A Regime Switching Analysis of Exchange Rate Pass-through*

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Abstract

We investigate changes in the pricing policies of exporters, including changes in the exchange rate pass-through elasticity, and changes in the elasticities of variables that affect the firm's markup. We set up a theoretical model of optimal export pricing in order to illustrate how changes in the pass-through elasticity can emerge together with changes in other elasticities in the pricing policy. Based on our theoretical formulation, we empirically study changes in all the elasticities that define the pricing policy as opposed to focusing only on the exchange rate pass-through. In the empirical model, we assume that in every period exporters get to set prices by following either a "high pass-through" or a "low pass-through" pricing policy. The transition from one policy to the other is governed by a Markov process whose transition probabilities depend on economic fundamentals. We estimate the model using data we have collected on 35 lines of imported cars to the US, from seven exporting countries, for the 1980-2004 period. We find that the "low pass-through" regime is characterized by: a low exchange rate pass-through; a low response to misalignments in the firm's relative price; a low volatility of technology and preference shocks; and a higher duration than the high pass-through regime. Monetary stability and the market structure are significant factors behind the switching of pricing policies. Ceteris paribus, monetary stability measured as the cross-country inflation differential explains abut 22% of the year-to-year variation in the exchange rate pass-through coefficient; when measured by the volatility of the exchange rate, it explains 37%. Market concentration measured by the Herfindahl index explains about 40%.

Key Words: Exchange Rate Pass-through; Markov Regime Switching; Export Pricing

JEL Classification: E31, F31, F41

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1 Introduction

There is a growing empirical literature that documents a decline in the exchange rate pass-through elasticities in various industries and for a number of countries—see, for example, Campa and Goldberg (2005) for OECD countries, Frankel et al. (2005) for a large set of developed and developing countries, and Marazzi and Sheets (2007) for the US economy. While theoretical studies examine the implications of the decline in the pass-through for adjustments of external imbalances and monetary policy, the sources of the instability of the pass-through elasticity are not fully established by empirical studies.

Theoretical studies suggest a number of economic fundamentals that determine an exporting firm's optimal degree of exchange rate pass-through. While some of the studies focus on product or industry specific characteristics, others highlight the role of macroeconomic conditions. Some of the product and/or industry specific factors that have been studied are substitutability of the export good—e.g., Giovannini (1988), Donnenfeld and Zilcha (1991), Friberg (1998), Goldberg and Tille (2005)—, competitive conditions in foreign markets—e.g., Krugman (1987), Froot and Klemperer (1989)—strategic complementarities and the market share of the exporting country—e.g., Feenstra et al. (1996), Bacchetta and van Wincoop (2005), Bodnar et al. (2002). The macroeconomic variables that have been identified theoretically as important for the degree of pass-through are exchange rate volatility and inflation—Taylor (2000), Devereux et al. (2004). As one or more of these factors vary across time for different exporters, the pricing policies of exports can change, which in turn affect the degree of exchange rate pass-through.

The aim of this paper is to empirically investigate the economic factors that affect the instability of the pricing policies of exporters, using a panel dataset of US automobile imports. Changes in the pricing policies may imply instability in the pass-through elasticity as well as instability in the elasticities of the determinants of the firm's mark-up.[1] The challenge in disentangling different factors behind changes in the degree of exchange rate pass-through is that the pricing policies of exporters are unobservable, and they might change along with other economic factors. Hence, one needs to draw inferences not only about the optimal pricing rules that the exporters follow, but also about the underlying economic fundamentals that can affect the choice of the pricing rule itself. For that reason, we consider the

[1] The idea of firms adjusting their mark-ups to stabilize prices in the face of exchange rate shocks has been referred to as "pricing-to-market" following Krugman (1987).

hidden regime switching methodology by Hamilton (1990) and Hamilton (1996), and its later extension by Diebold et al. (1993) as the appropriate econometric framework to build inferences about the underlying fundamentals that determine the choice of the pricing policy, and to simultaneously estimate the elasticities of the pricing policies.

We start by formulating a theoretical model of optimal export pricing decisions where the exporters optimally choose the degree of exchange rate pass-through as part of the optimal pricing plan. The optimal policy to choose the degree of exchange rate pass-through is a function of the volatility of the exchange rate and its correlation with other variables that determine the optimal price; our results generalize the results of Devereux et al. (2004). The crucial point in our generalization is to show that the economic fundamentals that determine the elasticities of the optimal price with respect to variables that determine the firm's markup—such as the price of competitors or consumers' income—are the same fundamentals that parametrize the optimal policy to choose the degree of exchange rate pass-through.[2] Therefore we can establish, for example, that changes in the fundamentals that determine the elasticity of the optimal price with respect to the price of competitors—i.e., the degree of strategic complementarities—may induce at the same time changes in the exchange rate pass-through even if we hold constant the exchange rate volatility. Similar arguments apply for other variables that determine the firms' markup. Hence, instead of focusing only on the potential changes of the pass-through parameter, we investigate the stability of the full pricing policies.

The empirical model assumes that in every period exporters set prices by following either a "high pass-through" or a "low pass-through" pricing policy. The transition from one policy to the other is governed by a Markov process whose transition probabilities depend on economic fundamentals. For the choice of the economic fundamentals, we rely on the theoretical literature on the determinants of the optimal choice of the exchange rate pass-through, and consider monetary stability, market concentration and exporting country's market share. The actual state of the firm is unobservable: we only observe the announced price, but do not observe the pricing regime that it comes from. Following the methodology in Diebold et al. (1993), we estimate the probability of being in one regime versus the other along with the parameters in the pricing equation. The estimated probabilities show

[2]The key for our results is to assume that the price elasticity of demand is a function of the same variables that determine the demand itself such as the the relative price of the good, income, etc. Instead, Devereux et al. (2004) assume a constant price elasticity.

which factors are significant in determining the degree of pass-through. Furthermore, analyzing the evolution in those factors, we investigate their role in the changes in the average exchange rate pass-through implied by the model.

Our dataset consists of 35 automobile models from 7 exporting countries, which we have collected from the *Ward's Automotive Yearbooks* for the 1980-2004 period. For each model we observe the manufacturer's suggested retail price, the number of units imported into the US, physical characteristics of the specific model, and location of assembly for the units sold in the US. The manufacturer's suggested retail price is the price at the port of entry; thus, the exchange rate pass-through coefficients that we estimate are at-the-dock rates.[3] The manufacturer's suggested retail price captures more accurately the behavior of exporters than the transaction prices since transaction prices are set in part by the dealer. The manufacturer's suggested retail prices are net of local taxes, transportation costs, or optional equipment added by the dealer that may contain domestic components; moreover they do not include variations due to dealers' discriminatory practices—see e.g., Goldberg (1996).

Our estimations suggest that the low pass-through (high pass-through) regime is characterized by: (i) a low (higher) exchange rate pass-through elasticity of between 10% and 15% depending upon the specification (of between 21% and 24%); (ii) lower (higher) sensitivity to misalignments in the firm's relative price, with an elasticity of 50% to 62% across specifications (between 85% and 92%); that is, the degree of strategic complementarities is much lower in the low pass-through regime; (iii) lower (higher) volatility of the unobservable shocks—a combination of preference shocks and technology shocks—of about only one percent of the volatility in the high pass-through regime; and (iv) longer (shorter) average duration of the adoption of the pricing policy; once a firm adopts the low pass-through pricing policy it keeps it for between two years and four months and three years and six months (between one year and ten months and two years and seven months). These findings are robust to including different variables in the transition probabilities.

The significant factors behind the switching of the pricing polices that we identify are the inflation rate in the US, volatility of the exchange rate, the exporting country's market share, and market concentration (measured by the Herfindahl index of the industry). Using the conditional probabilities that we estimate, we build inferences for the fraction of firms in

[3]The percentage of exchange rate fluctuations that the exporters choose to transmit is interpreted as the pass-through "at the dock". The exchange rate pass-through to the final consumption goods can also depend on local costs. See, for example, Burstein et al. (2003) and Corsetti and Dedola (2004).

the low pass-through regime for each year in our sample. Hence, we build an inference on the average exchange rate pass-through for the 1980-2004 horizon. We find that, everything else constant, the cross-country inflation differential explains about 22% of the year-to-year variations in the average exchange rate pass-through coefficient; everything else constant, the volatility of the exchange rate explains 37%, and the market concentration explains about 40%; in contrast, the country's market share variable explains less than 2%. In a five year horizon, the percentage due to market concentration falls to 17%, whereas the percentage due to exchange rate volatility increases to 53%, and the percentage due to the inflation differential does not change by much.

The paper is organized as follows: Section 2 develops the theoretical export pricing equation that we use in our estimations. Section 3 presents the empirical methodology. Section 4 describes the sources of our data and the variables that we construct. Section 5 presents and interprets the results. Section 6 discusses the exchange rate pass-through dynamics for the industry and its decomposition. Section 7 concludes.

2 A Model for Pricing of Exports

The purpose of this section is two-fold. First we illustrate how changes in the pass-through elasticity can emerge together with changes in other elasticities. Second, we formulate the pricing equation that will be used in the estimations. For our theoretical illustration we show that if there are long-run structural changes in the relative price of a firm (i.e. a shift in the steady state relative price), the full optimal pricing rule can change including the optimal exchange rate indexation rule.[4, 5] Hence, there will be a shift in the optimal pricing rule that will include changes in the exchange rate pass-through, as well as marginal cost pass-through and the responsiveness of prices to the competitors' prices—i.e. the degree of strategic complementarity.[6] Our theoretical formulation highlights the importance of studying the changes in the exchange rate pass-through concurrently with potential changes in the other determinants of the optimal pricing policies. The regime switching framework we

[4]We do not investigate theoretically the sources of the change in the steady state relative prices. One example can be a structural change in the firm-specific productivity, other example could be changes in the growth rate of nominal marginal costs across foreign and domestic firms, etc.

[5]Gopinath et al. (2007) use strategic complementarities in their model to show that medium-run pass-through can be different than long-run pass-through. In our model, a lower degree of strategic complementarities—perhaps driven by a higher steady-state relative price—can induce a lower pass-through.

[6]Formally we define the degree of strategic complementarities as the elasticity of the optimal price with respect to the industry price index, assuming it is positive. If the elasticity were negative then the goods would be strategic substitutes.

present in the following section allows us to do that.

The exporter's optimal pricing policy has two components: an optimal preset or baseline price[7], and an optimal degree of indexation of the preset price to the exchange rate surprise—i.e., the non-expected component of the exchange rate. In particular we assume that in period $t-1$, the exporter optimally chooses and commits to a pricing policy with a baseline preset price $p^*_{\ell t}$, and one out of two possible degrees of indexation of the preset price to the exchange rate surprises $\delta_j \in \{\delta_L, \delta_H\}$. As it will become clear later, our optimal indexation problem allows us to obtain as special case the optimal currency choice rule—producer currency pricing versus local currency pricing—obtained in Devereux et al. (2004). However, the general case allows us to demonstrate how changes of steady-state relations, such as shifts in the steady-state relative prices, can alter all the components of the optimal pricing rule, including the baseline price and the optimal indexation rule.

