Exchange Rate Pass-Through to Trade Prices: the Role of Non-linearities and Asymmetries[1]

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Abstract

A standard assumption in the empirical literature on exchange rate pass-through is that the degree of pass-through is both linear and symmetric, implying that (a) large and small exchange rate changes and (b) appreciations and depreciations have proportionally an effect of the same magnitude. The aim of this paper is to test these assumptions for export and import prices in the G7 economies, focusing on non-linearities in the reaction of profit margins to nominal exchange rate changes. The methodology consists in adding to a standard linear model non-linear terms, such as polynomial functions and interactive dummy variables. Results suggest that non-linearities and asymmetries cannot be neglected, especially on the export side, although their magnitude varies noticeably across countries.

JEL: C23, F15, F14.

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

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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% depreciation and does it have the same impact, with the opposite sign, as a depreciation of the same magnitude? The experience of euro area export and import prices[2] since the creation of the euro provides an illustration of what seems to constitute an asymmetric pattern. Since its creation in 1999, the euro experienced an appreciation followed by a depreciation 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 have 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 required before one can draw any conclusion.[3] The present paper therefore aims at testing 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[4] non-linear terms, such as polynomial functions of the exchange rate and interactive dummy variables for ("large" and "small") appreciations and depreciations. The model is estimated with quarterly data between 1980 and the third quarter of 2006.

For policy purposes, it is important to fully understand the determinants of trade prices for at least three reasons. First, changes in import prices being ultimately passed-through to domestic prices, the degree of exchange-rate pass-through is of key importance for central banks. 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 to low pass-through the lack of response of the US trade balance deficit to the

[2] The euro area is here considered as a single entity: exports and imports refer to extra-euro area trade only, i.e. excluding trade across euro area countries. Euro area prices are here proxied by unit value indices of goods (export and import prices are not available for extra-euro area trade flows) and import prices refer to manufacturing goods (i.e., excluding oil imports).

[3] This simple discussion in particular omits other factors that play a role as well, such as domestic costs and oil prices, while it also 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.

[4] The linear model, presented in detail in Section 4, is very similar to Yang (1997) and to Marazzi et al. (2005); it is also close to Campa and Goldberg (2004). The linear specification of the model presented here yields very similar results to these papers, and to the estimates provided by Warmedinger (2004) for euro area countries.

depreciation of the dollar that took place in the mid-1980s. More recently, the depreciation of the 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.[5] 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.

The key mechanism behind movements in trade prices was referred to as "pricing-to-market" by Krugman (1987); it relates to the pricing behavior of exporters who adjust the mark up over their marginal costs in order to stabilize import prices in the currency of the importing country. Given that domestic export prices are also foreign import prices (once converted with the exchange rate), there is a strong connection between export and import prices. In particular, the hypothesis that 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 foreign import prices (in foreign 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. Intuitively, this behavior could be rationalized if prices are particularly rigid downwards and quantities are rigid upwards. To borrow words from the title of Peltzman (2000), prices seem to "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 and they could then decide to increase their prices instead.[6] 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 recur 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 more and more 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 the 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

[5] See Goldberg and Tille (2006) for an informative discussion of the link between changes in import prices and trade balance adjustments.

[6] 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.

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 two sectors (small passenger cars and motorcycles) following the 1985 yen appreciation. 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 menu costs and if the elasticity of substitution between domestic and foreign goods is low. 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. 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.

Of course, the example of euro area prices during one depreciation and one appreciation episode is not enough to establish evidence, and the effect of other variables that can affect export and import prices needs to be controlled for. The paper therefore investigates this issue empirically using time series for the G7 economies, which go further back in time than for the euro area aggregate.[7] 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. The same exercise can however be repeated in future research with unit value indices broken down by industry in order to see whether different results emerge. In addition, for policy purposes it makes sense to focus on the big picture of total trade rather than on a detailed breakdown.[8] Meanwhile, the present exercise aims at introducing 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. Second, non-linearities/asymmetries cannot be rejected for most countries in the sample, especially on the export side. 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, such that they may be relatively imprecisely estimated. It is also 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.

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 preliminary results while Section 5 concludes.

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[7] Readers specifically interested in euro area trade prices can see for instance Anderton (2003) and Hahn (2003).

[8] It is in particular not clear where to stop the disaggregation; for instance, Gagnon and Knetter (1995) find sometimes substantial variation across engine sizes for exports of automobiles, suggesting that a very detailed commodity breakdown would be required.

2. Review of the literature and benchmark case

The purpose of this section is twofold: first, to present the key existing theoretical models of exchange rate pass-through and second, to review selected empirical applications, focusing in particular on the few studies that tackled the issue of non-linearities and asymmetries. The focus here is on exchange rate pass-through to import prices. To harmonize the presentation, notation is made consistent across all papers discussed in this section. Specifically, let us consider two countries Home and Foreign 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* (i.e., the export prices of Foreign in foreign currency), the nominal exchange rate, ER (defined in foreign currency per unit of domestic currency, which implies that an increase represents an appreciation), and finally domestic and foreign prices, P and P* respectively.[9]

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):

$$MP = XP^{*} / ER$$

Or, taking logs and first differences (the time subscript being dropped for now for convenience):

$$\Delta \ln(MP) = \Delta \ln(XP^{*}) - \Delta \ln(ER)$$

This identity shows that export and import prices are in fact two sides of the same coin. Understanding how foreign exporters adjust their export prices sheds light on the evolution of domestic import prices. There is therefore some value added in considering both, which is the approach chosen in the present paper. The literature has modeled exchange rate pass-through by considering how the exporter sets up export prices and how export prices change 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: (i) a change in the bilateral nominal exchange rate between Home and Foreign, (ii) a change in domestic prices in Home, (iii) a change in domestic prices in Foreign or (iv) a change in domestic demand in Home. The first two elements (i) and (ii) 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). To avoid losing market share, they need to lower their mark up in this example. The third element (iii) represents a rise in marginal costs; if Foreign's exporters keep their mark up constant, their export prices will rise with the same effect as a change in either (i) or (ii). The role of the fourth element (iv), domestic demand, is generally found to be small, or even negligible compared to the other two elements;[10] one possible

[9] The empirical literature usually considers either the producer price index (PPI), unit labor costs (ULC) or more rarely the deflator of the Gross Domestic Product (GDPD).

