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Abstract

Exchange rate pass-through literature identifies an important delay in price responses, especially in differentiated products. Using the methodology of Bajari, Benkard and Levin (2007), I estimate the structural price adjustment cost consistent with this fact in the European car market. My approach differs from previous work in that my framework allows me greater flexibility in estimating dynamic games. My main result is that relatively small adjustment costs rationalize the observed inertia in car prices. Intuitively, forward looking price setters face an autocorrelated economic environment (like the nominal exchange rates, GDP and wages) such that just a small cost of repricing justify the persistent prices in the European car market. Additionally, my estimates stress a market-specific heterogeneity in price stickiness suggesting a new dimension of pricing to market behavior.

Keywords: exchange rate pass-through, discrete choice model, structural estimation, menu costs.

JEL Classification: F10, F31, L11, L16

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1 Introduction

One of the most studied issues in international economics is the exchange rate pass-through, which is the effect of fluctuations in exchange rates on export/import prices.[1] Since exporters/importers have costs and revenues in different currencies, any exchange rate movement or delay in repricing affects markups directly. Therefore, a proper understanding of this phenomenon requires to focus on the optimal pricing policy of international traders. How firms set prices determine the degree and the dynamics of the exchange rate pass-through.

The degree and timing of exchange rate pass-through is crucial to policy makers. In fact, the optimal exchange rate regime and the transmission channels of international shocks are totally related to how exporters/importers react to exchange rate movements. For instance, the common wisdom that a devaluation boosts the export sector (expenditure - switching effect) disappears completely if international traders set prices in their consumers' currency.

The exchange rate pass-through literature strongly supports two stylized facts: i) an incomplete degree of pass-through, and ii) a persistent delay in the price response. The first fact emphasizes a heterogenous degree of pass-through with a usually complete exchange rate pass-through in commodities, but an incomplete pass-through especially in manufactured sectors. The second fact highlights the slow adjustment of prices after movements in the relevant exchange rates. Reduced form estimates usually identify "short-run" and "long-run" pass-through coefficients, stressing a delay in price responses.

These two stylized facts have had a deep impact on the field. The fist fact ruled out models of perfect competition, since the incomplete pass-through contradicts a constant markup. The persistent incomplete pass-through is consistent with "pricing to market" behavior, as coined by Krugman (1987). Pricing to market essentially allows for price discrimination based on the currency, and the market where the transaction takes place. This behavior requires segmented markets and imperfect substitution, such as in differentiated products. The second stylized fact challenges how to address dynamic pricing since delays in response may deviate the price from their optimum. Most empirical research has focused on time-series and panel data reduced forms to capture co-movements that can shed light on the underlying mechanisms of firm's behavior.

To have a deeper understanding, a new empirical literature has moved from reduced forms to structural estimation. This econometric approach

[1] I refer to "zero pass-through" if prices are totally insensitive to changes in exchange rates. On the other hand, I refer to "full pass-through" if prices change one to one due to changes in exchange rates.

allow us to identify parameters that have a clear root in the microeconomic foundations of the respective model. Goldberg (1995), Verboven (1996), Golberg and Verboven (2001) and Goldberg and Hellerstein (2008) have estimated structural parameters using the setting of differentiated products. So far, most of the structural estimations in this topic has only considered firms in a repeated static framework. A static setting can not fully address the pass-through delay already mentioned. A remarkable attempt of including dynamic considerations is done by Emi Nakamura and Dawit Zerom (2008), who solve a fully dynamic model for the coffee industry. However, they are only able to estimate the dynamic model under quite restrictive assumptions regarding the form of marginal costs. My framework allows me greater flexibility in estimating the model.

The aim of this paper is to extend the structural estimation of dynamic models to include price adjustment costs. Basically firms are forward looking in order to set current optimal prices because undoing previous actions will be costly in the future. In fact, expectations about future economic environment become crucial to determine the price level since the firm is aware of the costs associated with any future price change. The producers need to consider how far is the current scenario from the steady state environment, so to minimize adjustment costs in this autocorrelated, persistent but still convergent world. Most static previous literature relied on first order conditions in a Bertrand fashion with differentiated products. This approach differs from that, since I estimate the structural parameters that rationalize the pricing rule or policy function taken from the data.

I estimate this dynamic model for the European automobile market. Consistent with the evidence on this market, the model considers differentiated cars that are traded in segmented markets by international multiproduct oligopoly. The model explicitly consider a fully structural demand for differentiated products with heterogeneous consumers that may differ between destination markets. On the supply side the model considers international multiproduct firms who set prices simultaneously based on the characteristics of the car and the relevant economic environment. The estimation strategy does not require to assume a particular game (like Bertrand, Cournot). Instead, it relies on a reduced form of the optimal pricing rule that is consistent with a Markov Perfect equilibrium for a given set of state variables. The considered states are common knowledge (like exchange rates) and a subset that are private information (unobserved car's characteristics).

To estimate this dynamic game with private information, I use the recent methodology developed by Bajari, Benkard and Levin (2007, hereafter BBL). This methodology considers agents that face intertemporal constraints and a dynamic environment that lead them to set an optimal pricing policy, accounting for the optimal degree and temporal profile of cost pass-through. Basically, BBL suggest a two stage estimation. In this particular case, the first stage estimates two functions: i) a function to predict the evolution of the relevant economic environment (transition probabilities for state variables), and ii) a function to predict the optimal pricing for each player under a given state of the world (policy function). The second stage is a search for the structural parameters that rationalize the estimated first stage functions. Basically, BBL do forward simulations for a large number of alternative scenarios and compute the respective set of prices. For each of the simulated path BBL compute each player's discounted sum of profits using the estimated policy function. BBL repeat the procedure using an altered policy function, which should be sub-optimal. Consequently, the estimates are those structural parameters that minimize any profitable deviation and therefore make optimal the observed rule. Using those structural cost parameters I can decompose the sources of the incomplete exchange rate pass-through as well as the price adjustment cost that explain the inter-temporal profile that we observe.