Formally, let $\mathbb{L}$ be the set of firms in the US market and let $\ell \in \mathbb{L}$ be the index of a foreign firm. At time $t-1$ the foreign firm ℓ optimally chooses the baseline price for the product that will be sold at time t, $p^*_{\ell t}$, as well as one of two possible degrees of indexation of the preset price to the exchange rate surprises. Then, at time t the producer sets the final price $p_{\ell t}$ using the transformation:

$$p_{\ell t} = \left(s_t\right)^{\delta_j} p^*_{\ell t}, \tag{1}$$

where $s_t \equiv e_t/\mathbb{E}_{t-1}e_t$ is the exchange rate surprise; e_t is the exchange rate and $\mathbb{E}_{t-1}e_t$ is the expected exchange rate conditional on the information available in $t-1$. The parameter $\delta_j \in \{\delta_L, \delta_H\}$ is the degree of indexation of the preset price to the exchange rate surprise, with $\delta_j \in [0,1]$ and $\delta_L < \delta_H$. The optimal pricing equation dervied below shows that the parameter δ_j captures the effects of the exchange rate surprise s_t on the final price, whereas the optimal baseline preset price $p^*_{\ell t}$ contains the effects of the expected exchange rate $\mathbb{E}_{t-1}e_t$.

We assume that the demand for the good ℓ, produced by the firm ℓ, is a function of its relative price $p_{\ell t}/P_{\mathbb{L}t}$, where $P_{\mathbb{L}t}$ is the price index of the industry, and a function of a vector of variables $\underline{Y}_{\ell t}$ which can include observables such as consumers' income or unobservables such as preference shocks. Let

$$Q\left(\frac{p_{\ell t}}{P_{\mathbb{L}t}};\underline{Y}_{\ell t}\right) \tag{2}$$

be the demand function, and let $\eta\left(\frac{p_{\ell t}}{P_{\mathbb{L}t}};\underline{Y}_{\ell t}\right) \equiv -\frac{\partial Q(\cdot)}{\partial p_{\ell t}}\frac{p_{\ell t}}{Q(\cdot)} > 0$ be the price elasticity of demand.

[7]Throughout this section we use preset price and baseline price interchangeably.

Note that in general we assume that the price elasticity is a function of the same variables than the demand itself.

The production technology exhibits constant returns to scale. In the absence of technology shocks, the real marginal cost is $\frac{\psi^*_{\ell t}}{P^*_t}$, where $\psi^*_{\ell t}$ is the nominal marginal cost denominated in producer's currency and P^*_t is the price index of the foreign consumption basket.[8] However, the firm is subject to exogenous technology shocks $z^*_{\ell t}$; therefore, the effective real marginal cost is $\frac{\psi^*_{\ell t}}{P^*_t}\frac{1}{z^*_{\ell t}}$.

At time $t-1$ the producer chooses $p^*_{\ell t}$ and $\delta_j \in \{\delta_L, \delta_H\}$ to maximize the expected real profits $\Pi_{\ell t}$ (in terms of the foreign consumption basket):

$$\mathbb{E}_{t-1}\Pi_{\ell t} \equiv \mathbb{E}_{t-1}\frac{\Upsilon^*_t}{P^*_t}\left\{\frac{p_{\ell t}}{e_t}Q\left(\frac{p_{\ell t}}{P_{\mathbb{L}t}};\underline{Y}_{\ell t}\right) - \frac{\psi^*_{\ell t}}{z^*_{\ell t}}Q\left(\frac{p_{\ell t}}{P_{\mathbb{L}t}};\underline{Y}_{\ell t}\right)\right\}, \tag{3}$$

where Υ^*_t is the relevant stochastic discount factor between $t-1$ and t, subject to the transformation (1) and the demand function (2).

We analyze the optimal pricing policy using a second-order Taylor expansion of the profit function around a steady-state equilibrium. We assume that the steady-state price elasticity $\eta(\frac{p_\ell}{P_{\mathbb{L}}}, \underline{Y}_\ell)$ is increasing in the steady-state relative price as in Dotsey and King (2005) or Gust et al. (2006).[9]. Thus, $\eta_1 \equiv \frac{\partial\eta(\cdot)}{\partial(p_\ell/P_{\mathbb{L}})} > 0$

2.1 Optimal Preset Price

Let $\hat{x}_t \equiv \frac{x_t - x}{x}$ denote percentage deviation of any variable x_t from its steady-state x. Substituting the transformation (1) in the profit function (3) and using a second-order Taylor expansion of the profit function around a steady-state we can write the problem for the choice of the preset baseline price $p^*_{t\ell}$ as

$$\begin{aligned}\max_{p^*_{\ell t}}\mathbb{E}_{t-1}\Big\{ & -\omega_r^{p_\ell}\left(\hat{p}^*_{\ell t}\right)^2 + \omega_r^{e}\left(\hat{p}^*_{\ell t}\right)\left(\hat{e}_t\right) + \omega_r^{\psi}\left(\hat{p}^*_{\ell t}\right)\left(\hat{\psi}^*_{\ell t}\right) + \omega_r^{P_{\mathbb{L}}}\left(\hat{p}^*_{\ell t}\right)\left(\hat{P}_{\mathbb{L}t}\right) \\ & + \omega_r^{y}\left(\hat{p}^*_{\ell t}\right)\left(\hat{y}_{\ell t}\right) - \omega_r^{z}\left(\hat{p}^*_{\ell t}\right)\left(\hat{z}_{\ell t}\right) + \text{t.i.p.} + \mathcal{O}(\|\xi\|^3)\Big\}\end{aligned} \tag{4}$$

where the ωs are positive under the conditions detailed in Table 1, $y_{\ell t}$ represents a typical element of the vector $\underline{Y}_{\ell t}$, $\mathcal{O}(\|\xi\|^3)$ are terms of third order and higher, and t.i.p. are terms

[8]We denote the variables that belong to the producer's country with stars, and call them the foreign country variables. Throughout the paper, the destination country, US, is the domestic country.

[9]Gust et al. (2006) use a Dotsey-King aggregator in a model that shows that trade integration produces a decline in the exchange rate pass-through.

independent of prices.[10] As can be seen from the expressions in Table 1, the ωs depend on the steady state relative prices among other steady-state values. If there is a shift in the steady state relative prices, the parameters of the optimization problem, ωs, will change. Therefore, we append a subscript r to denote the set of parameters that are relevant for a particular steady state of relative prices.[11] It is also important to note that ωs are not functions of the degree of indexation δ_j, since in steady-state the exchange rate surprise is equal to one—see Table 1 for details.

[Table 1 about here.]

From (4) the optimal baseline price is

$$\hat{p}^*_{\ell t} = \gamma^e_r \mathbb{E}_{t-1}\hat{e}_t + \gamma^\psi_r \mathbb{E}_{t-1}\hat{\psi}^*_{\ell t} + \gamma^{P_{\mathbb{L}}}_r \mathbb{E}_{t-1}\hat{P}_{\mathbb{L}t} + \gamma^y_r \mathbb{E}_{t-1}\hat{y}_{\ell t} - \gamma^z_r \mathbb{E}_{t-1}\hat{z}_{\ell t}, \tag{5}$$

where $\gamma^e_r \equiv \frac{1}{2}\frac{\omega^e_r}{\omega^{p_\ell}_r}$, $\gamma^\psi_r \equiv \frac{1}{2}\frac{\omega^\psi_r}{\omega^{p_\ell}_r}$, $\gamma^{P_{\mathbb{L}}}_r \equiv \frac{1}{2}\frac{\omega^{P_{\mathbb{L}}}_r}{\omega^{p_\ell}_r}$, $\gamma^y_r \equiv \frac{1}{2}\frac{\omega^y_r}{\omega^{p_\ell}_r}$, and $\gamma^z_r \equiv \frac{1}{2}\frac{\omega^z_r}{\omega^{p_\ell}_r}$. The elasticities in the optimal baseline price equation, the γs, are functions of relative prices due to the general demand function that allows for a non-constant price elasticity (we will discuss the CES case below). In particular, the elasticity with respect to the expected exchange rate,

$$\gamma^e_r \approx \frac{1}{\kappa + 3}, \text{ with } \kappa \equiv 2 * \eta_1 \frac{p_\ell}{P_{\mathbb{L}}} \frac{1}{\eta(\eta - 1)},$$

is decreasing in relative prices whenever η_1 is small enough to satisfy

$$\frac{\eta(\eta - 1)}{2\eta - 1} > \frac{p_\ell}{P_{\mathbb{L}}}\eta_1, \tag{6}$$

(assuming η_1 constant).

Consequently, as long as the condition in (6) holds, an exporter acting around a high (low) relative price steady-state will have a lower (higher) expected exchange rate pass-through elasticity. Moreover, as shown in Table 1, $\gamma^e_r = \gamma^\psi_r$. Thus, around a steady-state equilibrium with high relative prices, the producer not only passes less of the expected deviations of the exchange rate but also less of the expected deviations in the marginal cost

[10] The term t.i.p. resembles the “terms independent of policy” in Woodford (2005).t.i.p. includes first- and second-order terms of variables that the producer takes as given. Thus they vanish from the producer’s first-order condition.

[11] Of course, we use steady-state relative prices as an illustration, but one can choose other steady-state values such as the steady-state value of the price elasticity itself (η) to elaborate the argument that we are trying to convey in this section.

(relative to the baseline price in an equilibrium with low relative prices). Similarly, we can show that a sufficient but not necessary condition for $\gamma_r^{P_{\mathbb{L}}}$ to be decreasing in relative prices is

$$\frac{1}{\gamma_{P_{\mathbb{L}}} - \frac{p_\ell}{P_{\mathbb{L}}}} > -\frac{\partial\kappa/\partial\left(p_\ell/P_{\mathbb{L}}\right)}{(2+\kappa)},$$

where $\partial\kappa/\partial\left(p_\ell/P_{\mathbb{L}}\right) > 0$. This condition states that strong strategic complementarities together a low relative price ensure that the degree of complementarities is decreasing in relative prices.

2.2 Optimal Final Price

Now we turn to the optimal choice for the indexation of the baseline price to the exchange rate surprises. Given the optimal baseline price the producer sets the final price as

$$\hat{p}_{\ell t} = \delta_j \hat{s}_t + \hat{p}^*_{\ell t}. \tag{7}$$

with $\hat{s}_t = \hat{e}_t - \mathbb{E}_{t-1}\hat{e}_t$, and $\hat{p}^*_{\ell t}$ defined in (5). In order to choose the degree of indexation, $\delta_j \in \{\delta_L, \delta_H\}$, the producer compares the expected profits obtained with the two indexation parameters. Using the second-order Taylor expansion of profits (4), it is straight forward to show that the producer chooses δ^H if and only if

$$\mathbb{E}_{t-1}\left[\hat{\Pi}_{\ell t}(\delta^H) - \hat{\Pi}_{\ell t}(\delta^L)\right] > 0,$$

that is, if and only if

$$\begin{aligned}\frac{1}{2}(\delta_H + \delta_L)var_{t-1}(\hat{e}_t) < \gamma_r^e var_{t-1}\left(\hat{e}_t\right) + \gamma_r^\psi cov_{t-1}\left(\hat{e}_t, \hat{\psi}^*_{\ell t}\right) \\ + \gamma_r^{P_{\mathbb{L}}} cov_{t-1}\left(\hat{e}_t, \hat{P}_{\mathbb{L}t}\right) + \gamma_r^y cov_{t-1}\left(\hat{e}_t, \hat{y}_{\ell t}\right) - \gamma_r^z cov_{t-1}\left(\hat{e}_t, \hat{z}_{\ell t}\right);\end{aligned} \tag{8}$$

otherwise it chooses δ_L.