[10] See for instance Yang (1997). NB this statement applies to the pass-through to import prices and not to the pass-through to domestic prices (see also the discussion in Bailliu and Fujii (2004), who do find an effect of the output gap on import prices).

explanation is that changes in demand are partly reflected in prices, such that empirically the effect of demand may be captured by the price variables. The theoretical reasons why exporters may change their mark up are analyzed in the next section.

2.1 Theoretical underpinnings

The literature on exchange rate pass-through is intimately 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 (see Obstfeld and Rogoff, 2000) and the general finding that pass-through is incomplete (see Goldberg and Knetter, 1996, for a survey).[11] Clearly, in a perfect competition framework with frictionless markets, pass-through would be complete because the mark up would always be equal to zero. Theoretical models have therefore been developed to explain why pass-through is not complete, i.e. why firms adjust their mark up in order to offset exchange rate changes (Krugman, 1987, Baldwin, 1988). 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. In this model like in the Baldwin (1988) model, there are barriers to entry, which gives firms a certain monopoly power in the short-run. A key element in these models is therefore whether an exchange rate is permanent or temporary. In practice however, it is very difficult for the econometrician to observe expectations, such that the difference between (expected) permanent or temporary exchange rate changes may not be feasible in practice.

The degree of exchange rate pass-through can depend on several factors which can be classified into two groups, following Campa and Goldberg (2002): microeconomic factors mostly related to industrial organisation considerations and macroeconomic factors, mostly related to monetary policy and the inflation environment.[12] The first category of factors that can affect the degree of pass-through relates to the industrial structure of the economy. In the Dornbusch (1987) paper, pass-through depends on

[11] Devereux and Engel (2002) show that a lower pass-through implies less variation in the real exchange rate when the nominal exchange rate varies.

[12] Of course, this classification is somewhat artificial in the sense that it is difficult to draw a border between micro- and macro-economic elements. It is still useful for expositional reasons and to clarify the determinants of pass-through, as outlined in Campa and Goldberg (2002). The overall objective here is not primarily to test what factors determine pass-through elasticities but rather to test whether these elasticities themselves depend on the exchange rate.

product substitutability, market structure (the degree of competition) and the number of foreign firms respective to local firms. This paper presents several models which yield different functional forms for the degree of pass-through. While there is no space here to reproduce all of them, it is interesting to consider the first one (the Cournot model), where the degree of pass-through (the elasticity of traded good prices to exchange rate changes[13]) is:

$$\varphi = \frac{n^*}{N}\frac{e\,w^*}{P}$$

Where n*/N is the ratio of foreign firms to total (domestic and foreign) firms and ew*/P is the mark up of exporting firms (in foreign currency). As the elasticity is the product of two ratios strictly below one, it is itself below one. In the Marston (1990) model, the degree of pass-through to export prices depends on (i) the convexity of the demand curve in the export market and (ii) 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. The development of the New Open Economy Macroeconomics (NOEM) provided a convenient tool where to address the issue of exchange rate pass-through. 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. In addition, 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 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) find that the decline in pass-through is better understood as a "micro" than a "macro" phenomenon, to borrow words from the title of their paper: the change in the commodity composition of imports (away from goods characterised by a high pass-through) explains most of the measured decline in pass-through, implying a smaller role for monetary policy.

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

[13] In this literature, exchange rate changes are assumed to be exogenous. While some recent empirical papers have started to relax this assumption (using VAR models), they all use linear techniques. Combining exchange rate endogeneity and non-linearities is a challenge that can be tackled in future research.

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.[14] Second, many of the variables are not directly observable and need to be proxied. This is clearly the case of the mark up and the marginal cost: one only observes trade prices and producer prices (alternatively unit labour costs), taken as a proxy for marginal costs. Third, although most models are static, it is unlikely that prices completely adjust within one period (especially when working with quarterly data), which motivates the use of a dynamic model. Fourth, some key variables that are missing from the model need to be added. These variables can cover a wide range of elements such as idiosyncratic characteristics in a panel framework or dummy variables for specific political events (such as the Gulf War or the German Reunification). In addition, the two country framework proposed in the standard models à la Dornbusch is not a good approximation of the real world because of competition in third market effects; this motivates the use of the *effective* rather than the *bilateral* exchange rate. 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 gauge what techniques have been used and what are their pros and cons.

Yang (1997) is an interesting example to start this review given that this paper combines a new theoretical model and an empirical application split in two stages. The paper 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:

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

The change in import prices is therefore regressed on its lag, on the nominal effective exchange rate and on lagged domestic prices. In the second stage, the pass-through elasticities found in the first stage are regressed on variables that proxy the elements included in the theoretical model.[15] The author takes the coefficient in front of the exchange rate, therefore focusing on the short-run rather than the long-run effect:

$$\delta_2^k = c_0 + c_1 PD^k + c_2 EMC^k + c_3 MR^k + \upsilon^k$$

Where PD stands for product differentiation, EMC the elasticity of marginal cost and MR the ratio of total imports to total supply in the economy (various proxies are used to measure in particular the

[14] Some papers use cointegration; see in particular Menon (1993), who uses Johansen's maximum likelihood technique.

[15] The second step uses weighted least squares in order to account for errors in the first step.

degree of product differentiation). Results show that three out of four proxies used for product differentiation have the correct sign and are significant, while the capital to labour ratio, used as a proxy for the elasticity of marginal cost with respect to output, is also significant with the correct (negative) sign. Finally, the coefficient of the import share is found to be insignificant.

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:

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

with XP for export prices and X the destination specific exchange rate (in fact, the destination specific market price level converted into domestic national). 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 are therefore entirely captured by the time dummies. Results indicate that the percentage of industries where local currency price setting could be detected reaches 89% for Germany, 79% for Japan, 67% for the UK and 45% for the US. However, the industry effect is found to be far larger than the source country effect, implying that the differences across source countries come from differences in the industry composition of exports. He also finds that the degree of local currency price setting is the same across destination markets (for a given good).

