*Notes: Standard errors in brackets; *, ** and *** indicate significance at 10%, 5% and 1% respectively. All variables are defined in first (log) differences.*
*All regressions include quarterly time dummies. Regressions for Germany include dummies for the 1991 unification.*
*Acronyms refer to Canada (CN), Germany (DE), France (FR), Italy (IT), Japan (JP), the United Kingdom (UK) and the United States (US).*

## Table A6: Testing for Threshold Effects.

### Table A6a: Large appreciations.

**Export Prices**

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Export prices (t-1) | 0.1067* | 0.0501 | 0.1591** | 0.0905 | -0.1389** | 0.1616* | 0.5033*** |
| | [0.0613] | [0.0429] | [0.0784] | [0.0859] | [0.0540] | [0.0837] | [0.0677] |
| PPI (t) | 0.7458*** | 0.7067*** | 0.4388*** | 0.5767*** | 0.3685*** | 0.7549*** | 0.3710*** |
| | [0.1103] | [0.0676] | [0.0844] | [0.1338] | [0.1337] | [0.1802] | [0.0808] |
| Oil prices (t), $ | 0.0278*** | -0.0134*** | 0.0002 | 0.0057 | -0.0157** | 0.0259*** | -0.0039 |
| | [0.0073] | [0.0027] | [0.0047] | [0.0080] | [0.0072] | [0.0099] | [0.0047] |
| ER (t) | -0.2794*** | -0.0893*** | -0.3269*** | -0.2633*** | -0.3480*** | -0.1949*** | -0.0513** |
| | [0.0640] | [0.0199] | [0.0490] | [0.0558] | [0.0320] | [0.0506] | [0.0212] |
| $D^{highap}(t)$ * ER(t) | -0.2163 | 0.0636 | 0.2479 | 0.7199** | -0.3114** | -0.1948 | -0.3909** |
| | [0.2038] | [0.1578] | [0.3445] | [0.3143] | [0.1296] | [0.2773] | [0.1797] |
| $D^{highap}(t)$ | 0.0170*** | -0.0002 | -0.004 | -0.0166** | 0.0166* | 0.002 | 0.0093 |
| | [0.0062] | [0.0056] | [0.0057] | [0.0083] | [0.0098] | [0.0118] | [0.0058] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.68 | 0.88 | 0.76 | 0.57 | 0.78 | 0.51 | 0.72 |

**Import Prices**

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Import prices (t-1) | 0.0714 | 0.0901 | 0.3186*** | 0.2295*** | 0.0882 | 0.1937*** | 0.1983*** |
| | [0.0535] | [0.0609] | [0.0603] | [0.0751] | [0.0656] | [0.0618] | [0.0484] |
| PPI (t) | 0.5998*** | 1.3748*** | 0.2577** | 0.3347* | 0.9045*** | 0.5595*** | 0.7833*** |
| | [0.0990] | [0.2016] | [0.1098] | [0.1954] | [0.3356] | [0.1469] | [0.1212] |
| Oil prices (t), $ | 0.0045 | 0.0033 | 0.0544*** | 0.0480*** | 0.0729*** | 0.0285*** | 0.0347*** |
| | [0.0069] | [0.0077] | [0.0068] | [0.0118] | [0.0152] | [0.0081] | [0.0078] |
| ER (t) | -0.4969*** | -0.3753*** | -0.5783*** | -0.4964*** | -0.5630*** | -0.3573*** | -0.2270*** |
| | [0.0592] | [0.0567] | [0.0675] | [0.0830] | [0.0676] | [0.0413] | [0.0347] |
| $D^{highap}(t)$ * ER(t) | 0.0946 | 0.7484* | 0.4092 | 0.3349 | -0.5932** | -0.28 | 0.0905 |
| | [0.1823] | [0.4499] | [0.4984] | [0.4569] | [0.2738] | [0.2267] | [0.2942] |
| $D^{highap}(t)$ | 0.0012 | -0.0162 | -0.0015 | -0.0193 | 0.0447** | 0.0057 | -0.0039 |
| | [0.0057] | [0.0161] | [0.0082] | [0.0119] | [0.0206] | [0.0096] | [0.0095] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.76 | 0.79 | 0.78 | 0.66 | 0.72 | 0.70 | 0.80 |