Note that, we can ideate scenarios where the condition above is less likely to hold when γ_r^e is smaller. That is, scenarios where the producer that passes through a smaller fraction of the expected change in the exchange rate onto its price is also more likely to pass-through a smaller fraction of the exchange rate surprise. For example, we showed above the conditions under which γ_r^e, γ_r^ψ and $\gamma_r^{P_{\mathbb{L}}}$ decrease when the steady-state relative price increases. In our sample the average relative price increased by 46% in the period 1994-2004 relative to the period 1981-1993. However, what pricing policy an exporter is more likely to adopt, given an evolving economy, is a question better approached empirically as we do in the following sections.

The optimal baseline price and the optimal indexation for a CES demand function, and omitting the technology shock, can be obtained as special cases of our specification. The optimal baseline price in that case is $\hat{p}^*_{\ell t} = \mathbb{E}_{t-1}\{\hat{e}_t + \hat{\psi}^*_t\}$; that is, $\gamma^e_{ces} = 1$, $\gamma^{\psi}_{ces} = 1$ and $\gamma^{P_{\mathbb{L}}}_{ces} = \gamma^{y}_{ces} = 0$. Moreover, considering $\delta_H = 1$ and $\delta_L = 0$ the condition above boils down to:

$$\frac{1}{2} var_{t-1}(\hat{e}_t) > -cov_{t-1}(\hat{e}_t, \hat{\psi}^*_{\ell t}). \tag{9}$$

The condition above is the same condition for which a firm chooses producer currency pricing (PCP) in Devereux et al. (2004).[12] This is perhaps not surprising if one notes that with $\delta_H = 1$ our indexation setup and PCP both imply full exchange rate pass-through: $p_{\ell t} = \hat{s}_t + p^*_{\ell t} = e_t + \mathbb{E}_{t-1}\{\hat{\psi}^*_t\}$. This result is in line with the equivalence result of Engel (2006) that shows that the choice of PCP versus LCP is a special case of a firm that chooses the optimal indexation of its export price to the exchange rate.

Finally, we can define the optimal pricing policy that we will use in our empirical framework as

$$\hat{p}_{\ell t} = \delta_{rj}\hat{s}_t + \gamma^{\psi}_r \mathbb{E}_{t-1}\hat{\psi}_{\ell t} + \gamma^{P_{\mathbb{L}}}_r \mathbb{E}_{t-1}\hat{P}_{\mathbb{L}t} + \gamma^{y}_r \mathbb{E}_{t-1}\hat{y}_{\ell t} - \gamma^{z}_r \mathbb{E}_{t-1}\hat{z}_{\ell t}, \tag{10}$$

where $\psi_{\ell t}$ is the marginal cost in units of the importing country's currency; this term is obtained by imposing $\gamma^e_r = \gamma^{\psi}_r$. This constraint implies that the exporter transforms the expected marginal costs in foreign currency to dollars by using the expected exchange rate. Such constraint can also be found in Feenstra et al. (1996), who impose $\gamma^e_r = \gamma^{\psi}_r$, and define one pass-through coefficient as both, the marginal cost pass-through and exchange rate pass-through in their empirical analysis. The first term in (10) captures the effects of the exchange-rate surprise in the exporter's price, where the chosen degree of indexation δ_{rj} embeds the information on γ^e_r, and the other parameters, thus we added the subscript r.

We divide the impact of changes in the exchange rate on the optimal price into two components: the impact of the expected exchange rate and impact of the exchange rate

[12] Note that $cov(\psi, e)$ here is minus such covariance in Devereux et al. because our definition of the exchange rate is the inverse of theirs.

surprise. Thus we define the exchange rate pass-through elasticity at the firm level as

$$\eta_\ell \equiv \frac{\partial \hat{p}_{\ell t}}{\partial[\hat{e}_t - \mathbb{E}_{t-1}\hat{e}_t]} + \frac{\partial \hat{p}_{\ell t}}{\partial \mathbb{E}_{t-1}\hat{e}_t} = \delta_{rj} + \gamma_r^e = \delta_{rj} + \gamma_r^\psi, \tag{11}$$

where the first term captures the effects of the exchange rate surprise in the exporter's price, and the second term captures the effects of the expected changes in the exchange rate.

3 A Regime Switching Model of Price Setting and its Estimation

3.1 Empirical Framework

We use the optimal pricing policy in (10) to build our empirical framework. The previous section provided an illustration of shifts in optimal pricing policies, where changes in exchange rate pass-through emerge together with changes in other elasticities. In the theoretical derivations, we exemplified a case where the parameters of the pricing policy might change due to shift in the steady state relative prices. In our empirical application, we generalize the argument, and we assume that in each period t, the foreign firm ℓ is subject to a random shock $\xi_{\ell t} \in \{0, 1\}$ that triggers one of the two different sets of parameter values in the optimal pricing policy (10), $\{\delta_{\xi_{\ell t}}, \gamma^e_{\xi_{\ell t}}, \gamma^\psi_{\xi_{\ell t}}, \gamma^{P_{\mathbb{L}}}_{\xi_{\ell t}}, \gamma^y_{\xi_{\ell t}}, \gamma^z_{\xi_{\ell t}}\}$, and hence determines the pricing regime. We assume that the random shock follows a two-state first-order Markov process, whose transition probabilities depend on economic fundamentals. We refer to the two pricing policies resulting from those sets of parameters as the "high pass-through" pricing regime and the "low pass-through" pricing regime. The actual state of the firm ℓ is unobservable to the econometrician, who only observes the actual price but does not observe the pricing regime it comes from. Our assumption of a first-order Markov process for $\xi_{\ell t}$ implies history dependence in the adoption of a particular pricing policy. Thus, estimates of the transition probability matrix of the Markov process provide estimates of the degree of persistence or stickiness of the high (low) pass-through pricing regime.

Accordingly, based on (10), we model observed changes in the optimal price denominated in dollars of the variety ℓ, $\Delta\hat{p}_{\ell t} \equiv \hat{p}_{\ell t} - \hat{p}_{\ell t-1}$, as:

$$\Delta\hat{p}_{\ell t} = \beta^s_{\xi_t}\Delta\hat{s}_t + \beta^\psi_{\xi_t}\Delta\hat{\psi}_{\ell t} + \beta^{P_{\mathbb{L}}}_{\xi_t}\Delta\hat{P}_{\mathbb{L}t} + \Delta\hat{Y}'_{\ell t}\beta^y_{\xi_t} + \varepsilon_{\xi_{\ell t}}, \tag{12}$$

where $\Delta\hat{s}_t$ is a proxy for the change in the exchange rate surprise; $\Delta\hat{\psi}_{\ell t} = \Delta\{\hat{\psi}^*_{\ell t} + \hat{e}_t\}$ is a proxy for the expected change in the exchange-rate-adjusted nominal gross marginal cost (recall $\gamma^e_r = \gamma^{\psi}_r$); $\Delta\hat{P}_{\mathbb{L}t}$ is a proxy for the expected change in the average price of the competitors; and $\Delta\hat{Y}_{\ell t}$ is a column vector of proxies for expected changes in other variables that may affect the firm's markup.[13] Section 4 describes in detail how we construct the variables utilized in our estimations.

The error term $\varepsilon_{\xi_{\ell t}}$ follows a standard normal distribution, $\varepsilon_{\xi_{\ell t}} \sim \text{i.i.d.}N(0, \sigma^2_{\xi_{\ell t}})$. Note that the error term $\varepsilon_{\xi_{\ell t}}$ contains innovations to unobservable technology shocks, $\hat{z}^*_{\ell t}$ in equation (10), as well as innovations to unobservable demand shocks or preference shocks for which we cannot control for in the vector $\Delta\hat{Y}_{\ell t}$. Hence, we can only identify the variance $\sigma^2_{\xi_{\ell t}}$ as the variance of an aggregate of both technology and preference innovations.

Following Diebold et al. (1993), we assume that the transition probability matrix that governs the two-state Markov process $\xi_{\ell t} \in \{0, 1\}$ contains the following elements:

$$\begin{aligned} g^{00}_{\ell t} &\equiv \Pr(\xi_{\ell t} = 0 | \xi_{\ell t-1} = 0) = \mathfrak{B}(\underline{z}'_{\ell t-1}\phi_0), \\ g^{11}_{\ell t} &\equiv \Pr(\xi_{\ell t} = 1 | \xi_{\ell t-1} = 1) = \mathfrak{B}(\underline{z}'_{\ell t-1}\phi_1), \\ g^{01}_{\ell t} &\equiv \Pr(\xi_{\ell t} = 0 | \xi_{\ell t-1} = 1) = 1 - g^{11}_{\ell t}, \end{aligned} \tag{13}$$

and

$$g^{10}_{\ell t} \equiv \Pr(\xi_{\ell t} = 1 | \xi_{\ell t-1} = 0) = 1 - g^{00}_{\ell t},$$

where $\mathfrak{B}(x) = \frac{\exp(x)}{1+\exp(x)}$ is the logistic function, $\underline{z}_{\ell t}$ is a vector of economic variables that determine the transition probabilities, and the ϕs are vectors of parameters to be estimated. We choose the determinants of the transition probabilities, $\underline{z}_{\ell t}$, based on the theories on optimal choice of the exchange rate pass-through and optimal choice of the currency denomination of exports. When $\underline{z}_{\ell t} = 1 \; \forall t$, the model reduces to that of Hamilton (1990) with constant transition probabilities.

[13] For example, we include fixed effects, oil price shocks and US disposable income in $\Delta\hat{Y}_{\ell t}$.

3.2 The Log-likelihood Function and Its Estimation

We jointly estimate the parameters in equations (12) and (13) by following closely the EM algorithm proposed by Diebold et al. (1993).[14] Accordingly, let $\beta_0 \equiv \left[\beta_0^s\ \beta_0^{\psi}\ \beta_0^{P_{\mathbb{L}}}\ \beta_0^{y\prime}\ \right]'$, $\beta_1 \equiv \left[\beta_1^s\ \beta_1^{\psi}\ \beta_1^{P_{\mathbb{L}}}\ \beta_1^{y\prime}\ \right]'$, and $\theta \equiv \left[\beta_0'\ \sigma_0\ \phi_0'\ \beta_1'\ \sigma_1\ \phi_1'\ \right]'$. Let $\mathbb{I}_{\ell t}^{0}$ be the indicator function equal to one if $\xi_{\ell t} = 0$ and zero otherwise (independent of $\xi_{\ell t-1}$); let $\mathbb{I}_{\ell t}^{00}$ be the indicator function equal to one if $\xi_{\ell t-1} = 0$ and $\xi_{\ell t} = 0$ and zero otherwise. Similarly, let $\mathbb{I}_{\ell t}^{11}$ be equal to one if $\xi_{\ell t-1} = 1$ and $\xi_{\ell t} = 1$ and zero otherwise. As a result, we also have $\mathbb{I}_{\ell t}^{10} = 1 - \mathbb{I}_{\ell t}^{00}$ and $\mathbb{I}_{\ell t}^{01} = 1 - \mathbb{I}_{\ell t}^{11}$.