The data taken from Brenkers and Verboven (2006)[2] fits nicely in this study for the following reasons: i) The car industry is the perfect example of differentiated products that exhibit incomplete exchange rate pass-through, with an stable oligopoly over the years and quite segmented markets, and ii) During the period 1970-1999 , I have the presence of several currencies, whose relative prices had large and persistent changes ensuring a proper exogenous source of variation to study the exchange rate pass-through.

My estimates support pricing to market behavior under the presence of heterogeneity in demand and supply parameters. Consumers have different degree of substitution among international producers, supporting different pricing policies by producers. The demand side improvement stress a substitution pattern based on characteristics only, not relying in any arbitrary decision nest. On the supply side I allow for policy functions that are producer-destination specifics, hence consistent with pricing to market behavior. Based on my estimates, I discard full pass-through because around one third of the costs are denominated in consumers' currency (destination currency wages along the same lines as Golberg and Verboven (2001)). Surprisingly, there is no need of huge adjustment costs to rationalize the actual large degree of inertia in prices. In this very autocorrelated and persistent world, just a small adjustment cost may generate autocorrelated and persistent prices. This empirical evidence supports the theoretical idea that small frictions can generate large price stickiness. My estimates show that less than 10% of total cost can generate the observed large price stickiness. Furthermore, my adjustment cost estimates of repricing seem to be market-specific. This finding has not been documented before at the best of my knowledge. This feature adds a new dimension of pricing to market

[2]The countries included in the sample are Belgium, France, Germany, Italy and United Kingdom. They account for around 80% of the sales in Europe, including 47 international multiproduct firms for the period 1970-1999.

heterogeneity not explored before.

Section 2 presents the entire dynamic game considered in the European car market for supply and the demand system to close the model. Section 3 presents the data on European car markets. Section 4 presents the results of estimating the model with some exercises of impulse-response functions. Finally section 6 presents the general conclusions.

2 The Model

This section presents the dynamic game of international firms who set prices in multiple currencies facing price adjustment costs. The first subsection presents the game in terms of Bajari, Benkard and Levin (2007), stating the objective function of producers, their control and state variables, and their information sets. The second subsection presents the demand system for differentiated products, which is the static discrete choice model as in Berry, Levinsohn and Pakes (1995).

2.1 A Dynamic Game with Price Adjustment Costs

This section presents the dynamic game of pricing with adjustment cost in several currencies as in the European car market before the adoption of the Euro. I set the problem and define the control and state variables, as well as the information sets.

The players of this game are the car manufacturers aggregated in F nationalities, so they are indexed by $f \in \{1, .., F\}$. All the players trade in M segmented markets indexed by $m \in \{1, .., M\}$. Since this is a multiproduct industry, each firm f sells a subset $\mathcal{F}_{fm}$ of the J_m car models available in each destination market $m \in \{1, ., M\}$.

I do not consider neither entry/exit of firms nor entry/exit of models, so I do not have a subscript t in the product sets. I mainly focus on price adjustment costs, whereas entry/exit issue requires a very different theoretical setting[3]. I discuss this issue again in section 3 to see their empirical relevance.

The action or control variable of player f is the set of nominal prices p_{jt}^m for all her models j in market m at time t $(j \in \mathcal{F}_{fm})$, hence the actions are the set $\{p_{jt}^m\}_{j \in \mathcal{F}_{fm}}$.

The vector of actions of all F players at time t in market m is given by the price vector $\mathbf{p}_t^m = (\{p_{it}^m\}_{i \in \mathcal{F}_{1m}}, .., \{p_{it}^m\}_{i \in \mathcal{F}_{Fm}})$.

[3]To address the entry/exit of firms I would need a benchmark to deal with mergers, exit of incumbents, and entry and location of the new firms. Similarly, to deal with entry/exit of cars I need a model to select those cars to withdraw and the multidimensional characteristics of the new entering models.

The players choose their optimal price simultaneously in all markets at the beginning of each period.

I assume that the relevant economic environment is totally summarized in a set of state variables $\mathbf{s}_t$. The considered state variables are the nominal exchange rates, the characteristics of all the products (own and competitors' models), the nominal wages, and the nominal GDP per capita. I explain the underlying economic reasons to consider this particular set in the respective terms of the profit function below.

I assume that cost parameters ν_f are firm specific. This set of parameters are constant over time and observable for competitors. This feature allows us to have different policy functions to account for "pricing to market" behavior.

So far the state variables are public information. I include an extra state variable for each player that is private information. There is a model-time specific characteristic ξ_{jt} that is unobservable for the competitors when setting prices. This random shock has mean zero and explain deviations from deterministic predictions. The vector of all shocks for firm f is denoted $\xi_t^m = (\{\xi_{it}^m\}_{i\in\mathcal{F}_{1m}}, .., \{\xi_{it}^m\}_{i\in\mathcal{F}_{Fm}})$.