Marston (1990) focuses on pricing-to-market in Japanese exporting firms; he is interested in the relative price of domestically produced goods sold in the foreign and in the domestic markets. He therefore estimates:

$$\Delta \ln\left(\frac{XP_i^t}{P_i^t}\right) = \alpha_1 \Delta \ln\left(RER_i^t\right) + \alpha_2 \Delta \ln\left(\frac{W_t}{P_t}\right) + \alpha_3 \Delta \ln\left(\frac{P_t^{COM}}{P_t}\right) + \alpha_4 \Delta \ln\left(GDP_t\right) + \alpha_4 \Delta \ln\left(GDP_t^*\right)$$

with the standard notation. Unlike other studies, he therefore uses as dependent variable the ratio of export prices to domestic prices rather than just export prices. The equation is estimated for 17 highly disaggregated products, using monthly data over the period from February 1980 to December 1987; results indicate considerable degree of pricing-to-market, with important differences across sectors.

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. More precisely, they find that this decline was brought about by inflation stabilization episodes that took place in the early 1990s and not in the 1980s. They proceed in two steps. First, they estimate for a panel of 11 industrialized countries i the following equation with annual data:

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

The above equation is estimated with a Generalized Method of Moments (GMM) for three different dependent variables: import prices, producer prices and consumer prices. Prices are therefore regressed on country and time dummy variables, their lags, the nominal effective exchange rate, the exchange rate interacted with policy dummy variables indicating shifts in the inflation environment, the change in foreign producer costs and 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). They first estimate the above equation without the dummy variables for regime shift; in this restricted setting, the long-run exchange rate pass-through is given by $\lambda/(1 - \varphi_1 - \varphi_2)$. They find that pass-through to import prices is around 0.75 in the short-run and 0.9 in the long-run; for consumer prices the corresponding numbers are 0.08 and 0.16, while for producer prices pass-through is equal to 0.2 in the short-run and 0.3 in the long-run. Concerning the interaction terms, the coefficient is significant only for structural changes in the 1990s; for import prices, the implication is that a shift to a low-inflation environment would have reduced pass-through from 0.86 to 0.71.

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:

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

This equation therefore relates CPI inflation to its lag and three lags of competitor's prices in domestic currency. For each individual country, the long-run measure of pass-through is given by $PT=(\delta_2+ \delta_3+ \delta_4)/(1- \delta_1)$ and reaches on average 23% (across all countries). The above equation is then re-estimated on two subsamples, splitting for each country the estimation period into two subperiods corresponding to high- and low-inflation environment, respectively. Results indicate accordingly that pass-through is by 0.1 higher in the first (high inflation) period; this decline is much higher than the decline in import prices measured by Campa and Goldberg (2002), which was only 0.04. Finally, they regress, across countries, PT on the mean and on the standard deviation of the inflation rate (in two separate regressions to avoid multi-colinearity problems between the mean and the standard deviation); they also regress the *change* in PT on the *change* in the mean and standard deviation of inflation and run additional regressions for robustness. Results all point to a substantial link between pass-through and inflation. This non-exhaustive review of the empirical literature has shown the heterogeneity in the modeling approach to the measurement of exchange rate pass-through, even though the theoretical framework behind these various papers is somewhat similar. 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 could constitute a possible extension for further research.[16] Pollard and Coughlin (2003) analyzed exchange rate pass-through to U.S. import prices for 30 industries and tested whether the direction and the size of exchange rate changes affect pass-through. They tested such effects using interactive dummy variables; starting from the following (linear) specification:

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

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 to sets of dummy variables that they introduce to the above equation:

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

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

replacing first $\beta_1 \Delta\ln(ER^i_t)$ 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.

Not all studies looking at this issue have detected significant non-linearities or asymmetries. Focusing on the UK, Herzberg, Kapetanios and Price (2003) have tested for but rejected significant non-linearities. In a study on pass-through to import prices of manufactured goods in Japan, Wickremasinghe and Silvapulle (2004) found an estimated pass-through coefficient of 98% for appreciations and 83% for depreciations.

[16] See for instance Frankel, Parsley and Wei (2005), p. 16.

3. Different types of non-linearities and how they relate to micro 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 α (α >0) of exchange rate movements in foreign currency terms:

$$\Delta \ln(XP^*) = - \alpha \, \Delta \ln(ER^*)$$

In that case the impact of exchange rate changes on import prices is simply:

$$\Delta \ln(MP) = - \Delta \ln(ER) + \Delta \ln(XP^*) = - \Delta \ln(ER) - \alpha \, \Delta \ln(ER^*)$$
$$= - \Delta \ln(ER) + \alpha \, \Delta \ln(ER) = - (1- \alpha) \, \Delta \ln(ER)$$

Figure 1 shows the reaction function of (Foreign) export prices (in Foreign currency) in Panel A and the reaction of (Domestic) export prices (in Domestic currency). The dotted line represents the 45 degree line (full pass-through). It is clear that if α is the reaction of export prices to exchange rate changes, (1- α) is the degree of pass-through. The coefficient α 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, the red line in Panel A coincides with the horizontal line while the blue line in Panel B coincides with the 45 degree line (full pass-through). If, on the other hand, foreign exporters always fully offset exchange rate changes by adjusting their export prices, 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, as suggested in the Dornbusch (1987) model. However, the assumption that exchange-rate pass-through is linear and symmetric is also not very 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 curve relating the exchange-rate and trade prices.

Assumption 1: export prices are rigid downwards. According to a growing body of the empirical literature, prices are rigid in the short-run, particularly on the downwards side. To borrow the title from Peltzman (2000), "prices rise faster than they fall". This implies that when the exchange rate depreciates, exporters will increase their export prices by a larger extent than they will decrease them when the exchange rate appreciates (in other words, they may be more prone to increase their mark up than to decrease it). This phenomenon is likely to be important in the short-run, but also in the longer-run. For instance, following a protracted appreciation, exporters may need to also change the price of their inputs (for example, by re-negotiating contracts with the labor force or the price of the goods used as input in the production process).