To simplify the notation below, let $y_{\ell t} \equiv \Delta\hat{p}_{\ell t}$ be the dependent variable in the price equation; let $X_{\ell t} \equiv \left[\Delta\hat{s}_t\ \Delta\hat{\psi}_{\ell t}\ \Delta\hat{P}_{\mathbb{L}t}\ \Delta\hat{Y}_{\ell t}'\right]'$ be the vector of explanatory variables at t in the pricing equation. Further, denote $\underline{m}_{\tau}$ to be a $\tau \times 1$ vector of observations of the corresponding variable m for $t = 1, \ldots \tau$. Thus, $\underline{y}_{\ell T}$ is the vector with T observations of our dependent variable, $\underline{X}_{\ell T}$ is the matrix of explanatory variables in the pricing equation (12), and $\underline{Z}_{\ell T}$ is the matrix of variables in the probability equations (13). Hence, the matrices $\underline{y}_{\ell T}$, $\underline{X}_{\ell T}$ and $\underline{Z}_{\ell T}$ represent our data after the appropriate transformations (see Section 4).

The contribution of the unit ℓ to the complete-data likelihood function is:[15]

$$
\begin{aligned}
L_{\ell}\left(\underline{y}_{\ell T}, \underline{\xi}_{\ell T}, |\underline{X}_{\ell T}, \underline{Z}_{\ell T}; \theta\right) &= \prod_{t=1}^{T} \mathfrak{F}\left(y_{\ell t}, \xi_{\ell t} | \underline{y}_{\ell t-1}, \underline{\xi}_{\ell t-1}, \underline{X}_{\ell T}, \underline{z}_{\ell T}; \theta\right) \\
&= \prod_{t=1}^{T} \mathfrak{F}\left(y_{\ell t} | \xi_{\ell t}, \underline{X}_{\ell T}; \beta_0, \beta_1, \sigma_0, \sigma_1\right) \Pr\left(\xi_t | \xi_{t-1}, \underline{z}_{t-1}; \phi_0, \phi_1\right)
\end{aligned}
$$

where

$$
\mathfrak{F}\left(y_{\ell t} | \xi_{\ell t} = i, \underline{X}_{\ell T}; \beta_i, \sigma_i\right) = \frac{1}{\sqrt{2\pi\sigma_i^2}} \exp\left(\frac{-\left(y_{\ell t} - X_{\ell t}'\beta_i\right)^2}{2\sigma_i^2}\right)
$$

for $i = 0, 1$.

We can conveniently write the contribution of the unit ℓ to the complete-data log-likelihood function in terms of the indicator function defined above as:

[14] However we extend their estimators to allow for equality constraints of some parameters across regimes and also extend their proposed time-series algorithm in a natural fashion to our panel data. A detailed technical appendix is available upon request.

[15] It is the complete-data likelihood function in the sense that it contains data in all possible states. That is, the complete-data likelihood function is what we could formulate if we could observe the pricing policies in all of the possible states. Of course, this is not feasible since we can only observe the prices $\hat{p}_{\ell t}$, and we have to make an inference about the state $\xi_{\ell t}$.

$$\log L_\ell \left(\underline{y}_{\ell T}, \underline{\xi}_{\ell T}, |\underline{X}_{\ell T}, \underline{Z}_{\ell T}; \theta\right) = \sum_{t=1}^{T} \Big\{ \mathbb{I}^0_{\ell t} \log \mathfrak{F}\big(y_{\ell t}|\xi_{\ell t} = 0, \underline{X}_T; \beta_0\big)$$

$$+ [1 - \mathbb{I}^0_{\ell t}] \log \mathfrak{F}\big(y_{\ell t}|\xi_{\ell t} = 1, \underline{X}_T; \beta_1\big) + \mathbb{I}^{00}_{\ell t} \log g^{00}_{\ell t} + \mathbb{I}^{10}_{\ell t} \log(1 - g^{00}_{\ell t})$$

$$+ \mathbb{I}^{11}_{\ell t} \log g^{11}_{\ell t} + \mathbb{I}^{01}_{\ell t} \log(1 - g^{11}_{\ell t}) \Big\}.$$

Assuming that the Markov processes ξ_ℓ are independent across units ℓ, we can write the complete-data log-likelihood function for the of $\mathbb{L}^*$ automobile lines as:

$$\log L \left(\underline{y}_T, \underline{\xi}_T, |\underline{X}_T, \underline{Z}_T; \theta\right) = \sum_{\ell=1}^{\mathbb{L}*} \log L_\ell \left(\underline{y}_{\ell T}, \underline{\xi}_{\ell T}, |\underline{X}_{\ell T}, \underline{Z}_{\ell T}; \theta\right).$$

Since the observed prices come from unobservable states, it is not feasible to construct the complete-data log-likelihood function. The EM algorithm is a two-step iterative procedure to maximize the expected complete-data log-likelihood function conditional on the observed data. It is initiated by assigning initial probabilities for being in each state. In the first step (the *expectation* step), conditional on the initial guess, inferences on $\xi_{\ell t}$ are obtained using all the information in the sample. These inferences are called the smoothed probabilities. Then, in the second step (*maximization),* the expected complete-data log likelihood is maximized with respect to the parameters of the model. The procedure is iterated until θ converges. Once the estimates of θ are obtained, we can make inferences about the regime that was more likely to have been in effect in setting the price of a specific automobile line for a given year.

We compute the variance-covariance matrix of the estimates following the supplemented EM algorithm (SEM) of Meng and Rubin (1991). The main idea behind SEM is to find the increased variability due to missing information (in our case unobservable regimes), and add it to the complete data variance-covariance matrix, which we find analytically based on the second derivatives of the log-likelihood function.[16]

[16]See Diebold et al. (1993) for a detailed description of the EM procedure. A technical Appendix describing our implementation is available upon request. The details on computing the variance-covariance matrix, and the SEM algorithm can also be found in our technical Appendix.

4 Data Description and Sources

Our data on automobile imports into the US come from *Ward's Automotive Yearbook*. Similar catalog prices for the European market have been used by Goldberg and Verboren (2001) and Goldberg and Verboren (2005) in order to study price dispersions in local markets and law of one price. We have collected information on automobile imports for the 1980-2004 period. Although *Ward's Automotive Yearbook* has information on more imported automobiles, we restrict our attention to 35 lines, see Table 2 for details. Our choice of automobile models depends on the availability of price and quantity data for the baseline models. Because we would like to analyze the changes in prices of individual goods and link them to macroeconomic developments, we look at the models that have information for at least ten consecutive years. Furthermore, we restrict our choice of models based on the availability of information on the assembly plant for each model in order to control for marginal costs.[17] As a result, we end up with 35 baseline models from seven exporting countries: France, Germany, Italy, Japan, Korea, Sweden and the United Kingdom.

[Table 2 about here.]

Car prices. As our dependent variable, we use the manufacturer's suggested retail price in US dollars at the port of entry; thus, the pass-though coefficients we estimate is at the dock rates and not pass-through to the final consumer price.[18] The manufacturer's suggested retail price captures more accurately the behavior of exporters than the transaction prices since transaction prices are set in part by the dealer. As documented in Goldberg (1996) transaction prices include discriminatory practices based on the characteristics of the purchase transaction such as first-time buyer, trade-in and financing through the dealer. Moreover, Ayres and Siegelman (1995) find evidence of dealers' discriminatory practices based on the consumers' characteristics.

Our prices: (i) do not include destination charges[19]; (ii) do not include domestic costs

[17]Some car models in our sample are assembled in more than one location to be sold in different markets; we have information on the location of the assembly plants for those units sold in the US. As detailed below, we are as careful as possible when measuring marginal cost since as Gron and Swenson (1996) point out: accounting for factor-market decisions of firms is important in measuring exchange rate pass-through.

[18]See e.g., Nakamura (2007) and Hellerstein (2005) for the impact of local costs on the incompleteness of pass-through to the final consumer prices.

[19]After 1990, Wards Automotive Yearbook reports prices including the destination charges. For those years, we collected the information on destination charges from the *Market Data Book*, and subtracted them from the reported prices. Destination charges are typically flat rates set equal for all models within a brand; thus, they do not generate much variation in the prices.

added by the dealer through optional equipment; (iii) do not include potential dealers' discriminatory practices; (iv) do not include state or local taxes; and (v) include ocean freight and US import duty.

Ward's Automotive Yearbook provides information on the physical attributes, segment and sales of each model. The physical attributes include engine specifications (size, horse power, cylinders, etc.) and dimensions (height, weight, length). We use the information on the physical characteristics of the car to adjust the prices for quality improvements over time, and use the quality-adjusted prices in our estimations. To obtain the quality-adjusted prices, we regress original prices (in logs) on the ratio of horse-power to car weight and eliminate the systematic component.

Exchange rate surprise. Except for car prices, all the other variables used as regressors in the pricing and the probability equations are constructed from monthly series so that the information set corresponds to the information set available to the exporter at the time of the price announcement. The model year runs from October to September of the following year. Hence, we construct a proxy for the expected exchange rate variable as an average of monthly nominal market rates (official rates if market rates are not available) over the past two model years (source: International Financial Statistics, IMF). The exchange rate surprise variable is constructed by taking away our proxy for the expected exchange rate from the exchange rate of October—that is, the exchange rate available at the beginning of the model year.[20]

Marginal cost. As a proxy for the expected marginal cost, we use the monthly manufacturing wage rates (reported by the Bureau of Labor Statistics) of the country where the assembly plant is located, convert them to dollar terms using the monthly exchange rates, and construct the averages over the past two model years; consistently with the construction of the expected exchange rate. For 28 of the models in our sample *Ward's Automotive Yearbook* reports the location of the assembly plant as the manufacturer's country of origin,

[20] We also constructed the expected exchange rate as an average over the past 12 and 36 months; moreover we additionally constructed the exchange rate surprise based on the exchange rate of September. The results do not change from the ones presented in the next section. Furthermore, we can also construct the exchange rate surprise measure by subtracting the forward exchange rate from the spot rate. The forward rates are available only from 1984 for most of the countries in our sample, from 1985 for Sweden and from 2002 for South Korea (source: Reuters and Barclays Bank, Datastream). Using this alternative measure would require us to drop one fifth of the observations. Given that the correlation between our measure of the exchange rate surprises and the one constructed with the forward rates is 0.9636, we choose to keep the maximum available number of observations, and use the former measure in our analysis.

see Table 2. Seven models in our sample, are assembled in the US. For those seven models we follow Gron and Swenson (1996) in that we use a weighted average of the manufacturing wage rates in the US and the producer's country of origin. The weights are percentages of the dollar value of foreign and US inputs in the total value of inputs reported by the Foreign Trade Zones Board.[21]

Competitors' prices. We use monthly information on the US CPI of new cars (source: Bureau of Labor Statistics) to build a proxy for the expected change in prices of competitors. Consistently with other proxies for the expected variables, we take the average over the 24 months corresponding to the previous two model years.

Market shares, Herfindahl index and country shares. From the *Ward's Automotive Yearbook*, we have information on the quantity of all the different automobile lines (domestic and imported) that were sold in a given year. Using the quantity information, we build a Herfindahl index to measure market concentration. Moreover, we use the data on quantity of total imports from a particular country to construct the total market share of the exporting countries. As suggested by Feenstra et al. (1996) and Bacchetta and van Wincoop (2005), the exporting country's market share is defined as quantity of exports by a country to the US as a ratio of total new automobile imports in the US.

Inflation and exchange rate volatility. The inflation variable is the 24-month average of annualized inflation rates calculated from consumer price indices over the previous two model years. Finally, our proxy for exchange rate volatility is the 24-month average of monthly squared changes in the log of the exchange rate during the two previous model years. The CPIs and exchange rates come from the International Financial Statistics, IMF.