Given a current state s_t, firm f's expected future profit is given by:

$$\mathbb{E}\left[\sum_{\tau=t}^{\infty} \beta_f^{\tau-t} \pi_{ft}(\mathbf{p}_\tau, \mathbf{s}_\tau, \xi_\tau, \nu_f)|s_t\right] \tag{1}$$

where

$$\pi_{ft} = R_{ft} - C_{ft} - AC_{f,t} \tag{2}$$

The profit function π_{ft} includes the current revenues R_{ft} and the current cost of production C_{ft}. The key new ingredient is the adjustment costs $AC_{f,t}$ or penalty associated with price changes, so undoing past decisions will be costly. Notice that the expectation is over the firm f competitors' actions in the current period, as well as future values of the state variables, and actions. I discuss these three terms in detail below.

First, I present the revenues of international producer f, R_{ft}. Since the firm f produces for domestic and foreign markets, they have revenues in foreign and domestic currencies. All the revenues across markets expressed in f's currency is given by:

$$R_{ft} = \sum_m \sum_{j\in\mathcal{F}_{fm}} e_{fmt} \cdot p_{jt}^m \cdot q_{jt}^m(\mathbf{p}_t^m, \mathbf{X}_t^m, Y_t^m, \xi_t^m) \tag{3}$$

where e_{fmt} is the ratio of currencies to convert revenues from destination currency m into firm f's currency (expressed as $f\$/m\$$). This justifies the inclusion of the nominal exchange rates as relevant state variables for the producer.[4] The next term p_{jt}^m is the nominal wholesale price of model $j \in \mathcal{F}_{fm}$ expressed in the currency of the selling market m. q_{jt}^m is the total number of units of model j sold at time t in market m. Notice that the demand depends on the entire vector of prices $\mathbf{p}_t^m$ and characteristics, $\mathbf{X}_t^m$, of the models in that respective market-time pair since consumers rank all the models before buying. Moreover, the demand function depends on real prices (not nominal prices), so I used the nominal GDP per capita in the destination market, Y_t^m, as denominator. This implies that the nominal GDP per capita must be also included as another state variable. I discuss in more detail the demand function for differentiated products in section 2.3.

The second term in the profit function is the direct production cost C_{ft}. I assume that producers only own plants in their origin country[5], hence the costs of production are expressed in domestic currency only.

$$C_{ft} = \sum_m \sum_{j \in \mathcal{F}_{fm}} C_{jt}^m(X_{jt}^m, W_{ft}, W_{mt}, q_{jt}^m, \xi_{jt}^m; \nu_f) \tag{4}$$

Basically the production cost of each model $j \in \mathcal{F}_{fm}$ depends on the characteristics X_{jt}^m of that model, the nominal wages of the manufacturing sector in the source country f and the destination market m (W_{ft} and W_{mt} respectively) and the number of manufactured units q_{jt}^m. Recall that the demand $q_{jt}^m(\mathbf{p}_t^m, \mathbf{X}_t^m, Y_t^m)$ depends on all competitor's prices and characteristics as well as the consumer's income. Thus, the production cost term justifies the inclusion of the nominal wages as state variable. I assume that the evolution of nominal labor cost is observable through the nominal wage time series and it is same within each country.

I assume that capital price is firm specific since it is closely related to the idiosyncratic firm's risk. Capital price is important for investment decisions (such as to build a manufacturing plant), but pricing decisions are based on marginal cost that I assume are mainly driven by labor cost. I can not identify sunk cost of production such as investments, research and development of new cars. Capital effects can be seen as nuisance parameter all over the cost parameters of the firm f, ν_f, but it can not be recovered separately.

Finally, I turn to the price adjustment cost term AC with structural parameters $\Psi_{fm} \subset \nu_f$. I observe continuous smooth changes in yearly prices, hence a fixed cost of price adjustment seems not to be the best approach. Instead, I have penalty term that is proportional to the magnitude of the price change. Thus. I estimate two specifications in order to study the

[4]The extensive list of producer and destination currencies are: Belgian Franc, French Franc, German Mark, Italian Lira, British Pound, Japanese Yen and American Dollar.

[5]I have data on models produced outside the headquarter's country. Unfortunately, there are too few observations to be reliable in the empirical estimation.

relative size of price adjustment cost:

$$AC_{f,t,1} = \sum_{m} \sum_{j \in \mathcal{F}_{fm}} \Psi_{fm} \cdot e_{fmt} \cdot |p_{jt}^{m} - p_{jt-1}^{m}| \qquad (5)$$

and I also estimate:

$$AC_{f,t,2} = \sum_{m} \sum_{j \in \mathcal{F}_{fm}} \Psi_{fm} \cdot |\log(p_{jt}^{m}) - \log(p_{jt-1}^{m})| \qquad (6)$$

This term is crucial to turn this setting into a dynamic problem since it is the one that links two consecutive periods. Without this term, the model is reduced to an infinitely repeated static game, in which the producer do not care about future consequences of current actions, since undoing is free.[6] Lagged price will be considered also a state variable, since past prices will be the source of the dynamics.

I assume that there is no penalty to set the first price, thus the term that only appears at first time pricing, say p_{-1} is equal to p_0 for all models and for any p_0 the first Ψ-term is zero. I think this as equivalent to assume a zero entry cost.[7] Recall that in the model there is no decision about entry\exit of firms\models, hence a fixed entry cost (zero or positive) only appears once.

As a real world evidence to support the inclusion of this term, Gopinath and Rigobon (2008) report estimates of price stickiness at-the-dock prices in the US. They found the astonishing duration of 14.5 months for cars. Theoretical literature has developed several frameworks to rationalize the concept of price adjustment cost.[8]

As in Goldberg and Hellerstein (2008), "...the specific causes of this cost is beyond the scope of this paper, however I define costs of repricing in the broadest possible way. It may include the small costs of re-pricing ("menu-costs") as well as the more substantive costs associated with the managements time and effort in figuring out the new optimal price, the additional costs of advertising and more generally communicating the price change to the consumers". An important contribution of this paper is that in this fully dynamic framework I can account for the sticky pricing behavior in the face of ongoing uncertainty.