Assumption 2: export quantities are rigid upwards. When exporting firms are already at full capacity, it is reasonable to assume that export quantities are rigid upwards: 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 local 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. This is another justification for the first assumption that prices are rigid downwards. While these first two 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).

Assumption 3: menu costs and switching costs. The presence of menu costs or switching costs is another set of 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: 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, there must be an increase in pass-through on the export price side (in the currency of the exporters). Although the set of countries included in the present study does not include the whole world, it is interesting to test whether (i) one sees a decline in the long-run reaction of import prices to exchange rate changes over time and (ii) whether this decline is associated with an increase in the reaction of export prices. Preliminary evidence suggests a fall in the average long-rate pass-through coefficient for import prices (from 60% over the period 1975-1989 to 45% for the period 1990 till end-2006 on average for the countries in the sample). There is however no corresponding increase 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. This can be in particular the case of several emerging markets in Asia, as pointed out for instance in Marazzi et al. (2006), see in particular exhibit 19 p. 65.

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 this fraction varies with the magnitude of the exchange rate changes:

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

In that case, the impact of exchange rate changes on import prices is:

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

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

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), 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). 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).

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[17] (Figure 3a and 3b). It is a mixed case: the sign of the convexity varies for positive and negative values.

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

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

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. 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).

[17] Assuming of course that the intercept and the first order exchange rate term are zero.

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. 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 I 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 reasonable range of parameters, this function is hard to distinguish from other, more simple functional forms (see Figure 4).

$$\Delta XP^* = -(\alpha - \beta \gamma_t)\, \Delta ER^*$$

$$\Delta MP = -(1-\alpha)\, \Delta ER - \beta\, (\gamma_t\, \Delta ER)$$

$$\gamma_t = \frac{1}{1+e^{\gamma(ER_t - c)}} - \frac{1}{2}$$

The above example features a smooth transition from low to high pass-through (polynomial functions are continuous). An alternative is to use thresholds. For instance, instead of a straight line as in Figure 1, there could be two different lines with different slopes for positive and negative exchange rate changes (the threshold is set up at 0). The slope can also change for a given value of the change in the exchange rate. The key question is then how to determine the value of this threshold. Theoretically, if there is a single representative exporting firm, this threshold should be equal in level to the marginal cost of the exporter (assuming a strictly positive mark up). In a country peopled by different firms exporting differentiated goods, it is not clear how to choose the threshold. 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 exchange rate first differences. This is evidently subject to a number of caveats, in particular because it may be somewhat arbitrary and because the episodes selected with this rule may not always correspond to what the general public usually sees as “large” changes. Separating exchange rate changes into appreciations and depreciations gives roughly a 50% split across all countries over the sample, the share of appreciations being comprised between 42% (for Italy) and 56% (for 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 such episodes.

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

Specifically, I estimated the following models. For export prices:

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

And for import prices:

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

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, it allows testing one against the other. The linear version of the model relates the change in the logs of export and import prices (for equation (1) and (2), respectively) to two key explanatory variables: the nominal effective exchange rate (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 specification (1) and (2), the immediate effect of the exchange rate is given by the coefficient α_2 and α'_2, whereas the long-run effect is given by $\alpha_2/(1- \alpha_1)$ and $\alpha'_2/(1- \alpha'_1)$, 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. 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.[18]

The series for trade prices come from the OECD Economic Outlook for total exports and imports of goods and services (codes PXGS and PMGS). The exchange rate is the nominal effective exchange rate provided by the IMF (code NEU), PPI come from the OECD MEI (code PPI). 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.[19] The set of "other controls" includes quarterly dummy variables, a dummy variable for the 1991 German unification, and oil prices. Oil prices entered the export price equation significantly only for Canada and the UK, whereas their coefficient was significant for all countries in the import prices 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 more directly capture the effect of shift in demand, such as the output gap, GDP, or domestic demand. However, this effect is most likely going

[18] In some cases the goodness-of-fit, measured by the adjusted R2, 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.
[19] 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.

to be reflected in changes in domestic prices (in one follows the argument that higher domestic demand, for instance, would tend to raise domestic and import prices).

Results from the linear specification

Before turning to the non-linear results, it may be worthwhile looking at the performance of the linear model, i.e. when the non-linear terms are not included in (1) and (2), and compare this with results from the existing literature. Table 1 reports the 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 at the Fed by Marazzi et al. (2005), henceforth MSV, by Ihrig et al. (2006), henceforth IMR, by Campa and Goldberg (2004), henceforth CG and at the ECB by Thomas Warmedinger (2004), henceforth TW.

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	-0.20	-0.06	-0.32	-0.25	-0.37	-0.23	-0.06
Long-run	-0.23	-0.07	-0.43	-0.30	-0.33	-0.27	-0.13
R^2	0.65	0.86	0.74	0.54	0.74	0.50	0.72
Imports							
Short-run	-0.52	-0.37	-0.55	-0.60	-0.55	-0.39	-0.20
Long-run	-0.58	-0.41	-0.89	-0.78	-0.59	-0.48	-0.26
R^2	0.79	0.79	0.78	0.65	0.72	0.69	0.82

Note: the full results are presented in the Table Appendix (Table 3a and 3b) and correspond to equation (1) and (2), respectively, where the non-linear terms are excluded. Estimation period corresponds to 1980Q1-2006Q3, except Italy (starting 1981Q2). Negative coefficients indicate that an appreciation of the nominal effective exchange rate implies a fall in export and import prices.

Overall, the results from the linear specification are very much in line with the literature. Estimates of the long-run elasticity of export prices to exchange rate changes appear to be rather low for Germany (7%) and the US (12%), 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 (33% against 47%) and for Canada (23% against 36%). The discrepancy observed for Japan seems to be 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. This implies some “overshooting” for Japanese export prices, which are estimated to react by a large amount in the short-run, and to be subsequently adjusted to a smaller magnitude. For Italy and especially France, the elasticity of export prices is found to be substantially higher than for Germany, at 30% and 43%, 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 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. In addition, price homogeneity cannot be rejected for all countries, which is another indication that the model is very satisfying.