5 Empirical Results

In this section we present the estimates of the pricing policies defined by equations (12) and (13) using our panel data of prices of 35 narrowly defined car models imported to the US

[21] Each Foreign Trade Zone (FTZ) reports the dollar value of inputs from domestic sources and the dollar value of foreign inputs. We use that information to construct the weights in the marginal cost. We are able to match the specific models to a particular FTZ using the location of the assembly plant.

that covers the period 1980-2004 for seven exporting countries: England, France, Germany, Italy, Japan, Korea and Sweden.

Our strategy in the sequence of models is first to keep the transition probabilities constant as in Hamilton (1990), and discuss the dimensions in which the "low pass-through" regime differs from the "high pass-through" regime. Next, we consider the fundamental variables that various theories have identified as important determinants for the choice of currency denomination of exports and the degree of exchange rate pass-through. Hence, we allow for time-varying transition probabilities as in Diebold et al. (1993), and discuss the significance of various economic indicators in the light of our estimation results.

5.1 Constant Transition Probabilities

As highlighted in equation (12), we allow the optimal export price to respond to changes in the exchange rate surprise, expected changes in marginal cost, and to expected changes in the prices of competitors; Section 4 describes how we construct proxies for such variables. We also control for the automobile line specific fixed effects and US disposable income.[22] In preliminary specifications, we used likelihood ratio tests to investigate the equality of marginal cost and disposable income coefficients across regimes, and we find that we cannot reject the cross-regime equality of the parameters. Therefore, we only report the constrained results, and provide the likelihood ratio statistics for the validity of the constraints in Table 3.

[Table 3 about here.]

As in Hamilton (1990), the transition probabilities in (13) are constant.[23] The parameter estimates, standard errors and some statistics for the model with constant transition probabilities are reported in the first column of Table 3. This first specification with constant transition probabilities shows four key robust results that also hold for the other specifications presented in Table 3:

- First, as mentioned in Section 2.2, we decompose the effects of the exchange rate on prices into two terms: the effect of the expected exchange rate that works through the exchange-rate-adjusted marginal cost and the effect of the exchange rate surprise. We

[22]In an alternative specification, we have also controlled for oil price shocks. The results look very similar, and are available upon request.

[23]For the specification of the constant transition probability if we include segment dummies that correspond to luxury, medium and small cars, instead of a single constant, our conclusions below do not change.

obtain two statistically different and highly significant exchange-rate surprise pass-through coefficients—see the standard errors and the likelihood ratio test in Table 3. While the exchange-rate surprise pass-through is 4.92% in the "low pass-through" (LPT) regime, it is 14.87% in the "high pass-through" (HPT) regime. The component associated to the expected exchange rate and the marginal cost pass-through is 6.9% and we can not reject the null hypothesis that they are equal across regimes. These estimations amount to a total exchange rate pass-through, as defined by equation (11), of 11.82% in the LPT regime and of 21.77% in the HPT regime.

- Second, the LPT regime is also characterized by lower sensitivity to changes in the competitors' prices measured by the US CPI of new cars; that is, the degree of strategic complementarities is substantially different across regimes. Everything else constant, in the LPT regime a one percent increase in the average competitors' prices increases the average price of imported cars by 0.50%, whereas in the HPT regime it causes an increase of 0.86%. That is, in the LPT regime an increase in the average price of competitors reduces the firm's relative price; whereas in the HPT regime the exporter's price responds with a magnitude that leaves the relative price almost unchanged; indeed, we can not reject the hypothesis that the relative price remains unchanged.

- Third, the joint volatility of technology and preference shocks, measured by the variance of the error term in the pricing equations, varies substantially across regimes. In the LPT the variance is $\hat{\sigma}_0^2 = 0.0002$, whereas in the HPT regime it is $\hat{\sigma}_1^2 = 0.0128$.[24] Thus, in states of the economy where exporters are faced with a mix of preference and technology shocks with low volatility (LPT), they smooth further prices by passing a lower percentage of changes in both, exchange rates and competitors' prices; therefore, the LPT regime is consistent with an state of the economy with stickier prices.[25,26]

- Fourth, the estimated probabilities $\hat{g}^{00}$ and $\hat{g}^{11}$ in equation (13) predict a slightly higher duration of the LPT regime. The average duration of the LPT regime of 2.73 years, whereas the duration of the HPT regime is 2.5 years.[27]

[24] As a reference, business cycle models for the US estimate the variance of technology shocks in the US around 0.00008 and preference shocks around 0.001. Our estimates of σs jointly account for both, technology shocks in the exporter's country and preference shocks in the US.

[25] Gopinath et al. (2007) and Devereux and Yetman (2002) study the effects of sticky prices in the exchange rate pass-through.

[26] These results hold even after controlling for oil price shocks.

[27] The expected duration is calculated using $\frac{1}{1-\bar{g}_{ii}}$ where $\bar{g}_{ii}$ is the average predicted probability for regime $i = 0, 1$ for the case of time varying probabilities.

While tests about the existence of two regimes versus one regime are not fully developed in the literature at this time—see discussion in Hamilton (2008) and Hamilton (1996)—, the three significantly different coefficients we identify exposes the instability of the whole export pricing policy, and not only instability in the pass-through coefficient.

Although this first specification with constant transition probabilities is illustrative, and the results discussed above hold robustly, there are theoretical arguments to believe that the transition probabilities across the pricing regimes are not constant over time, but vary with macroeconomic and/or microeconomic conditions. For example, Section 2 shows that the rule to optimally choose the degree of indexation to the exchange rate surprise is a function of the expected volatility of the exchange rate, and some covariances as described in equation (8). We explore some of those theoretical arguments in the next subsection.

5.2 Economic Factors as Drivers of Transition Probabilities

The theoretical literature on export pricing suggests a diverse set of variables for the determination of the optimal degree of exchange rate pass-through. While a strand of the literature focuses on firm specific and industry specific factors affecting the firms' decisions, other studies focus on country specific factors or macroeconomic conditions. Each of the factors can affect the likelihood of the price being in one of the two regimes. By allowing the transition probabilities to be functions of one or more of these factors, we investigate their significance in the export pricing and pass-through decisions.

To clarify the interpretation of our estimates of the conditional probabilities (13), and to shed some light on the relevance of the economic factors for the pass-through, we consider the following. Assume that there is a continuum of mass one of firms exporting to the US; out of that mass of firms, the fraction Λ_t is subject to the LPT state in t and a mass $(1 - \Lambda_t)$ is subject to the HPT state. Without loss of generality, let us define $\xi_t = 0$ as the "low pass-through regime." Recall that g_t^{00} defined in equation (13) is the probability of a firm acting under the LPT state in t given that it was in the same state in $t - 1$; and $(1 - g_t^{11}) = g_t^{01}$ is the transition probability of a firm switching from the HPT state in $t - 1$ to the LPT state in t. Thus, in this setting, the evolution of the mass of firms in the LPT state is given by

$$\Lambda_t = \Lambda_{t-1} g_t^{00} + (1 - \Lambda_{t-1})(1 - g_t^{11}), \tag{14}$$

where the transition probabilities g_t^{00} and g_t^{11} defined by (13) are functions of economic fundamentals. Given the initial condition Λ_{-1}, the dynamics of the fraction of firms in the low pass-through regime is driven by the transition probabilities g_t^{00} and g_t^{11}.[28]

The major factors that we focus on in our estimations of the pricing equations (12) with time-varying transition probabilities (13) are: industry concentration, exporting country's market share and monetary stability. Each of these factors have been theoretically shown to be important in the pass-through decisions of the exporting firms.

5.2.1 Market concentration in the Industry

Setting export prices based on competitive conditions in the destination market has been called "pricing-to-market" by Krugman (1987). Pricing to market, and the related relationship between exchange rate pass-through, profit margins and the degree of competition in the destination market has been studied in Mann (1986), Marston (1990) and Knetter (1993) among many others. The idea is that higher competition increases the likelihood of the exporters to absorb more of the fluctuations in the exchange rates, and to vary their mark-ups accordingly. To capture the effects of the degree of competition in the US automobile market on the pricing decisions of the exporters, we consider the change in the Herfindahl index for the US automobile market as a determinant of the transition probabilities.[29]

The second column of estimates in Table 3 shows that the market concentration is a statistically significant determinant of both transition probabilities $g_{\ell t}^{00}$ and $g_{\ell t}^{11}$. To make clear the economic interpretation of the estimated coefficients in the transition probabilities, we construct the percentage of firms in the LPT state using equation (14). Panel A of Figure 1 shows that the Herfindahl index has a downward trend in the period 1981-2004—implying a less concentrated market overall. Panel B of Figure 1 shows that the implied percentage of firms in the LPT regime is on average slightly higher after 1990. This suggests that the lower market concentration in the post-1990 sample is associated with more firms adopting the "low exchange pass-through" policy, and hence a lower average pass-through in the industry.

[28] To be precise, we use $g_t^{ii} = 1/\mathbb{L}^* \sum_{\ell=1}^{\mathbb{L}^*} g_{\ell t}^{ii}$ for $i = 0, 1$; and as initial condition we use the steady-state expression for Λ evaluated with the probabilities estimated for $t = 1$, that is $\Lambda_{-1} = \frac{(1-g_1^{11})}{2-g_1^{00}-g_1^{11}}$. We verified that the initial condition only affects substantially the first couple of years, and after that, the path of Λ_t is virtually independent of the initial condition. In the results reported we eliminate the first 4 years to minimize the impact of the initial condition.

[29] Including the level of the Herfindahl index in the probability function created problems in the convergence of the SEM algorithm. Therefore, we examine the results for the difference of the variable.

[Figure 1 about here.]

5.2.2 Exporting Country Market Share

Secondly, we consider the total market share of an exporting country as a factor in the determination of the pricing policies. The importance of this factor in the presence of strategic interactions, has been studied by Feenstra et al. (1996), Bodnar et al. (2002) and Bacchetta and van Wincoop (2005). The third column of Table 3 shows that the country share variable is a significant determinant of both of the conditional probabilities, $g^{00}_{\ell t}$ and $g^{11}_{\ell t}$. Moreover, the estimates of the conditional probabilities imply that a firm in the LPT regime will stay in that regime on average for 3.06 years, whereas the duration in the HPT regime is only 1.81 years.

[Figure 2 about here.]

Figure 2 shows the country market shares and the percentage of firms in the LPT state implied by equation (14). Germany, Korea, Sweden, UK and Japan in the post-1995 sample display a systematic positive relationship between the market share and the implied percent of firms in the LPT regime. Germany, Korea , Sweden and UK have an upward trend in their market shares in the corresponding period whereas Japan post-1995 has a downward trend. On the other hand, France, Italy and Japan in the pre-1995 period show a systematically negative relation between market shares and percentage of firms in the state LPT.

The results for Japan pre-1995, Germany, Korea, Sweden and the UK, resemble the empirical findings in Feenstra et al. (1996), whose estimates imply that pass-through increases with country market share when market share is already large (i.e. we expect a negative relation between the percent of LPT firms and the country market share), and it decreases with market share when it is small (i.e. in this case we expect a positive relation). Japan pre-1995 has a large market share of about 66% and we find an inverse relation between changes in its market share and the implied percent of Japanese firms in the LPT state; whereas Germany, Korea, Sweden and the UK have market shares of less than 16% and display a positive relation.[30]

Since all countries, except for Japan, have small shares of the US automobile market, the propensity to choose a low degree of pass-through decreases for the firms in those

[30] As a matter of reference, Feenstra et al. (1996) calculate a negative relation between market shares and pass-through for a market share less that 40% in the Swedish car exports to Canada and a positive relation for a market share above 40%.

countries. The implications for the average pass-through can be drawn by looking at the total fraction of firms in the LPT regime. Panel (H) in Figure 2 shows a downward trend in the estimated mass of firms in the LPT regime up until 2000. These results may be driven by the Japanese country share dynamics, given their dominant share in the market.