We already know that prices are persistent at micro level in differentiated products like cars. However, it is only through a dynamic structural benchmark that I can properly estimate the magnitude of the parameters

[6] As in Golberg and Verboven (2001).

[7] Assuming $p_{-1} = p$ different from zero, lead us to an one-time punishment term $\Psi|p_0 - p_{-1}|$ that could be interpreted as a positive fixed entry cost.

[8] I mention the classic papers in menu costs (Barro (1972), Rotemberg (1982), Mankiw (1985)) and staggering contracts (Taylor (1980, 2000)). In a different setting, Krugman (1987) included reputation cost in a two stage purchase.

Ψ_{fm}. Previous dynamic reduced forms can not identify these parameters since the effect might be mixed with other sources of stickiness. Most of the previous structural estimations strongly relies on the static first order conditions of a multiproduct firms competing a la Bertrand. Only Nakamura and Zerom (2008) solve a fully dynamic model for the coffee industry. However, they are only able to estimate the dynamic model under quite restrictive assumptions regarding the form of marginal costs. My framework allows me greater flexibility since I do not need to solve the dynamic game to estimate the structural parameters.

2.2 Estimating the Dynamic Game: BBL approach

This subsection presents the main methodology of this paper, which was developed by Bajari, Benkard, and Levin (2007, hereafter BBL). I present the general functional forms so in the empirical section I focus in the particular specifications.

The BBL algorithm has two stages. The first stage estimates two functions: i) how the relevant economic environment evolves (transition probabilities denoted $\mathbb{P}(s_{t+1}|s_t)$), and ii) the way players decides in each state of the world (policy functions denoted $\sigma_f(s)$). The second stage uses the equilibrium conditions to estimate structural parameters that rationalize the first stage estimates. Consequently, the main contribution of BBL is to estimate the structural parameters without solving the theoretical game.

Suppose the state vector at date $t+1$ ($\mathbf{s}_{t+1}$) is drawn from a known probability distribution $\mathbb{P}(\mathbf{s}_{t+1}|\mathbf{p}_t, \mathbf{s}_t)$, which we want to estimate. I assume that current car prices do not affect future state variables like exchange rates, car's characteristics, GDP per capita or nominal wages. Therefore the state variables $\mathbf{s}_{t+1}$ are exogenous. Furthermore, I assume that the process is a first order Markov process. Formally, the transition probabilities for tomorrow's states $\mathbf{s}_{t+1}$ are given by:

$$\mathbb{P}(\mathbf{s}_{t+1}|\mathbf{p}_t, \mathbf{s}_t) = \mathbb{P}(\mathbf{s}_{t+1}|\mathbf{s}_t) \tag{7}$$

Second to analyze equilibrium behavior, I focus on pure strategy Markov perfect equilibria (MPE). In a MPE, each firm's behavior depends only on the current state $\mathbf{s}_t$ although the function might be firm specific. The definition of Markov Perfect equilibrium requires that players only care about the current states and not "how the state was reached", so I rule out the possibility of "state path dependance". I should think the price decision as any other "investment decision" that only depends on the current situation and the last decision.[9]

[9]The logic is the same as in other BBL applications for entry/exit or investment decisions: current decisions depend on what happened last period, but not how we reached the current state.

Formally in this setting, a Markov strategy for firm f is a function $\sigma_f : S \rightarrow P_f$, where S is the set of relevant state variables and P_f is the action space for firm f. A profile of Markov strategies is a vector, $\sigma = (\sigma_1, .., \sigma_F)$, where $\sigma : S \rightarrow P = (P_1, ..P_F)$. If the behavior is given by a Markov strategy profile σ, the firm f's expected profit $V_f(s, \sigma)$ given a state $\mathbf{s}$ can be written recursively:[10]

$$V_f(s, \sigma_f) = \mathbb{E}\left[\pi_f(\sigma_f(s), s) + \beta_f \int V_f(s', \sigma) d\mathbb{P}(s'|\sigma, s)|s\right] \quad (8)$$

The profile σ is a Markov perfect equilibrium if, given the opponent profile σ_{-f}, each firm f prefers its strategy σ_f to all alternative Markov strategies σ'_f,

$$V_f(s, \sigma) = V_f(s, \sigma_f, \sigma_{-f}) \geq V_f(s, \sigma'_f, \sigma_{-f}) \quad (9)$$

This inequality requires that for each firm f and initial state s, σ_f outperforms each alternative Markov strategy σ'_f so there is no profitable deviations.

Suppose the profit functions for firm f is a known function[11] indexed by a finite cost parameter vector ν_f so the structural parameters of the model are given by the profit functions $\pi_1(p, s; \nu_1), ..., \pi_F(p, s; \nu_F)$. Assuming the data is generated by a unique MPE of the model, the goal is to recover the true value of $\nu = (\nu_1, .., \nu_F)$, denoted ν_0.

The first step of BBL approach is to estimate the policy functions, $\sigma_f : S \times \nu_f \rightarrow p_f$ for $f = \{1, .., F\}$, and state transition probabilities, $\mathbb{P} : S \rightarrow \Delta(S)$. The purpose of estimating the equilibrium policy functions is that they allow us to construct estimates of the equilibrium value functions, which can be used in turn to estimate the structural parameters of the model. Forward simulation are used to estimate firms' value functions for given strategy profiles (including the equilibrium profile) given an estimate of the transition probabilities $\mathbb{P}$.