On the import side, the average elasticity to exchange rate changes appears to be larger (around 60% for the G7 countries) than for export prices (around 25%).[20] In line with the predictions of the Dornbusch (1987) model, pass-through is found to be lower for the larger countries:[21] 26% for the US, and 41% for Germany. For the US, the pass-through coefficient presented here is somewhat lower than in IMR (32%) and CG (42%). For Germany by contrast, the estimate presented in Table 1 is higher than in IMR (around 30%), very much in line with TW (48%) and much below CG (80%). For Canada, the present estimate (58%) is close to CG (65%) but much below that of IMR (89%); for Japan it is the opposite, the present estimate (55%) being closer to IMR (61%) than that of CG (113%), which appears to be somewhat high[22]. For the UK all three studies provide estimates in the same ballpark of 50% to 60%. For France the present estimate is found to be very high, at 90%. Although CG find an even higher estimate (98%), this is somewhat higher than TW (73%) and especially IMR (16%). Preliminary results, not reported here, suggest that pass-through has declined substantially in France: an regression starting in 1990 yields a long-run coefficient of 42% only. Finally, for Italy, the present estimate (80%) is somewhat higher than in the other studies (more around 50% for TW and IMR, 35% for CG). Overall, the results are therefore in the ballpark of previous empirical work published on the subject (one obvious caveat in the comparison being that the estimation samples do not always coincide exactly). This standard linear model can therefore constitute a useful framework in which to test for non-linearities.

Results from the non-linear specification

The next step then consists in introducing into the above specification additional terms that aim at capturing 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. The results are summarised

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[20] 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). Data on invoicing can also be found in Kamps (2005), who investigates the determinants of invoicing decisions.

[21] 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).

[22] However, Wickremasinghe and Silvapulle (2004) also find estimates in the ballpark of 90% for Japanese import prices.

in Table 2, while the full results are presented in Table 4 in the Table appendix. Using both threshold dummy variables and polynomial functions allows to compare and complement the different approaches.

Starting with export prices, non-linearities can be detected in 5 out of 7 countries, the two exceptions being Canada and the UK, for which the additional polynomial terms are not significant. 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, which is confirmed by the fact that the individual dummy variables for depreciations have a significantly negative sign, unlike the dummy variables for appreciations. In the case of Italy, the results therefore seem to suggest that there is an asymmetry between appreciations and depreciations, the latter having a larger effect on export prices than the former.

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

	Canada	Germany	France	Italy	Japan	UK	US
Exports							
Linear impact	-0.20	-0.06	-0.32	-0.25	-0.37	-0.23	-0.06
Quadratic (+)		>0		>0	<0		<0
Quadratic (-)		>0	>0				<0
High appreciation	-0.38				-0.73		-0.21
Low appreciation			-0.50		-0.36	-0.50	
High depreciation			-0.50	-0.26	-0.67		
Low depreciation				-0.81	-0.43		
Imports							
Linear impact	-0.52	-0.37	-0.55	-0.60	-0.55	-0.39	-0.20
Quadratic (+)			>0				
Quadratic (-)			>0				
High appreciation	-0.37				-0.73	-0.49	
Low appreciation	-1.00				-0.70	-0.56	
High depreciation	-0.52		-1.00	-0.66		-0.46	
Low depreciation					-0.90		-0.29

Note: the full results are presented in the Table Appendix (Table 4a and 4b) and correspond to equation (1) and (2), respectively, including the non-linear terms. Only significant results are reported in Table 2. All regressions involving interactive dummy variables also allow for different intercepts.

Germany also shows a positive coefficient for the quadratic terms (both during appreciations and depreciations). However, the fact that none of the dummy variables is significant suggests that the non-linearities may not be very strong in the data, the overall coefficient being anyway very small. In the case of France, the quadratic term defined for depreciations is positive, while the dummy variable for high depreciations is significant. Both results would point to a more than proportional reaction of export prices in the midst of large depreciations; however, this may be mostly driven by the period of the early 1980s. The case of the three euro area countries therefore contrasts with that of the US and Japan, for which the quadratic case defined for appreciations is negative and significant. For Japan and the US, export prices react more than proportionally to large appreciations, which is confirmed by the results using the interactive dummy variables. In the case of the US, the quadratic term for depreciations is also significant and negative, but results using the dummy variables do not point to the same kind of convexities. Overall, improvement in terms of goodness-of-fit is modest, 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; also, the use of a dynamic model partly accounts for possible non-linearities. However, during specific episodes, the difference between linear and non-linear models can be relatively substantial. Taking the example of Italian exports during the 1995-1996 appreciation episode, the predicted increase was closer to the actual increase (6.7%) for the quadratic model (exactly 6.7%) and for the threshold model (6.0%) than with the linear model (4.4%).

On the import side, the non-linearities are very clearly present only in the case of France, where both quadratic terms are significant, with the dummy variable for strong depreciations being significant and large. It seems however that this result is largely driven by the depreciation episode of the early 1980s. For the other countries, evidence is more mixed. For Italy as well, the dummy variable for large depreciations is significant and relatively large, but this result must be contrasted with the fact that the quadratic terms are not significant. The fact that non-linearities can be detected mostly on the export side is somewhat puzzling: if the countries included in the sample constituted the whole world, there should be a perfect matching between export and import prices. However, as mentioned in the discussion of export prices, different countries have different convexities (contrasting, roughly speaking, the euro area countries on the one hand and the US and Japan on the other hand). It could therefore be that these different convexities cancel out in the aggregate. Another possible explanation is the behavior of the countries not included in the sample.