5.2.3 Monetary Stability

The last set of factors that we consider relate to monetary stability in the importing and exporting countries. Taylor (2000) shows that stable inflation rates affect the degree to which firms pass-through fluctuations in the exchange rate to their prices by reducing their pricing power. Similarly, Devereux et al. (2004) show, in a general equilibrium framework, that the firms optimally set prices in the currency of the country that has more stable money growth; this result is based on a similar condition to the condition (9) derived as special case of our theoretical setup in Section 2. Hence, the models in Taylor (2000), Devereux et al. (2004) and the setup in Section 2 imply that if the importing country has relatively low and stable inflation rates, more exporting firms will set their prices in the importing country's currency, and as a result, the importing country will experience a lower pass-through.[31]

We include inflation rates of both countries as explanatory variables in the probability functions as well as a measure of the volatility of the exchange rate. The column "inflation" in Table 3 shows the results for the specification with transition probabilities as functions of the US inflation rate and the inflation rate in the exporter country. While the variable US inflation (rows Z_1 in Table 3) is significant in the transition probability of the LPT regime, the inflation rate of the exporting country is not significant. Similar to the previous specification, the expected duration of the LPT regime is longer: they are 3.54 and 2.34 years, respectively for the LPT and HPT regimes.

Figure 3 shows that the reduction in the US inflation rates imply an increase the fraction of firms in the low pass-through regime. This is consistent with the idea that increased monetary stability in the US has lead the exporters to pass-through less of the exchange rate fluctuations, contributing to a decline in the pass-through.[32]

[31] In a setup similar to Devereux et al. (2004), Goldberg and Tille (2005) contrast the role of that macroeconomic conditions to industry specific features for the firms' optimal choice of currency. They show that macroeconomic variability matters for the firms' decisions if their products are highly differentiated. In industries with high elasticities of demand, the firms tend to herd together in the choice of currency rather than basing their decisions on macroeconomic conditions.

[32] Using aggregate prices Marazzi et al. (2005) also find a steady decline in the exchange-rate pass-through in US automotive products since the 1980s using rolling regressions.

[Figure 3 about here.]

[Figure 4 about here.]

The last column in Table 3 shows our estimates for the model with the volatility of the exchange rate. The volatility of the exchange rate is highly significant in the high pass-through regime. As shown in Figure 4, there is a negative relationship between the volatility of the exchange rate and the fraction of firms in the low pass-through regime. During periods of high volatility, firms tend to pass-through more of the fluctuations. The reduction in the volatilities towards the end of our sample imply a higher fraction of firms adopting low pass-through (see Panel H in Figure 4). Hence, one could argue that lower exchange rate volatility has lead the average pass-through to decline.

6 Implications for the Exchange Rate Pass-Through Dynamics

To study the implications of our estimates for the evolution of the exchange rate pass-through in the automobile industry, we aggregate the individual prices in a price index. Consider the price index of imported cars

$$\hat{P}_t = \sum_{\ell} \omega_{\ell t} \hat{p}_{\ell t}$$

where ω_ℓ is the weight associated with the car model ℓ, and $\hat{p}_{\ell t}$ follows the pricing policy in (12). Let $\mathbb{I}^0_{\ell t}$ be an indicator function equal to one if the firm ℓ is in the low pass-through regime in period t and zero otherwise. Following our definition of exchange rate pass-through at the firm level in equation (11), from the price index and the pricing policy (12) it follows that the empirical exchange rate pass-through coefficient for the industry is[33]

$$\eta_t \equiv \frac{\partial \hat{P}_t}{\partial[\hat{e}_t - \mathbb{E}_{t-1}\hat{e}_t]} + \frac{\partial \hat{P}_t}{\partial \mathbb{E}_{t-1}\hat{e}_t} = \sum_{\ell} \omega_{\ell t} \Big[\mathbb{I}^0_{\ell t}(\beta^s_0 + \beta^\psi) + \big(1 - \mathbb{I}^0_{\ell t}\big)(\beta^s_1 + \beta^\psi) \Big].$$

[33]Remember that $\beta^e = \beta^\psi$ and empirically $\beta^\psi_0 = \beta^\psi_1$.

Next, using the implied mass of firms in the LPT state given by Λ_t in equation (14), we compute the aggregate pass-through coefficient at time t as

$$\eta_t = \Lambda_t(\beta_0^s + \beta^\psi) + \big(1 - \Lambda_t\big)(\beta_1^s + \beta^\psi). \tag{15}$$

Table 4 presents a general specification that includes market concentration, exporting country's market share, inflation differential and the exchange rate volatility as the determinants of the transition probabilities. We calculate the aggregate exchange rate pass-through based on this general specification and equation (15).

[Table 4 about here.]

To understand the contribution of each factor driving the transition probabilities in the variation of the exchange rate pass-through, we perform the following experiment. First we calculate the year-to-year variation in the implied pass-through coefficient from our general specification (Table 4); then, we compute the year-to-year variation that one obtains when the variation in only one factor (among market concentration, exporting country's market share, inflation differential and the exchange rate volatility) is included in the estimated transition probabilities, and the other factors are kept at their average values. With this, we obtain a measure of the contribution of each factor in the year-to-year variation of the aggregate exchange rate pass-through. Then we repeat the experiment for different horizons. The results of our decomposition are presented in Table 5.

[Table 5 about here.]

Table 5 shows that country market share has a minimal contribution (of less than 2%) to the variations in exchange rate pass-through. On the other hand, changes in the market concentration, inflation differential and exchange rate volatility all have sizable effects. Market concentration, measured by changes in the Herfindahl index explain about 40% of the year-to-year variations in the exchange rate pass-through coefficient; the cross-country inflation differential explains about 22%; and the volatility of the exchange rate explains about 37%. In a five year horizon, the percentage due to market concentration falls to 17%, whereas, the percentage due to the exchange rate volatility increases to 53%. The contribution of inflation does not change by much.

One needs to be careful in interpreting these decomposition results since they are obtained in a partial equilibrium framework. In a general equilibrium model, there may be clear interactions and feedback mechanisms between the exchange rate volatility and the the cross-country inflation differentials or between the country market shares and the degree of market concentration. By the nature of the exercise, we abstract from such endogenous relationships.

7 Conclusions

We investigate the changes in the pricing policies and the exchange rate pass-through decisions of automobile firms exporting to the US. To that end, we set up and estimate a regime switching model of export pricing, where the changes in the pricing regimes are governed by a Markov process. The transition probabilities of the Markov process depend on both macroeconomic and microeconomic factors. We estimate our model using data on 35 automobile models imported to the US from seven countries in the period 1980-2004. As our estimations show, the pricing policy characterized by a lower exchange rate pass-through also implies a lower sensitivity to misalignments in the firm's relative price. Furthermore, the low pass-through pricing policy we identify is associated with periods of low volatility of demand and technology shocks, and our estimates indicate that the adoption of such policy has a longer duration than the adoption of the policy characterized by a higher exchange rate pass-through.

From our estimation results, we conclude that both microeconomic and macroeconomic factors are important in the pricing policy determination. While changes in the Herfindahl index of the industry are positively associated with the propensity to be in a low pass-through regime, the inflation rate in the US and the exchange rate volatility are negatively correlated to such propensity. Our results highlight the fact that in the recent decades, there has been some structural changes in the pricing policies of exporters based on a number of factors. Therefore, it is constructive to study the pass-through phenomenon at a disaggregated level to understand the reasons behind its decline. We conclude that, for the automobile industry, variations in the aggregate exchange rate pass-through can be attributed to enhanced monetary stability in the US, as well as the decreased market concentration in the industry.

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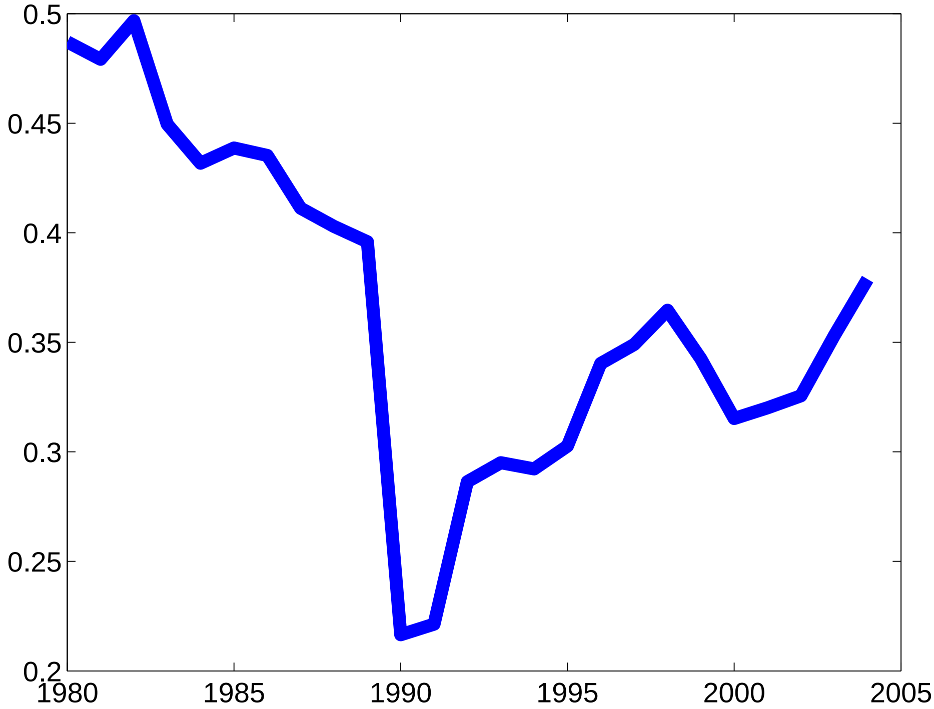
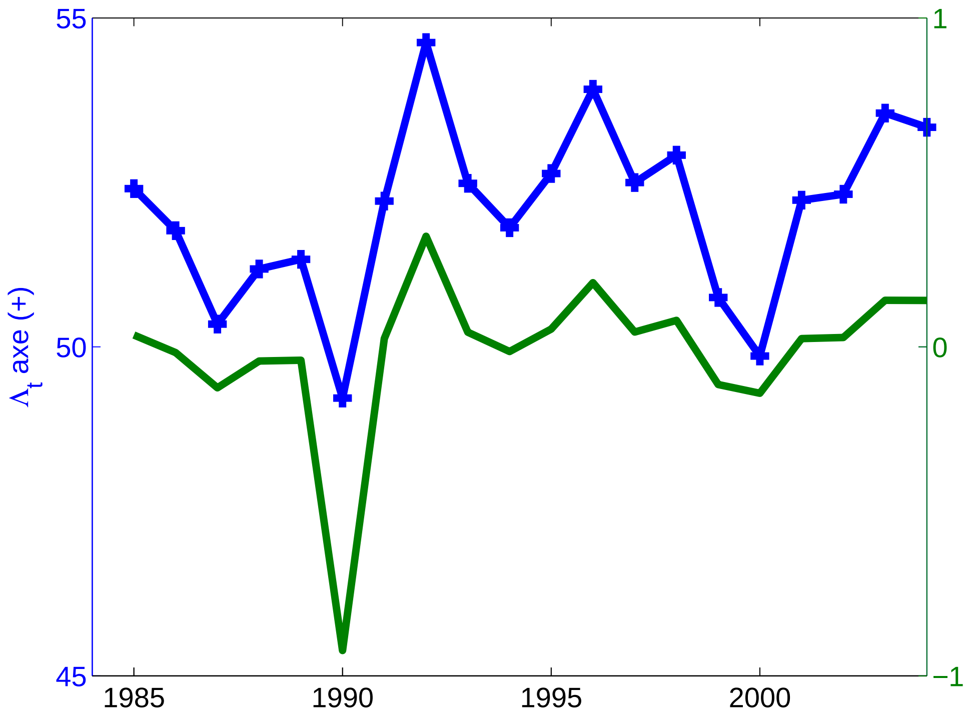
Figure 1: Market Concentration & Percent of Firms in LPT State