Given any policy function σ and transition probability $\mathbb{P}$, a simple single simulated path of play can be obtained as follows:

1.- Set an initial cost parameters $\nu = \{\nu_1, .., \nu_F\}$ and initial state $s_0 = s$.

2.- Draw a sequence of states over T periods using the estimated transition probabilities $\mathbb{P}(\cdot|s_t)$, hence I generate the sequence $\{\mathbf{s}_1, \mathbf{s}_2, .., \mathbf{s}_T\}$.

3.- Compute the actions for every player f through the estimated policy function, thus: $p_t = \sigma_f(\mathbf{s}_t)$, hence I generate the respective sequence $\{\mathbf{p}_1, \mathbf{p}_2, .., \mathbf{p}_T\}$.

[10] Assume that V_f is bounded for any Markov strategy profile σ.

[11] For econometric purposes, I treat the player specific discount factor β_f as known. I use the average inflation over 30 years to account for differences in the inflation rates between countries.

4.- Given the known functional form of profit function π_{ft} and the discount factor β_f, I compute the resulting profits $\widehat{\pi}_{ft}(\mathbf{p}_t, \mathbf{s}_t; \nu_f)$, for all players $f \in \{1, .., F\}$ at every simulated time period t.

5.- Compute the present discounted value for each player: $\widehat{V}_f(\nu_f, \sigma, \mathbb{P}) = \sum_{\tau=0}^{T} \beta_f^{\tau} \widehat{\pi}_{f\tau}(\nu_f, \sigma, \mathbb{P})$

6.- Repeat steps 1-5 for a large number, **NR**, of alternative paths each of T periods.

Averaging firm f's discounted sum of profits over many simulated paths of play yields an estimate of expected value of the players' payoff:

$$\widehat{\mathbb{E}}(V(\nu_f, \sigma_f, \mathbb{P})) = \frac{1}{NR} \sum_{h=1}^{NR} \left[\widehat{V}_f^h(\nu_f, \sigma_f, \mathbb{P}) \right] \tag{10}$$

Notice that the data is only used to estimate the pair $(\sigma, \mathbb{P})$ in the first stage. After that, the entire forward simulation depends on those estimates and does not require actual data.

Such an estimate can be obtained for any (σ, ν_f) pair, including $(\widehat{\sigma}, \nu_f)$, where $\widehat{\sigma}$ is the policy profile estimated in the first stage. Because first stage estimation $\widehat{\sigma}$ is based on the actual data, BBL infer that it represents the optimal policy function given the equilibrium beliefs.

It follows that $\widehat{V}_f(s, \widehat{\sigma}, \nu_f)$ is an estimate of firm f's payoff from playing $\widehat{\sigma}_f$ in response to opponent behavior $\widehat{\sigma}_{-f}$, and $\widehat{V}_f(s, \sigma_f, \widehat{\sigma}_{-f}, \nu_f)$ is an estimate of its payoff from playing σ_f in response to $\widehat{\sigma}_{-f}$, in both cases conditional on all players parameters ν. Combining such estimates with the equilibrium conditions of the model permits the estimation of the underlying structural parameters.

Based on MPE definition, optimality requires no profitable deviations, i.e.:

$$V_f(s|\sigma_f, \sigma_{-f}, \nu_f) \geq V_f(s|\sigma'_f, \sigma_{-f}, \nu_f) \quad \forall \sigma'_f \tag{11}$$

Let $x \in X$ index the equilibrium conditions, so that each x denotes a particular (f, s, σ'_f) combination. In a slight abuse of notation, define:

$$g(x, \nu, \alpha) = V_f(s, \sigma_f, \sigma_{-f}, \nu, \alpha) - V_f(s, \sigma'_f, \sigma_{-f}, \nu, \alpha) \tag{12}$$

The dependence of $V_f(s, \sigma, \nu, \alpha)$ on α reflects the fact that functions σ and $\mathbb{P}$ are parameterized by first stage parameters α. The inequality defined by x is satisfied at ν, α if $g(x, \nu, \alpha) \geq 0$.

Define the function

$$Q(\theta, \alpha) \equiv \int (\min\{g(x, \nu, \alpha), 0\})^2 dH(x) \tag{13}$$

where H is a distribution over the set X of inequalities. The true parameter vector, ν_0, satisfies:

$$Q(\nu_0, \alpha_0) = 0 = \min_{\nu \in \Theta} Q(\nu, \alpha) \tag{14}$$

Given a sequence of inequalities $\{X_k\}_{k=1,..n_I}$, I use an alternative policy

$$\widetilde{\sigma}_f(s, \nu_f) = \sigma_f(s, \nu_f, \widehat{\alpha}) + u \tag{15}$$

where u is white noise. By definition of σ_f, this alternative policy function $\widetilde{\sigma}_f$ is suboptimal. For each chosen inequality the forward simulation procedure can construct analogues of each of the V_f terms, say $\widetilde{V}_f$. Formally;

$$\widetilde{g}(x, \nu, \widehat{\alpha}_n) = V_f(s, \sigma_f, \sigma_{-f}, \nu, \widehat{\alpha}_n) - V_f(s, \widetilde{\sigma}_f, \sigma_{-f}, \nu, \widehat{\alpha}_n) = V_f - \widetilde{V}_f \tag{16}$$

whenever $\widetilde{g}$ is negative it means that $\widetilde{\sigma}_f$ was a profitable deviation for firm f.