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 the third quarter of 2006. The empirical exercise was conducted with the export and import prices of the 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. Preliminary results indicate first, that the linear version of the model is very much in line with existing estimates from the literature, and second, that such effects cannot be neglected, although the direction of the asymmetries and the magnitude of the non-linearities vary across countries. Considering non-linearities and asymmetries yields a more accurate understanding of the subject 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 strong competitiveness during an appreciation episode, it actually implies lower competitiveness during a depreciation episode (compared with a lower absolute response).

Several assumptions were used in this exercise, which can be relaxed in future research. In particular, the right-hand side variables were here assumed to be exogenous (in line with the theoretical literature presented in Section 2.1), whereas there is evidence in the literature that at least some of them are endogenous (NB suggestive evidence using the IV estimator however shows that conclusions are robust when domestic costs are instrumented). This can be solved by moving to a different econometric framework such as GMM estimation or a VAR model. However, introducing non-linearities in a single equation framework already sheds light on the subject and constitutes a result in itself. Future research may also seek to 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 extract from the results a measure of convexity and regress it, in a second stage, on explanatory variables. The sectoral composition of trade flows and differences in market power constitute potential candidates for this second stage regression. However, as there are currently only seven countries in the sample, one would also need to extend the dataset in order to estimate such regression.

Finally, a word of caution should be added here. Although the results seem to be robust to a variety of tests, they are very sensitive to the inclusion in the sample and the treatment of specific historical episodes. For instance, the depreciation of the French Franc in the early 1980s triggered a significant increase in import prices. The question is therefore whether one considers this episode as a one-off event which should be excluded from the sample because it will not be repeated, or whether one should take it as an example of what happens in case of a large depreciation. Almost by definition, results on non-linearities very much depend on few specific events; it is still an open debate whether one should consider these events as typical or not and use them for inference about future shocks.

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Table Appendix

Table 3a: Export Price Equation, Linear Specification.

	CN	DE	FR	IT	JP	UK	US
Export Prices (t-1)	0.1228*	0.0583	0.2408***	0.1517*	-0.1397**	0.1635*	0.5183***
	[0.0622]	[0.0451]	[0.0797]	[0.0850]	[0.0577]	[0.0837]	[0.0699]
Exchange Rate (t)	-0.2003***	-0.0651***	-0.3233***	-0.2514***	-0.3733***	-0.2279***	-0.0638***
	[0.0543]	[0.0197]	[0.0474]	[0.0529]	[0.0242]	[0.0423]	[0.0143]
PPI (t)	0.7812***	0.7744***	0.4918***	0.6341***	0.5991***	0.8675***	0.3717***
	[0.1051]	[0.0662]	[0.0880]	[0.1328]	[0.1237]	[0.1715]	[0.0789]
Oil prices (t), $	0.0303***	-0.0146***	0.003	0.0063	-0.0099	0.0255**	-0.0021
	[0.0077]	[0.0026]	[0.0049]	[0.0082]	[0.0078]	[0.0098]	[0.0048]
Constant	-0.0005	0.001	0.0032**	0.0029	0.0033	-0.0012	-0.0013
	[0.0020]	[0.0007]	[0.0014]	[0.0024]	[0.0021]	[0.0028]	[0.0011]
# obs.	107	107	107	102	107	107	107
R^2	0.65	0.86	0.74	0.54	0.74	0.5	0.72

Table 3b: Import Price Equation, Linear Specification.

	CN	DE	FR	IT	JP	UK	US
Import Prices (t-1)	0.1121**	0.0962	0.3839***	0.2274***	0.0653	0.1913***	0.2332***
	[0.0487]	[0.0587]	[0.0601]	[0.0744]	[0.0689]	[0.0622]	[0.0499]
Exchange Rate (t)	-0.5190***	-0.3727***	-0.5487***	-0.6006***	-0.5502***	-0.3921***	-0.1962***
	[0.0435]	[0.0513]	[0.0661]	[0.0771]	[0.0488]	[0.0348]	[0.0238]
PPI (t)	0.6158***	1.5916***	0.3673***	0.5229***	1.5028***	0.7812***	0.9495***
	[0.0851]	[0.1821]	[0.1108]	[0.1904]	[0.3116]	[0.1412]	[0.1226]
Oil prices (t), $	0.0110*	0	0.0575***	0.0514***	0.0804***	0.0281***	0.0322***
	[0.0064]	[0.0070]	[0.0070]	[0.0118]	[0.0160]	[0.0080]	[0.0080]
Constant	-0.0006	0.0021	0.0038*	-0.0051	0.0081*	-0.0046**	-0.0049***
	[0.0016]	[0.0017]	[0.0020]	[0.0035]	[0.0043]	[0.0023]	[0.0018]
# obs.	107	107	107	102	107	107	107
R^2	0.79	0.79	0.78	0.65	0.72	0.69	0.82

*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 4a: Export Price Equation, Non-Linear Results.

	CN	DE	FR	IT	JP	UK	US
High appreciations	-0.3799*	0.1698	-0.2141	0.0305	-0.7254***	-0.2675	-0.2067*
Low appreciations	0.12	-0.0336	-0.4926*	-0.3635	-0.3569***	-0.5009**	0.0059
High depreciations	-0.2611	-0.1343	-0.4943***	-0.2562**	-0.6658***	-0.1659	-0.0021
Low depreciations	0.1707	-0.0395	0.0316	-0.8118*	-0.4349***	-0.4331	-0.1286
NEER (t)	-0.2038***	-0.0774***	-0.2982***	-0.2274***	-0.3626***	-0.2399***	-0.0693***
NEER $(t)^2$	0.5999	1.5697*	1.8439*	0.497	-0.4186	-0.551	-0.8341**
NEER (t)	-0.1560**	-0.0994***	-0.2539***	-0.2671***	-0.3056***	-0.2407***	-0.0532*
NEER $(t)^3$	-32.7167	44.0931	-60.7515	2.8176	-10.0720**	2.4106	-4.6937
NEER (t)	-0.0899	-0.0989*	-0.3746***	-0.2705***	-0.3108***	-0.1961**	-0.008
NEER $(t)^2$, appr.	-1.0538	2.3417*	1.6354	6.0708*	-0.9583*	-1.1008	-1.7029**
NEER (t)	-0.0492	-0.0152	-0.2646**	-0.135	-0.3688***	-0.2799***	-0.1032***
NEER $(t)^2$, depr.	3.9436	2.555*	2.8901*	1.0156	-0.2836	-0.8896	-1.4657*

Table 4b: Import Price Equation, Non-Linear Results.