### Table A6b: Large depreciations.

**Export Prices**

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Export prices (t-1) | 0.0831 | 0.0475 | 0.1625** | 0.1144 | -0.1380** | 0.1447* | 0.4810*** |
| | [0.0623] | [0.0432] | [0.0799] | [0.0817] | [0.0554] | [0.0840] | [0.0682] |
| PPI (t) | 0.7995*** | 0.7194*** | 0.4370*** | 0.5702*** | 0.4117*** | 0.7764*** | 0.3842*** |
| | [0.1094] | [0.0679] | [0.0846] | [0.1314] | [0.1378] | [0.1750] | [0.0824] |
| Oil prices (t), $ | 0.0273*** | -0.0139*** | 0.0003 | 0.006 | -0.0160** | 0.0246** | -0.0051 |
| | [0.0076] | [0.0026] | [0.0047] | [0.0079] | [0.0076] | [0.0097] | [0.0049] |
| ER (t) | -0.0518 | -0.0715*** | -0.3070*** | 0.0801 | -0.4104*** | -0.3169*** | -0.1474*** |
| | [0.0865] | [0.0250] | [0.0988] | [0.1211] | [0.0291] | [0.0835] | [0.0338] |
| $D^{highdep}(t)$ * ER(t) | -0.1611 | 0.0142 | -0.0321 | -0.3104** | 0.0233 | 0.2113* | 0.1925** |
| | [0.1550] | [0.0774] | [0.1183] | [0.1373] | [0.1580] | [0.1229] | [0.0759] |
| $D^{highdep}(t)$ | 0.0012 | 0.0011 | -0.0004 | 0.0051 | -0.0023 | 0.0054 | 0.004 |
| | [0.0041] | [0.0025] | [0.0021] | [0.0031] | [0.0106] | [0.0052] | [0.0030] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.65 | 0.88 | 0.75 | 0.59 | 0.76 | 0.51 | 0.72 |

**Import Prices**

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Import prices (t-1) | 0.0751 | 0.0873 | 0.3227*** | 0.2397*** | 0.0729 | 0.1975*** | 0.2032*** |
| | [0.0537] | [0.0627] | [0.0593] | [0.0757] | [0.0669] | [0.0624] | [0.0486] |
| PPI (t) | 0.5900*** | 1.4308*** | 0.2377** | 0.315 | 0.9288*** | 0.5633*** | 0.7647*** |
| | [0.0961] | [0.2079] | [0.1081] | [0.2008] | [0.3412] | [0.1429] | [0.1217] |
| Oil prices (t), $ | 0.004 | 0.0023 | 0.0554*** | 0.0465*** | 0.0741*** | 0.0273*** | 0.0364*** |
| | [0.0069] | [0.0075] | [0.0067] | [0.0121] | [0.0159] | [0.0079] | [0.0079] |
| ER (t) | -0.3870*** | -0.3285*** | -0.2053 | -0.6292*** | -0.5911*** | -0.5054*** | -0.2097*** |
| | [0.0763] | [0.0726] | [0.1391] | [0.1851] | [0.0602] | [0.0684] | [0.0555] |
| $D^{highdep}(t)$ * ER(t) | -0.0567 | 0.0863 | -0.4118** | 0.1785 | 0.3319 | 0.1324 | -0.1232 |
| | [0.1363] | [0.2254] | [0.1664] | [0.2113] | [0.3307] | [0.1007] | [0.1237] |
| $D^{highdep}(t)$ | 0.0018 | 0.003 | -0.0007 | 0.0053 | 0.0209 | -0.0022 | -0.0039 |
| | [0.0037] | [0.0072] | [0.0030] | [0.0047] | [0.0222] | [0.0043] | [0.0048] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.76 | 0.77 | 0.79 | 0.65 | 0.70 | 0.71 | 0.80 |