Finally the second stage estimator is:

$$\widehat{\nu} = \arg\min_{\nu \in \Theta} \frac{1}{n_I} \sum_{k=1}^{n_I} (\min\{\widetilde{g}(x_k, \nu, \widehat{\alpha}), 0\})^2 \tag{17}$$

I explain the details about functional forms estimated in the empirical section.

2.3 Estimating the Demand: BLP Approach

This section presents the general framework to estimate demand for differentiated products as in BLP (1995). The mixed logit (also called random coefficients model) is the starting point of this approach taking advantage of a more realistic substitution patterns than logits models and allowing estimation with market level data. As in previous sections, a market is defined as a combination of a buying country m at time t, although for simplicity I just use the subscript t in this subsection.

Following the usual approach (Nevo 2000), the utility of individual $i = \{1, .., R\}$ for product $j = \{1, .., J\}$ in market (destination-time pair) $t = \{1, .., T\}$ is given by:

$$U_{ijt} = X'_{jt}\alpha_{1i} + \alpha_{2i}(y_i - p_{jt}) + \xi_{jt} + \varepsilon_{ijt} \tag{18}$$

where X_{jt} is a K-dimensional vector of observable characteristics, y_i is consumer's income, p_{jt} is the price, ξ_{jt} is an unobserved (by the econometrician) scalar product characteristic, and ε_{ijt} is a mean-zero stochastic term. Finally, α_{1i} is a K-dimensional vector of individual-specific taste coefficients, and α_{2i} is consumer i's marginal utility from income. Notice that the marginal utility parameter vary across consumers but not across products for given a individual. I specify the list of considered characteristics in the empirical section 4.

Formally, the distribution of the idiosyncratic parameters is given by:

$$\begin{pmatrix} \alpha_{1i} \\ \alpha_{2i} \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} + \Sigma v_i = \alpha + \Sigma v_i \qquad \text{where} \qquad v_i \sim \mathbb{N}(0, \mathbb{I}_{K+1})$$

where v_i captures the unobservable consumer heterogeneity and $\mathbb{I}$ is a $K+1$ by $K+1$ identity matrix. Since I assume a standard multivariate normal distribution, the matrix Σ is the unknown parameter for the variance-covariance matrix $\Sigma\Sigma'$.

Let $\theta = (\alpha, \Sigma)$ be a vector containing all the parameters of the demand where α is the linear parameter vector and Σ is the non linear parameter matrix.

Define

$$\delta_{jt}(\alpha) \equiv X'_{jt}\alpha_1 - \alpha_2 p_{jt} + \xi_{jt} \tag{19}$$

$$\mu_{ijt}(\Sigma) \equiv [X'_{jt}, p_{jt}]\Sigma v_i \tag{20}$$

So the utility can be re-written as:

$$U_{ijt} = \alpha_{2i} y_i + \delta_{jt}(\alpha) + \mu_{ijt}(\Sigma) + \varepsilon_{ijt} \tag{21}$$

First, the term $\alpha_{2i} y_i$ plays no role in the consumer's ranking, since it is the same for all goods. Second, δ_{jt} is called the "mean utility", which is the component of utility from consumer's choice of product j that is the same across all consumers (it includes an unobservable term ξ_{jt}). Third $\mu_{ijt}(\Sigma)$ is a heteroscedastic disturbance and, fourth ε_{ijt} is a homoscedastic disturbance.

This approach consider an outside good $j = 0$, that represents "not to buy a new car" and it is normalized to zero, i.e., $U_{i0t} = \varepsilon_{i0t}, \forall (i, t)$.

Let us define the set A_{jt}, which contains the individuals who choose model j at market t:

$$A_{jt}(x_{\cdot,t}, p_{\cdot,t}, \xi_{\cdot,t}, \theta) = \{(v_i, \varepsilon_{i0t}, .., \varepsilon_{iJt}) | U_{ijt} \geq U_{ilt}, \forall l = \{0, ..J\}\}$$

Because income enters in a linear fashion, it cancels out in all the utility comparisons. Assuming ties occur with zero probability, the market share s_{jt} of the j^{th} product is just an integral over the mass of consumers in the region A_{jt}, that depends on random variables v_i and $\varepsilon = (\varepsilon_{i0t}, .., \varepsilon_{iJt})$.

Consequently, the total demand is just the market share times the population of market t, denoted pop_t. Formally:

$$q_{jt} = pop_t \cdot s_{jt}(x_{\cdot,t}, p_{\cdot,t}, \xi_{\cdot,t}, \theta) = pop_t \cdot \int_{A_{jt}} dF_\varepsilon(\varepsilon) d\Phi(v_i)$$

where the joint distribution of shocks ε and v are the product of the density functions due to the independence assumption.

The next step is to compute the individual probability of buying a particular good j, hence the total market share of this good is the integral over all the consumers of that probability given by:

$$s_{jt}(x_{\cdot,t}, p_{\cdot,t}, \xi_{\cdot,t}, \theta) \quad = \quad \int_{A_{jt}} dF_\varepsilon(\varepsilon) d\Phi(v_i) = \int_{A_{jt}} s_{ijt} d\Phi(v_i)$$

If the εs have the usual extreme value distribution, then I have a closed form for the individual probability:

$$s_{ijt} = \frac{\exp(X'_{jt}\alpha_{1i} - \alpha_{2i}p_{jt} + \xi_{jt})}{1 + \sum_h \exp(X'_{ht}\alpha_{1i} - \alpha_{2i}p_{ht} + \xi_{ht})} = \frac{\exp(\delta_{jt} + \mu_{ijt})}{1 + \sum_h \exp(\delta_{ht} + \mu_{iht})} \quad (22)$$

And the market share integrates over all consumers:

$$s_{jt}(x_{\cdot,t}, p_{\cdot,t}, \xi_{\cdot,t}, \theta) \quad = \quad \int_{A_{jt}} \frac{\exp(\delta_{jt} + \mu_{ijt})}{1 + \sum_h \exp(\delta_{ht} + \mu_{iht})} d\Phi(v_i) \quad (23)$$

The integral over the individual shocks v_i is computed through simulation as explained in the appendix B. I simulate R individuals and I compute their decisions for each market, obtaining the predicted market shares for each product at market level.