	CN	DE	FR	IT	JP	UK	US
High appreciations	-0.3684**	-0.3136	-0.3174	-0.475	-0.7292***	-0.4940**	-0.2488
Low appreciations	-1.0043***	0.1388	-0.3953	-0.9322	-0.7040***	-0.5593***	-0.0732
High depreciations	-0.5230*	-0.0128	-1.0062***	-0.6568***	-0.6814	-0.4574***	-0.0771
Low depreciations	-0.3821	-0.3435	-0.0227	-1.0150*	-0.9010***	-0.1335	-0.2866*
NEER (t)	-0.5240***	-0.3802***	-0.4715***	-0.6272***	-0.5395***	-0.3978***	-0.2001***
NEER $(t)^2$	0.7228	0.9054	5.6490**	-0.5525	-0.4082	-0.2638	-0.5485
NEER (t)	-0.5439***	-0.3902***	-0.4315***	-0.6156***	-0.5690***	-0.3754***	-0.1737***
NEER $(t)^3$	17.6213	22.3564	-102.4384*	2.6905	2.813	-3.1079	-9.9909
NEER (t)	-0.5939***	-0.2685*	-0.6937***	-0.4818***	-0.4644***	-0.3372***	-0.2022***
NEER $(t)^2$, appr.	1.661	-1.0065	14.7540**	1.0919	-0.6516	-1.1674	-0.977
NEER (t)	-0.5245***	-0.2842***	-0.2656*	-0.3865**	-0.5285***	-0.3672***	-0.2569***
NEER $(t)^2$, depr.	0.9949	1.1569	8.8751***	1.2337	-1.3019	-0.0026	-0.8506

*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).

Chart Appendix

Figure 1. The benchmark linear case.

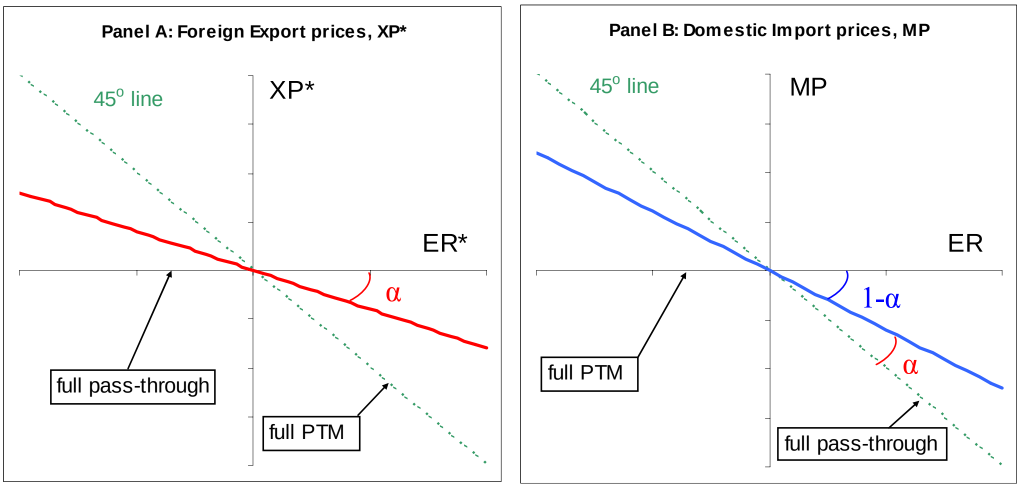

Figure 2a: quadratic model, β>0 ("prices rigid downward" hypothesis)