*Notes: Standard errors in brackets; *, ** and *** indicate significance at 10%, 5% and 1% respectively. All variables are defined in first (log) differences. All regressions include quarterly time dummies. Regressions for Germany include dummies for the 1991 unification. Acronyms refer to Canada (CN), Germany (DE), France (FR), Italy (IT), Japan (JP), the United Kingdom (UK) and the United States (US).*

*Table A6a presents the results of equation (21) for export prices and (22) for import prices, with the dummy variable D chosen to be equal to $D^{highap}$. Table A6b presents the same specification using dummy variable $D^{highdep}$.*

## Table A6: continued.

## Table A6c: Small appreciations.

**Export Prices**

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Export prices (t-1) | 0.0824 | 0.0547 | 0.1647** | 0.127 | -0.1425** | 0.1666* | 0.5013*** |
| | [0.0617] | [0.0430] | [0.0776] | [0.0836] | [0.0549] | [0.0845] | [0.0701] |
| PPI (t) | 0.8189*** | 0.7074*** | 0.4512*** | 0.6187*** | 0.3887*** | 0.7302*** | 0.3423*** |
| | [0.1088] | [0.0674] | [0.0845] | [0.1365] | [0.1353] | [0.1757] | [0.0834] |
| Oil prices (t), $ | 0.0280*** | -0.0135*** | 0.0002 | 0.0057 | -0.0141* | 0.0270*** | -0.0018 |
| | [0.0077] | [0.0025] | [0.0046] | [0.0081] | [0.0073] | [0.0101] | [0.0049] |
| ER (t) | -0.1302** | -0.0593** | -0.3179*** | -0.2700*** | -0.4107*** | -0.2374*** | -0.0852*** |
| | [0.0532] | [0.0240] | [0.0433] | [0.0511] | [0.0254] | [0.0464] | [0.0187] |
| $D^{lowap}$(t) * ER(t) | -0.6588 | -0.0726 | 1.1072 | -0.5621 | 0.2309* | -0.216 | 0.0095 |
| | [0.6919] | [0.0739] | [0.7816] | [0.7004] | [0.1383] | [0.4129] | [0.1516] |
| $D^{lowap}$(t) | -0.001 | -0.0003 | -0.0041 | 0.0088* | -0.0018 | 0.0035 | 0.0008 |
| | [0.0051] | [0.0010] | [0.0030] | [0.0047] | [0.0035] | [0.0047] | [0.0017] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.66 | 0.88 | 0.76 | 0.57 | 0.77 | 0.50 | 0.70 |

**Import Prices**

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Import prices (t-1) | 0.0513 | 0.0995 | 0.3227*** | 0.2353*** | 0.0795 | 0.1976*** | 0.1965*** |
| | [0.0542] | [0.0606] | [0.0593] | [0.0748] | [0.0669] | [0.0628] | [0.0480] |
| PPI (t) | 0.6050*** | 1.3744*** | 0.2788** | 0.3989** | 0.9569*** | 0.5480*** | 0.7928*** |
| | [0.0957] | [0.1999] | [0.1104] | [0.1980] | [0.3424] | [0.1441] | [0.1186] |
| Oil prices (t), $ | 0.006 | 0.0045 | 0.0534*** | 0.0506*** | 0.0744*** | 0.0266*** | 0.0342*** |
| | [0.0070] | [0.0073] | [0.0067] | [0.0119] | [0.0155] | [0.0083] | [0.0076] |
| ER (t) | -0.4379*** | -0.2143*** | -0.5251*** | -0.5954*** | -0.5792*** | -0.3954*** | -0.2465*** |
| | [0.0472] | [0.0683] | [0.0600] | [0.0758] | [0.0527] | [0.0381] | [0.0296] |
| $D^{lowap}$(t) * ER(t) | -1.0303 | -0.2796 | 2.0996* | -0.198 | 0.1942 | 0.2307 | -0.0022 |
| | [0.6233] | [0.2101] | [1.1273] | [1.0391] | [0.2939] | [0.3415] | [0.2372] |
| $D^{lowap}$(t) | 0.0051 | -0.0032 | -0.005 | 0.0085 | -0.005 | -0.0014 | 0.0018 |
| | [0.0047] | [0.0029] | [0.0044] | [0.0070] | [0.0073] | [0.0039] | [0.0026] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.76 | 0.79 | 0.79 | 0.66 | 0.70 | 0.70 | 0.81 |