The unobservable characteristics $\xi_{\cdot,t}$ are the only unobservable variable that can explain an imperfect fit with the actual shares.

Stacking the predicted shares in vector $s(\cdot)$. On the other hand let **Sh** be the actual observed share vector for each market[12]. Naturally, the estimator $\widehat{\theta}$ is:

$$\widehat{\theta} = \arg\min_{\theta \in \Theta} \parallel s(X_{\cdot,t}, p_{\cdot,t}, \xi_{\cdot,t}, \theta) - \mathbf{Sh} \parallel \quad (24)$$

BLP (1995) suggested instruments to control for the endogeneity of prices because of the potential correlation between unobserved characteristics ξ and prices p. Roughly speaking this approach takes two steps: first identify the δ_{jt} terms for each product in each market matching the market shares, and second, use those δs to identify β vector through a standard instrumental variables regression. Appendix B describes in detail the particular generalized method of moments (GMM) estimation that I used.

3 Data

This section describes and discuss the data. The dataset was collected by Brenkers and Verboven (2006) and is an updated version of the one used by Goldberg and Verboven(2001).[13]

[12]Recall that a market is defined as a combination of country m and time t.

[13]The data is available in the authors' webpage.

The yearly data set consists of prices, sales and physical characteristics of (essentially) all car models sold in five European markets from 1970 until 1999. The included destination markets are Belgium, France, Germany, Italy and the United Kingdom. The definition of market is a country-year combination. The total number of observations is 11,549 implying that on average about 80 models are sold in every market/year.

There are about 350 different car models during this period, although many of them are successors of old models. Examples are the Fiat Uno, VW Golf, Toyota Corolla, Peugeot 405, and BMW 5-series.

Sales are new car registrations for the model range. Physical characteristics (also from consumer catalogues) include dimensions (weight, length, width, height), engine characteristics (horsepower, displacement) and performance measures (speed, acceleration and fuel efficiency). The data set also includes variables to identify the model, the brand, the firm, the country of origin/production location, and the market segment ("class" or "category"). The data set is augmented with macro-economic variables including population, exchange rates, nominal and real GDP.

3.1 Car Prices and Characteristics.

This section briefly describes the trends of the data across different European markets. The price data are pre-tax and post-tax list prices, i.e., the final prices suggested by manufacturers to retailers. For each *market* I have the prices expressed as share of GDP per capita, in the domestic currency and in a common currency.

As mentioned above the data includes several characteristics from consumer catalogues such as weight, length, width, height, horsepower, displacement, speed, acceleration and fuel efficiency at different speeds. Because many of them are very collinear I reduced the dimensionality of this state space constructing three variables that summarize the observed characteristics.

The summarized characteristics are:
Size: It is the product of length (Le), height (He) and width (Wi), i.e., $Size = He * Le * Wi$.
Inverse of Motor Power: I explore several specification to summarize the car's motor characteristics. The best fit in a linear model was the inverse of motor power given by $InvPow = (Hp * Cy * Sp)^{-1}$, where Hp is horse power, Cy is the number of cylinders and Sp is the maximum speed.
Fuel efficiency: is the arithmetic average between the fuel efficiency at "city speed", 90 and 120 kilometers per hour (measured as liters per kilometer).

The trends of all these three characteristics in the five destination markets are in figure 1, 2 and 3 respectively. Size and Motor power have some linear trend and/or clear autocorrelated process. Instead full efficiency seems to be less systematic.

Figure 1: **Evolution of car size across Europe.**

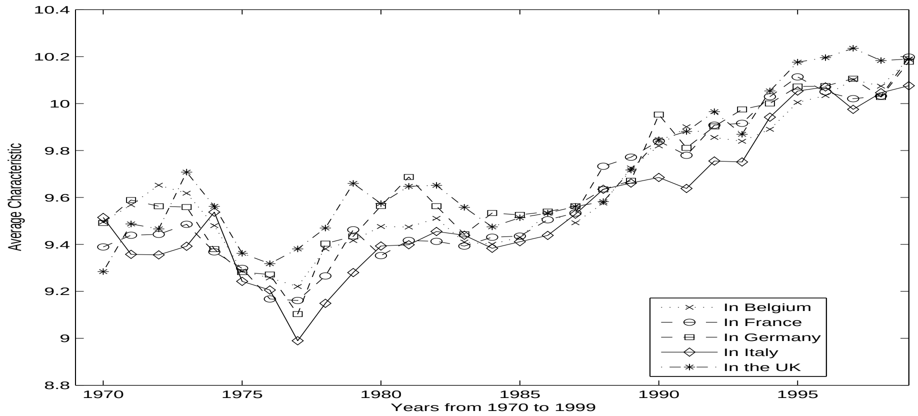
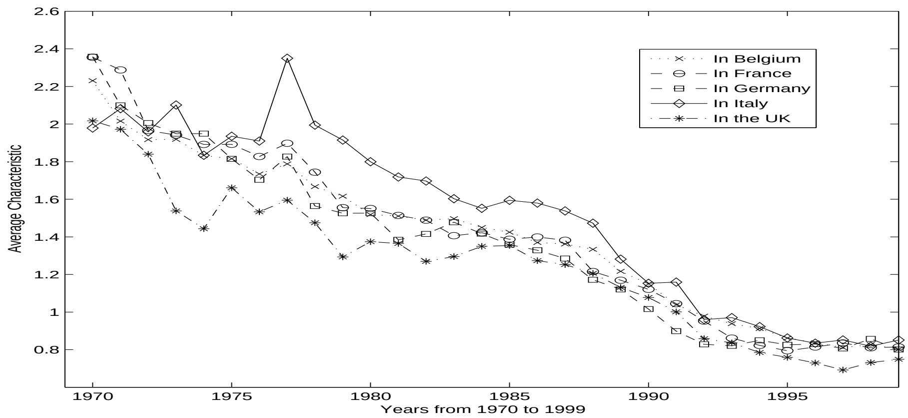