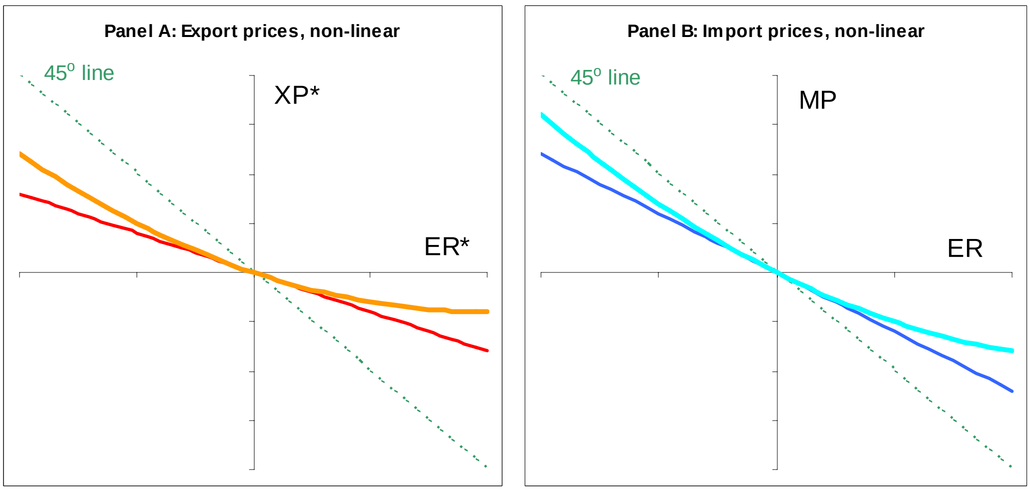

Figure 2b: quadratic model, β<0

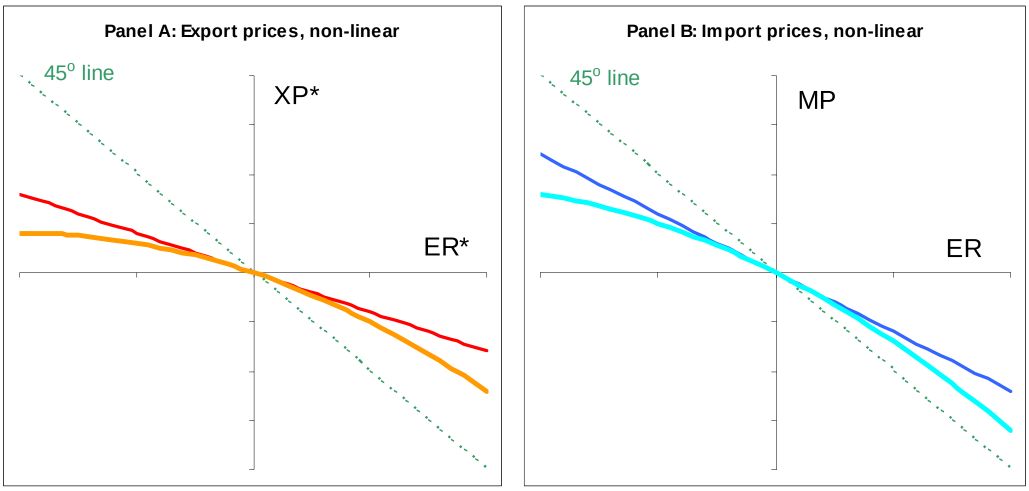

Figure 3a: Cubic function (β<0, "menu costs" on the exporter side)

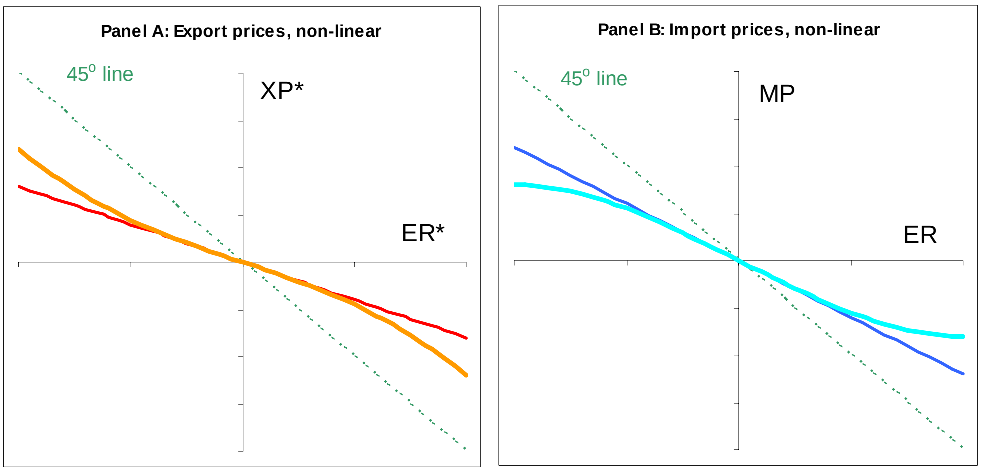

Figure 3b: Cubic function (β>0, "menu costs" on the importer side)

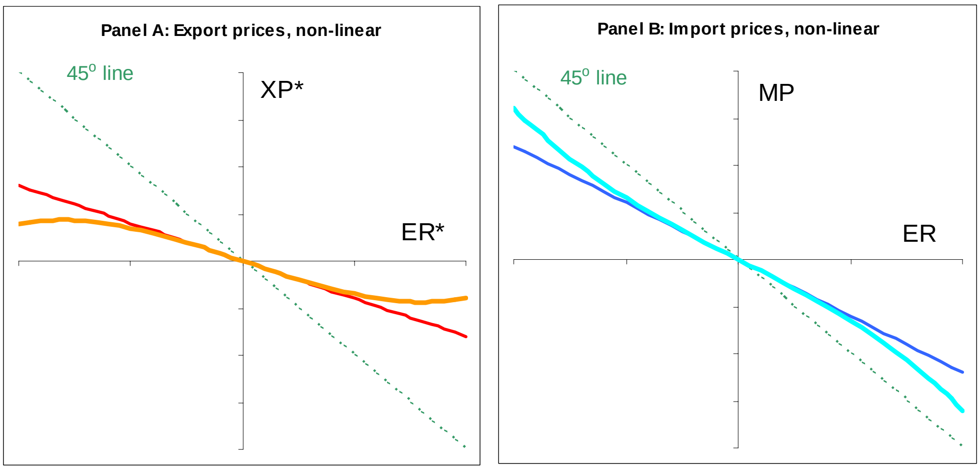

Figure 4: Logistic function (β=-0.5, γ = 0.1, c=100).

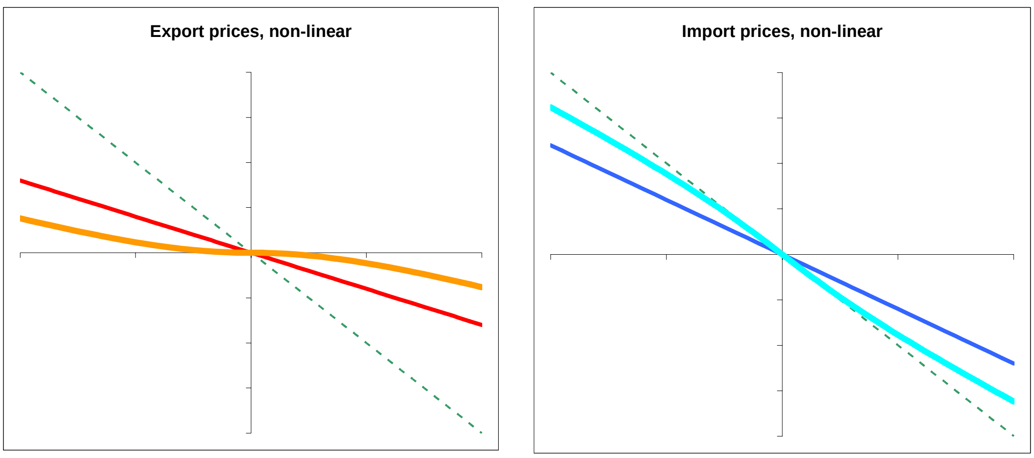

Figure 5: “The tipping point” and the linear interval.