## Table A6d: Small depreciations.

**Export Prices**

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Export prices (t-1) | 0.0942 | 0.0525 | 0.1618** | 0.1203 | -0.1401** | 0.1617* | 0.4863*** |
| | [0.0611] | [0.0428] | [0.0807] | [0.0801] | [0.0559] | [0.0841] | [0.0716] |
| PPI (t) | 0.7805*** | 0.7148*** | 0.4436*** | 0.6087*** | 0.4145*** | 0.7076*** | 0.3609*** |
| | [0.1086] | [0.0668] | [0.0853] | [0.1283] | [0.1377] | [0.1806] | [0.0848] |
| Oil prices (t), $ | 0.0261*** | -0.0139*** | 0 | 0.0061 | -0.0145* | 0.0259** | -0.003 |
| | [0.0076] | [0.0025] | [0.0047] | [0.0076] | [0.0076] | [0.0100] | [0.0050] |
| ER (t) | -0.1726*** | -0.0845*** | -0.3277*** | -0.2189*** | -0.3915*** | -0.2265*** | -0.0787*** |
| | [0.0499] | [0.0184] | [0.0426] | [0.0471] | [0.0275] | [0.0424] | [0.0172] |
| $D^{lowdep}$(t) * ER(t) | 1.0084 | 0.1512* | 0.1596 | 0.4126 | -0.0136 | -0.2887 | -0.1106 |
| | [0.6114] | [0.0892] | [0.4638] | [0.6108] | [0.1234] | [0.3584] | [0.1630] |
| $D^{lowdep}$(t) | 0.0039 | 0.0019 | 0.0013 | -0.0071 | 0 | -0.0025 | 0.0001 |
| | [0.0046] | [0.0013] | [0.0024] | [0.0045] | [0.0033] | [0.0043] | [0.0018] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.65 | 0.88 | 0.76 | 0.61 | 0.76 | 0.50 | 0.70 |

**Import Prices**

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| Import prices (t-1) | 0.0711 | 0.0913 | 0.3146*** | 0.2409*** | 0.079 | 0.1999*** | 0.2100*** |
| | [0.0535] | [0.0617] | [0.0593] | [0.0756] | [0.0671] | [0.0622] | [0.0491] |
| PPI (t) | 0.5836*** | 1.4127*** | 0.2343** | 0.3590* | 0.9539*** | 0.5436*** | 0.7523*** |
| | [0.0970] | [0.2029] | [0.1102] | [0.1976] | [0.3425] | [0.1452] | [0.1205] |
| Oil prices (t), $ | 0.0036 | 0.002 | 0.0540*** | 0.0497*** | 0.0738*** | 0.0258*** | 0.0371*** |
| | [0.0070] | [0.0074] | [0.0067] | [0.0119] | [0.0158] | [0.0082] | [0.0078] |
| ER (t) | -0.4527*** | -0.3316*** | -0.5157*** | -0.5422*** | -0.5771*** | -0.3854*** | -0.2363*** |
| | [0.0445] | [0.0534] | [0.0579] | [0.0738] | [0.0558] | [0.0346] | [0.0272] |
| $D^{lowdep}$(t) * ER(t) | 0.4056 | 0.4059 | 0.3333 | -0.8339 | -0.008 | -0.2255 | 0.2366 |
| | [0.5475] | [0.2587] | [0.6493] | [0.9566] | [0.2578] | [0.2925] | [0.2552] |
| $D^{lowdep}$(t) | 0.001 | 0.0066* | -0.0027 | -0.0094 | 0 | 0.0013 | 0.0009 |
| | [0.0041] | [0.0036] | [0.0034] | [0.0071] | [0.0068] | [0.0035] | [0.0028] |
| Observations | 107 | 106 | 106 | 102 | 106 | 107 | 106 |
| R-squared | 0.76 | 0.78 | 0.79 | 0.65 | 0.70 | 0.70 | 0.81 |