A) Herfindahl Index



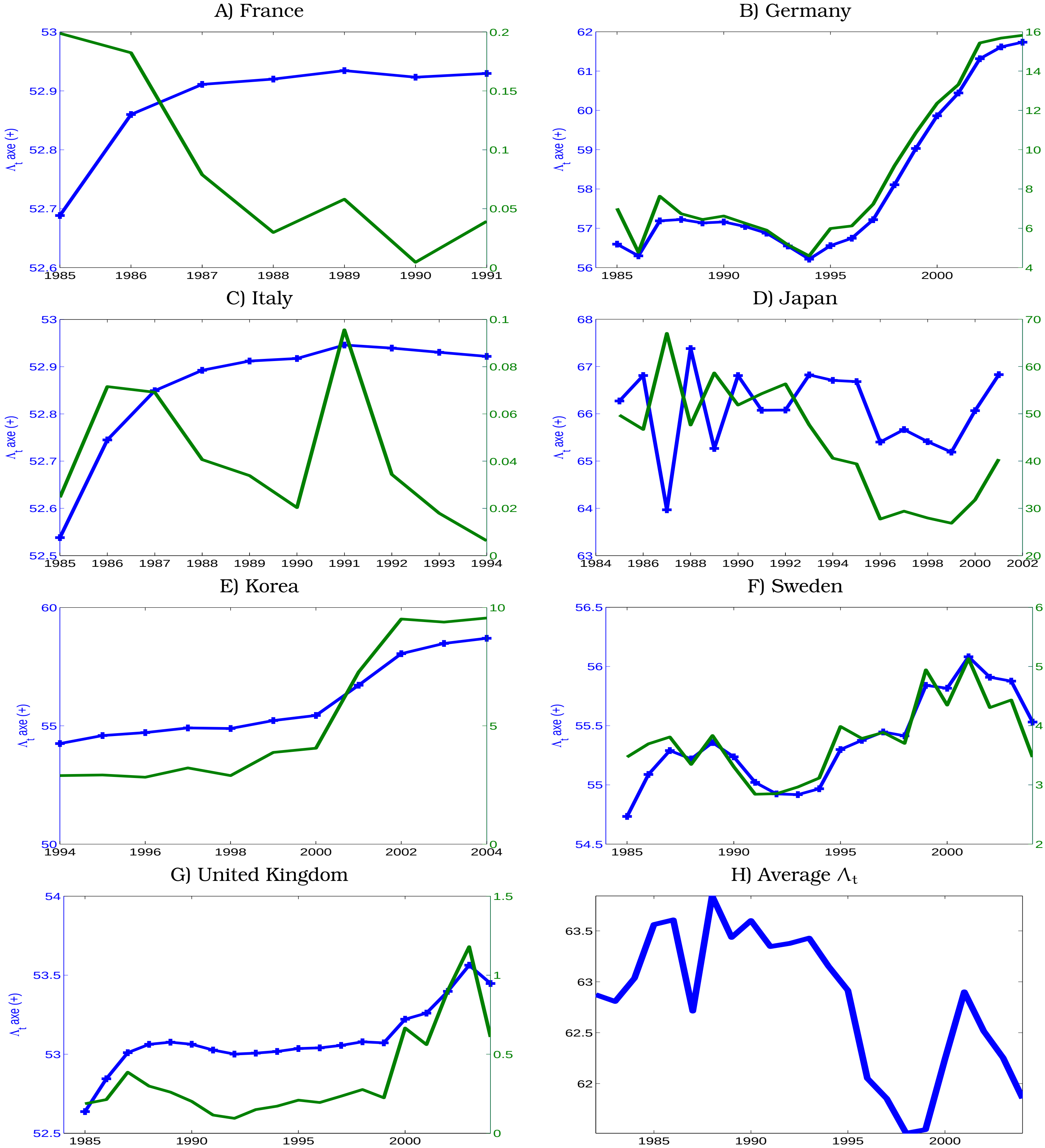
B) Percentage of Firms in LPT state & Change in Herfindahl Index



Panel A shows the Herfindahl index for the automobile industry. Panel B shows the percent of firms in the "low pass-through" (LPT) state calculated with the equation (14) and the estimations in the column 2 of Table 3. We dropped the first four years to minimize the impact of the initial conditions.

For Panel B: –+– percentage of firms in LPT (left scale); — change in Herfindahl index (right scale).

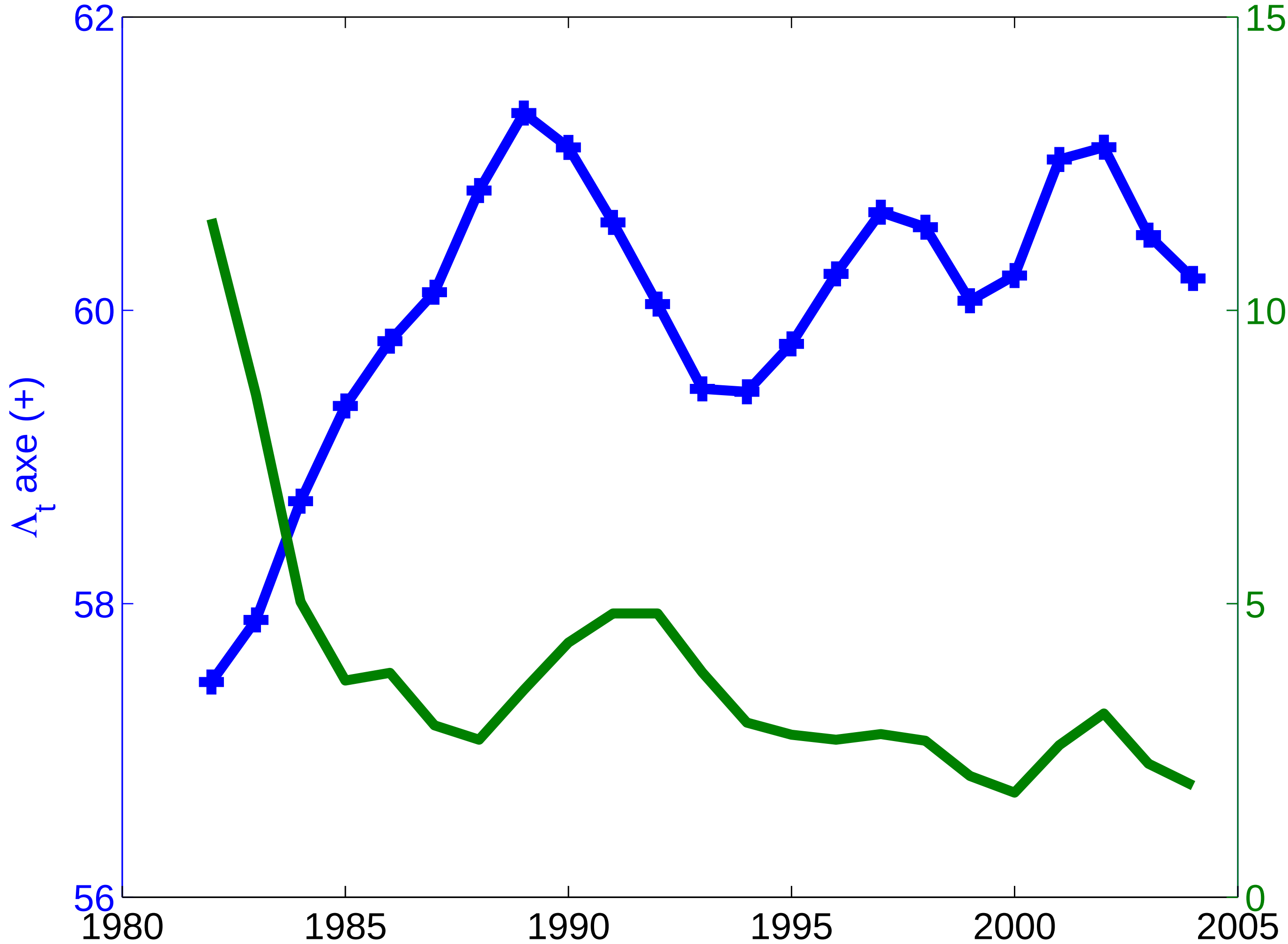
Figure 2: Exporter's Country Market Share & Percent of Firms in LPT State



The percent of firms in the "low pass-through" (LPT) state is calculated with the equation (14) and the estimations in the column 3 of Table 3. We dropped the first four years to minimize the impact of the initial conditions.

–+– percentage of firms in LPT (left scale) ; — exporter's country market share (right scale)

Figure 3: US inflation & Percent of Firms in LPT State



The percent of firms in the "low pass-through" (LPT) state is calculated with the equation (14) and the estimations in the column 4 of Table 3. We dropped the first four years to minimize the impact of the initial conditions.

–+– percentage of firms in LPT (left scale) ; — US inflation rate (right scale)

Figure 4: Exchange Rate Volatility & Percent of Firms in LPT State

The percent of firms in the “low pass-through” (LPT) state is calculated with the equation (14) and the estimations in the column 5 of Table 3. We dropped the first four years to minimize the impact of the initial conditions.