*Notes: Standard errors in brackets; *, ** and *** indicate significance at 10%, 5% and 1% respectively. All variables are defined in first (log) differences. All regressions include quarterly time dummies. Regressions for Germany include dummies for the 1991 unification. Acronyms refer to Canada (CN), Germany (DE), France (FR), Italy (IT), Japan (JP), the United Kingdom (UK) and the United States (US).*

*Table A6c presents the results of equation (21) for export prices and (22) for import prices, with the dummy variable D chosen to be equal to $D^{lowap}$. Table A6b presents the same specification using dummy variable $D^{lowdep}$.*

**Table A7: Teräsvirta (1998) Linearity Tests, p-values.**[30]

| | CN | DE | FR | IT | JP | UK | US |
|---|---|---|---|---|---|---|---|
| **Export Prices** | | | | | | | |
| FL | 0.02 | 0.00 | 0.74 | 0.09 | 0.02 | 0.25 | 0.03 |
| F3 | 0.00 | 0.02 | 0.71 | 0.23 | 0.51 | 0.21 | 0.48 |
| F2 | 0.57 | 0.00 | 0.59 | 0.00 | 0.03 | 0.01 | 0.09 |
| F1 | 0.00 | 0.00 | 0.72 | 0.00 | 0.67 | 0.00 | 0.03 |
| **Import Prices** | | | | | | | |
| FL | 0.35 | 0.03 | 0.16 | 0.19 | 0.67 | 0.22 | 0.81 |
| F3 | 0.08 | 0.03 | 0.98 | 0.04 | 0.55 | 0.36 | 0.56 |
| F2 | 0.42 | 0.00 | 0.59 | 0.00 | 0.69 | 0.39 | 0.10 |
| F1 | 0.00 | 0.00 | 0.00 | 0.05 | 0.45 | 0.00 | 0.40 |

*Note: The table reports the p-values from Teräsvirta (1998) linearity tests. Given a transition variable $z_t$, the following auxiliary regression can be estimated:*

$$\hat{\varepsilon}_{t+k} = \boldsymbol{\beta_0 A_t} + \boldsymbol{\beta_1 A_t} z_t + \boldsymbol{\beta_2 A_t} z_t^2 + \boldsymbol{\beta_3 A_t} z_t^3$$

*where the βs are vectors of parameters, ε the residuals from the equation (1) and (2) and A a vector of explanatory variables in these regressions. A general test for linearity against nonlinearity of the smooth threshold regression (STR) form is the F-test of the null hypothesis: $H_{0L}$: $\beta_1 = \beta_2 = \beta_3 = 0$. The choice between a LSTR and an ESTR model is based on a sequence of nested tests conditional on the rejection of $H_{0L}$, namely: $H_{03}$: $\beta_3 = 0$; $H_{02}$: $\beta_2 = 0 \mid \beta_3 = 0$; $H_{01}$: $\beta_1 = 0 \mid \beta_2 = \beta_3 = 0$. Again, an F-test is used, with the corresponding test statistics denoted $F_3$, $F_2$, and $F_1$, respectively. The decision rule is as follows: if the test of $H_{02}$ has the smallest p-value, an ESTR specification is chosen, otherwise an LSTR specification is selected.*

[30] I am indebted to Arnaud Mehl for his help with the econometric programs and the results presented here.

# Chart Appendix

**Figure 1.** The benchmark linear case.

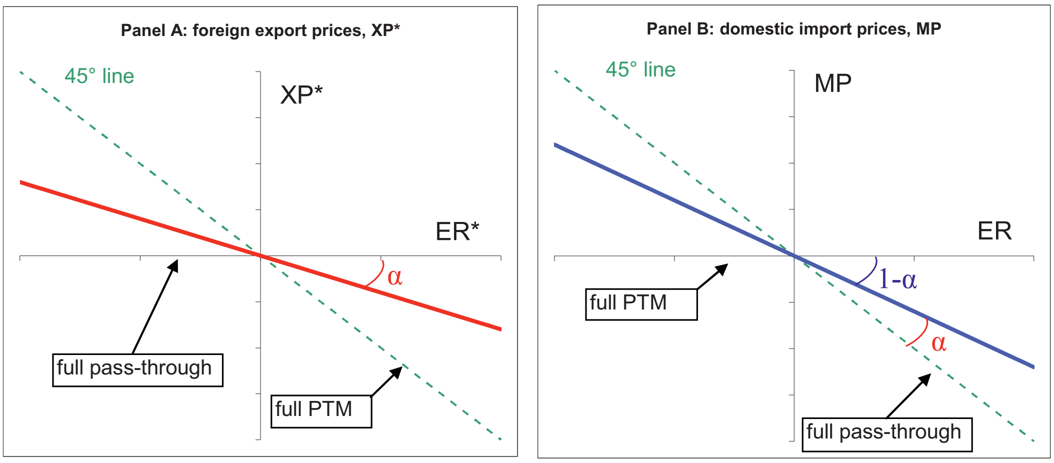



**Figure 2a:** quadratic model, β>0.

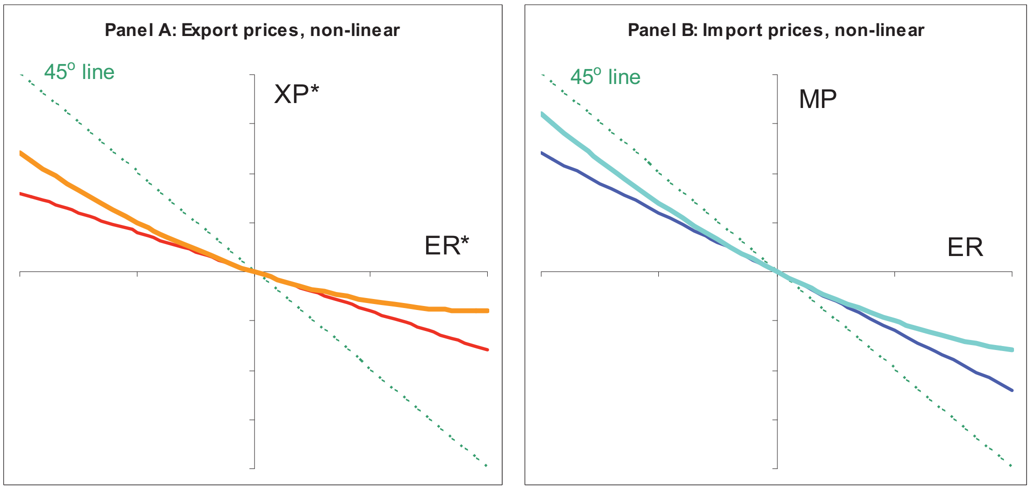



**Figure 2b:** quadratic model, β<0

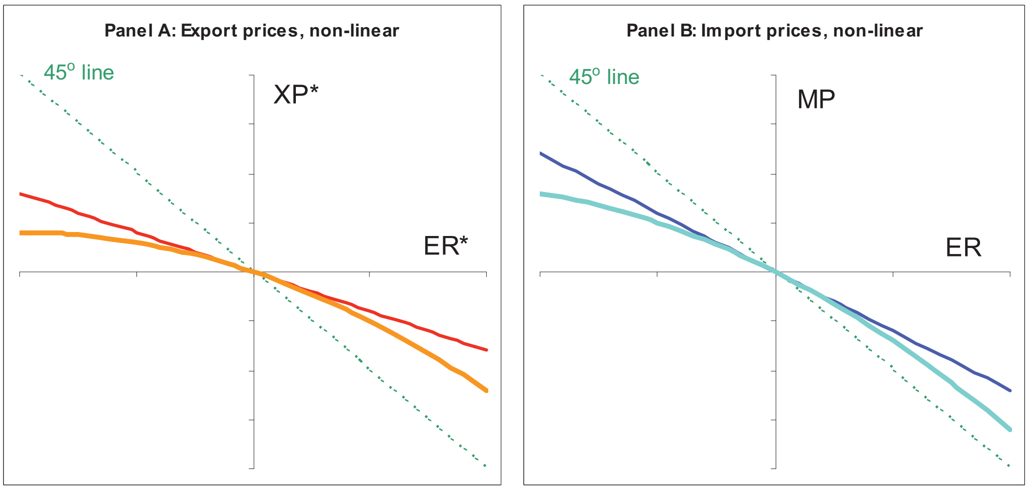