–+– percentage of firms in LPT (left scale) ; — Exchange rate volatility (right scale)

Table 1: Parameters in Second-Order Taylor Expansion & Optimal Price

$\omega_r^{p_\ell}$	$\frac{\Upsilon}{P^*} Q \frac{1}{e} \left\{ \eta_1 \frac{p_\ell}{P_{\mathbb{L}}} \frac{1}{\eta} + (\eta - 1) \right\}$
ω_r^{e}	$\frac{\Upsilon}{P^*} Q \frac{1}{e} (\eta - 1)(1 - \gamma_e)$
ω_ψ^{r}	$\frac{\Upsilon}{P^*} Q \frac{1}{e} (\eta - 1)(1 - \gamma_\psi)$
$\omega_r^{P_{\mathbb{L}}}$	$\frac{\Upsilon}{P^*} Q (1 - \gamma_{P_{\mathbb{L}}}) \frac{1}{P_{\mathbb{L}}} \frac{1}{e} \left[(\eta - 1) - \eta_1 \frac{p_\ell}{\eta} \right]$
ω_r^{z}	$\frac{\Upsilon}{P^*} Q \frac{1}{e} (\eta - 1)(1 + \gamma_z)$
ω_r^{y}	$-\frac{\Upsilon}{P^*} \frac{Q}{Y} \frac{1}{e} \left[(\eta - 1)\gamma_y + Y\eta_2 \frac{1}{\eta} \right]$
γ_r^{e}	$\frac{1}{3+\kappa}$; where $\kappa \equiv 2\eta_1 \frac{p_\ell}{P_{\mathbb{L}}} \frac{1}{\eta(\eta-1)}$
γ_r^{ψ}	$\frac{1}{3+\kappa}$
$\gamma_r^{P_{\mathbb{L}}}$	$\frac{\frac{1}{P_{\mathbb{L}}} - \frac{1}{2}\kappa}{1 + \frac{1}{P_{\mathbb{L}}} + \frac{1}{2}\kappa}$
γ_r^{z}	$\frac{1}{\kappa+1}$
γ_r^{y}	$\frac{-\eta_2}{\eta(\eta-1)[\kappa+1/Y+2]}$

Note 1 (notation): η is the price elasticity of demand; η_1 is the derivative of price elasticity w.r.t. $p_\ell/P_{\mathbb{L}}$; η_2 is the derivative of price elasticity w.r.t. the element y of the vector $\underline{Y}_\ell$; γ_x is the elasticity of the price p_ℓ^* w.r.t. x.
Note 2 (assumptions): The derivations above assume $\frac{\partial p_\ell^*}{\partial \psi_\ell} = \frac{\partial p_{\mathbb{L}}}{\partial \psi_\ell}$, this is a simplifying assumption but we can also assume $\frac{\partial p_{\mathbb{L}}}{\partial \psi_\ell} = 0$ and obtain similar results by constraining γ_ψ; $\frac{\partial p_\ell}{\partial e} = \frac{\partial p_{\mathbb{L}}}{\partial e}$ this amounts to assume that the size of importers is large enough in the sector, however we can also assume that the fraction of importers is small enough so that even though $\frac{\partial p_\ell^*}{\partial e} \geq 0$ we can still approximate $\frac{\partial p_{\mathbb{L}}}{\partial e} = 0$, we obtain similar results; $\frac{\partial p_\ell^*}{\partial y} = \frac{\partial p_{\mathbb{L}}}{\partial y}$; and $\frac{\partial p_\ell}{\partial z} = \frac{\partial p_{\mathbb{L}}}{\partial z}$.
Note 3 (approximation of elasticities): The γs in the upper panel that define the ωs are the non-linear elasticities of the optimal price p_ℓ^* w.r.t. the corresponding element; the approximations in the lower panel assume that the coefficients in the linear price p_ℓ^* approximate the non-linear elasticities.

Table 2: Car Models in Sample

Model†	Brand country	Assembly Plant	Sample	FTZ††	Average Import††
Alfa Spider	Italy	Pininfarina, Italy	1980-1994		
Audi A6	Germany	Ingolstadt, Germany	1983-2004		
BMW Series 3	Germany	Munich, Germany	1980-2004		
BMW Series 5	Germany	Dingolfing, Germany	1980-2004		
BMW Series 7	Germany	Dingolfing, Germany	1980-2004		
Honda Prelude	Japan	Sayama, Japan	1980-2001		
Huyndai Elantra	Korea	Ulsan, Korea	1992-2004		
Huyndai Sonata	Korea	Asan, Korea (93-04)	1989-2004		
Jaguar XJ6	UK	Birmingham, UK	1980-2004		
Mazda 323	Japan	Hiroshima, Japan	1980-1994		
Mazda Protégé	Japan	Hiroshima, Japan	1990-2003		
Mercedes 300E	Germany	Sindelfingen, Germany	1980-1999		
Mercedes 560SEL	Germany	Sindelfingen, Germany	1984-2004		
Mitsubishi Diamante	Japan	Nagoya, Japan	1992-2004		
Mitsubishi Mirage	Japan	Okazaki, Aichi, Japan	1987-2001		
Nissan 300ZX	Japan	Oppama, Japan	1984-1996		
Nissan Maxima	Japan	Oppama, Japan	1982-2004		
Peugeot 505	France	Aulnay, France	1980-1991		
Porsche 911	Germany	Zuffenhausen, Germany	1981-2004		
Porsche 928	Germany	Zuffenhausen, Germany	1980-1995		
Saab 900	Sweden	TrollhAttan, Sweden	1980-2004		
Saab 9000S	Sweden	TrollhAttan, Sweden	1990-2004		
Subaru Impreza	Japan	Ota City, Japan	1993-2004		
Subaru Loyale	Japan	Ota City, Japan	1980-1993		
Toyota Celica	Japan	Tahara, Japan	1980-1997		
Toyota Cresida	Japan	Tahara, Japan	1980-1992		
Volvo C70	Sweden	Uddevalla, Sweden	1994-2004		
VW Passat	Germany	Emden, Germany	1990-2004		
Honda Accord	Japan	Marysville, Ohio	1980-2004	46B	70%
Honda Civic	Japan	East Liberty, Ohio	1980-2002	46D	27%
Mazda 626	Japan	Flat Rock, Michigan	1980-1993	70I	30%
Mitsubishi Galant	Japan	Normal, Illinois	1985-1996	114C	38%
Nissan Sentra	Japan	Smyrna, Tennessee (91-94)	1983-1994	78A	42%
Toyota Camry	Japan	Georgetown, Kentucky	1984-2000	29E	35%
Toyota Corolla	Japan	Fremont, California	1980-1997	18B	50%

†The series were constructed using predecessor and successors of the models listed above.
††FTZ is the Foreign Trade Zone number for those models with assembly plant in the US. Average Import is the average dollar value of imported inputs as percentage of the total value of imported and domestic inputs reported by the FTZ.

Table 3: Parameter Estimates

		Specification of the Probability Equation (variables in vector Z):				
		constant model 1	market concentration model 2	country share model 3	inflation model 4	volatility of exch.rate model 5
Parameters in Pricing Equation						
Exchange Rate Surprise	*LPT*	0.0492** (0.0148)	0.0414** (0.0158)	0.0677** (0.0184)	0.0811** (0.0238)	0.0390** (0.0133)
	HPT	0.1487** (0.0621)	0.1484** (0.0071)	0.1631** (0.0730)	0.1400* (0.0779)	0.1482** (0.0585)
Industry Price Index	*LPT*	0.5048** (0.0461)	0.5203** (0.0596)	0.5522** (0.0563)	0.6243** (0.0238)	0.4858** (0.0480)
	HPT	0.8599** (0.2514)	0.8511** (0.2650)	0.9121** (0.2928)	0.9186** (0.3280)	0.8112** (0.2323)
Marginal Cost		0.0690** (0.0153)	0.0729** (0.0142)	0.0644** (0.0197)	0.0707** (0.0233)	0.0683** (0.0145)
Income		-0.2826** (0.1321)	-0.2427** (0.1217)	-0.3055** (0.1487)	-0.1416 (0.2267)	-0.3119** (0.1342)
Parameters in Probability Equation						
Constant	*LPT*	0.5507** (0.2264)	0.1988** (0.0969)	1.2017** (0.3170)	0.3049** (0.0000)	0.1442 (0.3615)
	HPT	0.4057* (0.2183)	0.0518 (0.1153)	1.0474** (0.3228)	-0.5076 (0.4774)	-0.4657 (0.3524)
Z_1	*LPT*		-2.6939** (1.1329)	-0.0186** (0.0079)	1.3204** (0.0000)	2.1758 (1.8347)
	HPT		-3.9574** (1.2400)	-0.0573** (0.0099)	1.3135 (1.5503)	6.0476** (2.1397)
Z_2	*LPT*				0.1036 (1.0084)	
	HPT				0.6505 (0.9797)	
Variances of Pricing Errors						
σ_0^2	*LPT*	0.0002** (0.0001)	0.0002** (0.0000)	0.0004** (0.0001)	0.0005** (0.0000)	0.0002** (0.0001)
σ_1^2	*HPT*	0.0128** (0.0015)	0.0125** (0.0000)	0.0146** (0.0018)	0.0150** (0.0020)	0.0121** (0.0013)
Average Duration *LPT*		2.73	2.25	3.06	3.54	2.63
Average Duration *HPT*		2.50	2.07	1.81	2.34	2.60
Log-likelihood		539.3208	545.3112	550.9166	536.6366	548.1131
Obs.		583	583	583	583	583
RMSE		0.0788	0.0787	0.0783	0.0785	0.0788
AIC		-4.8946	-4.8865	-4.8968	-4.8841	-4.8845
LR Test of $\beta_0^s = \beta_1^s$		5.9580	4.0168	3.3380	8.0022	8.5722
LR Test of $\beta_0^y = \beta_1^y$ & $\beta_0^\psi = \beta_1^\psi$		0.5752	2.7736	1.1116	5.1386	2.0180

Notes:

- Each of the columns correspond to the specification where the transition probabilities are functions of that particular factor (Z_1) and a constant. In the "inflation" specification, Z_1 corresponds to the US inflation and Z_2 corresponds to the inflation rate of the exporting country.
- Each of the specifications also includes automobile-line specific fixed effects.
- In the last two rows, the likelihood ratio statistics for the equality of the pass-through coefficients across the regimes, and the equality of US income and marginal cost coefficients are reported. For a p-value of 0.05, the corresponding chi-square value is 3.84 and 5.99, respectively.

Table 4: General Specification

Pricing Equation Parameters					
Exchange Rate Surprise		Industry Price Index		Marginal Cost	Income
LPT	HPT	LPT	HPT		
0.0465	0.1557**	0.5849**	0.8920**	0.0616**	-0.2139**
(0.0311)	(0.0000)	(0.0209)	(0.2056)	(0.0000)	(0.0000)
σ_0^2	σ_1^2				
0.0002**	0.0126**				
(0.0000)	(0.0000)				

Transition Equation Parameters					
constant		market concentration		country share	
LPT	HPT	LPT	HPT	LPT	HPT
0.4917**	-0.1366	-1.4199	-2.4314	-0.0341**	-0.0413**
(0.0000)	(0.4644)	(1.5543)	(1.6665)	(0.0000)	(0.0000)
inflation differential		volatility of the exch. rate			
LPT	HPT	LPT	HPT		
2.3198**	1.6863*	2.4791**	5.9206**		
(0.0000)	(0.9210)	(0.0000)	(1.9971)		

Duration LPT	Duration HPT
2.4893	2.0801

Log-likelihood	Obs.	RMSE	AIC
566.1687	583	0.0787	-4.8628

Notes:

- The specification includes fixed effects that are constrained to be the same across the two regimes.
- Inflation differential is defined as the difference between the Us inflation rate and the exporting country's inflation rate.

Table 5: Decomposition of the Variations in the Exchange Rate Pass-through

horizon	country share	market concentration	inflation differential	volatility of exchange rate
k=1	1.7862	39.7625	21.7776	36.6737
k=2	-0.8075	36.0701	34.8364	29.9010
k=3	0.9296	20.5816	30.4865	48.0023
k=4	-0.1293	22.5110	22.8341	54.7842
k=5	1.6127	17.2551	28.0538	53.0784

Notes:

- Each row reports the percent of the k-year variation in the exchange rate pass-through due to the different variables mentioned.
- The exchange rate pass-through elasticity is calculated with equation (15) and the estimations in Table 4. The first 4 year were dropped to minimize the impact of initial conditions.