**Figure 3a:** Cubic function (β<0, “menu costs” on the exporter side)

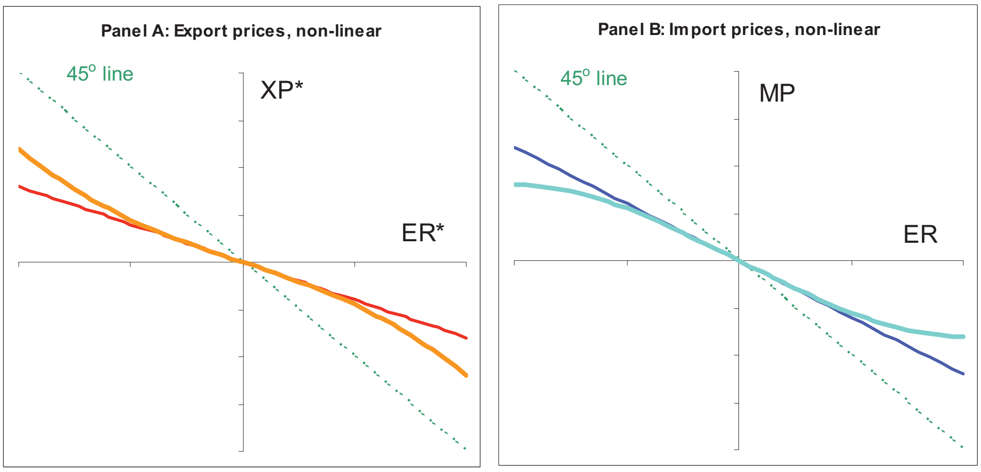



**Figure 3b:** Cubic function (β>0, “menu costs” on the importer side)

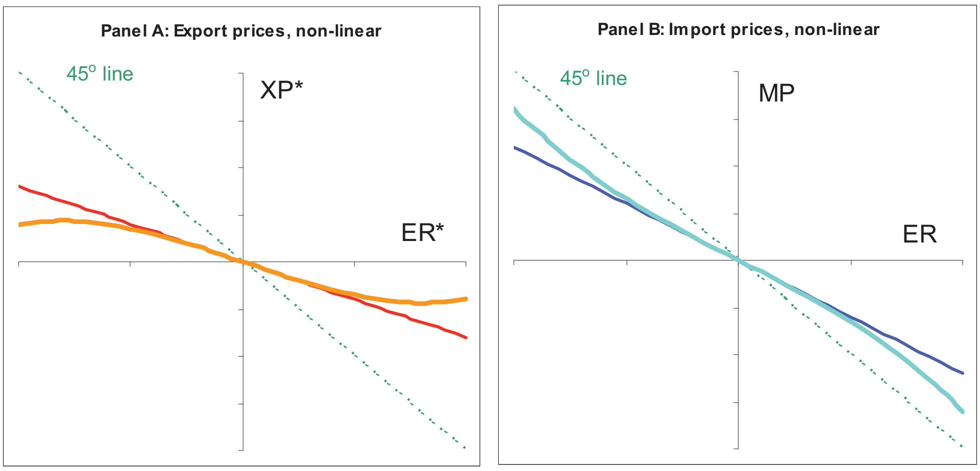



**Figure 4:** Logistic function (β=-0.5, γ = 0.1, c=100).

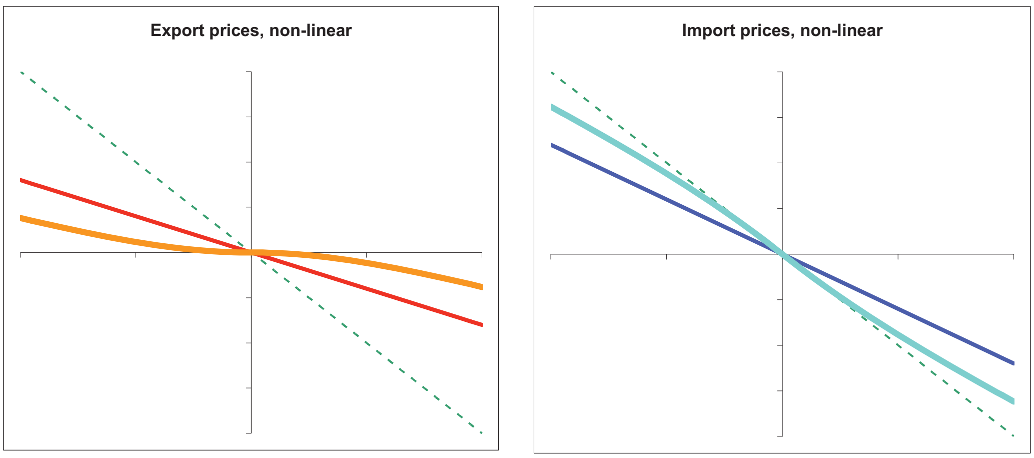
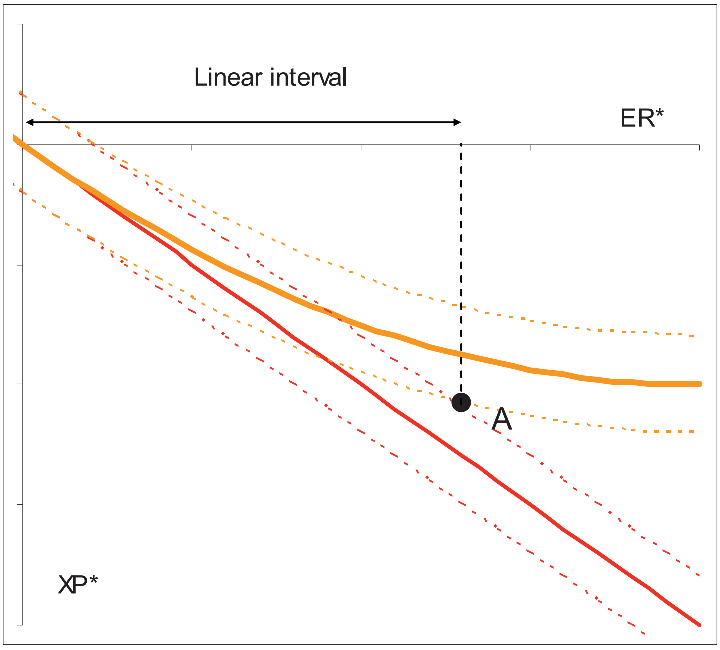


**Figure 5:** “The tipping point” and the linear interval.



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