Figure 2: **Evolution of the inverse of Motor Power across Europe.**



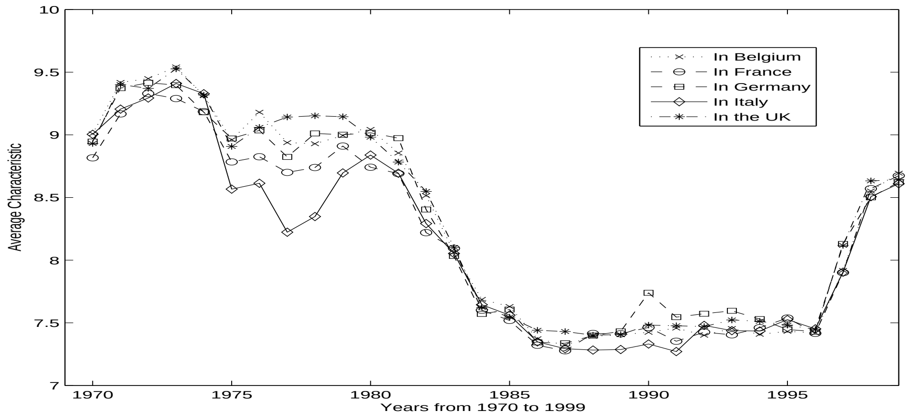
The data contains the manufacturer firm, place of production, information about the segment of the car (compact, subcompact, standard, intermediate and luxury) and the specific model. Using the latter, Goldberg and Verboven kept track of the consecutive models in each market.

3.2 Nationalities and Market Shares

This section presents the most salient features of the European car market.

The definition of nationality of the product is fundamental. First, I need to define "domestic" producers so to account for any home bias in the

Figure 3: **Evolution of fuel efficiency across Europe.**



demand side of the model. Second, I need to define the relevant currency of each producer in order to express the revenues in a single currency.

Thus, I consider the historic brand association for the demand side and firm's headquarters for the supply side.[14] Appendix A shows in detail the nationalities criteria and their market shares. Now I turn over the nationality based on brand history. Table 1 shows the models available per market of each nationality based on firms' brand (demand perspective).

Table 1: **Available models across Europe by nationality of the brand**

Nationality of brand	Belgium	France	Germany	Italy	UK	Total
American	130	126	126	123	126	631
French	566	561	509	509	502	2647
German	338	325	347	317	293	1620
Italian	408	379	340	478	242	1847
British	329	274	224	229	364	1420
Japanese	629	377	533	136	523	2198
Others	273	223	204	235	251	1186
Total	2,673	2,265	2,283	2,027	2,301	11,549

Market shares of the domestic producers are astonishing large based on the historic consumers' perception of nationalities. Based on this demand side perspective, table 2 presents the market shares for each nationality in the five European markets.

[14]Consequently, from the consumers' point of view, mergers do not change the perceived nationality of the brands, although for the supply side the revenues belong to a different firm.

Table 2: **Average Market Share across Europe by nationality of the brand**

Nationality of Brand	Belgium	France	Germany	Italy	UK
American	9.7	6.1	10.8	5.8	25.4
French	28.2	**69.9**	10.6	15.9	15.5
Germans	19.9	8.1	**44.6**	9.8	8.2
Italians	6.9	6.2	5.2	**59.0**	3.8
British	13.4	5.6	18.9	5.5	**33.0**
Japanese	17.3	2.3	7.8	1.1	9.7
Others	4.6	1.9	2.0	2.8	4.2

Based on these striking differences the natural question is whether the domestic cars are really different from foreign cars. Since the domestic cars in one market are the foreign cars in the rest of the markets, I should expect similar characteristics. Goldberg and Verboven (2001, 2005) present compelling evidence that (observed) characteristics can not explain alone the dramatic market share differences. To illustrate this point table 3 compares characteristics between foreign and domestic cars, showing that cars seem alike.[15]

Table 3: **Domestic and Foreign Car characteristics across Europe**

Characteristic	Origin	Belgium	France	Germany	Italy	UK
Size	Domestic		9.60	10.34	8.94	9.66
	Foreign	9.65	9.64	9.57	9.80	9.74
Motor Power Inv.	Domestic		1.97	1.03	1.87	1.06
	Foreign	1.36	1.16	1.37	1.31	1.23
Fuel Efficiency	Domestic		7.85	8.75	8.10	8.53
	Foreign	8.22	8.21	8.15	8.07	8.17
Price	Domestic		0.69	0.80	0.98	1.08
	Foreign	0.72	0.77	0.63	0.99	1.04

Therefore, any demand estimation should consider some sort of home bias preference to match these market shares. I discuss it again when presenting the demand results in section 4.1.

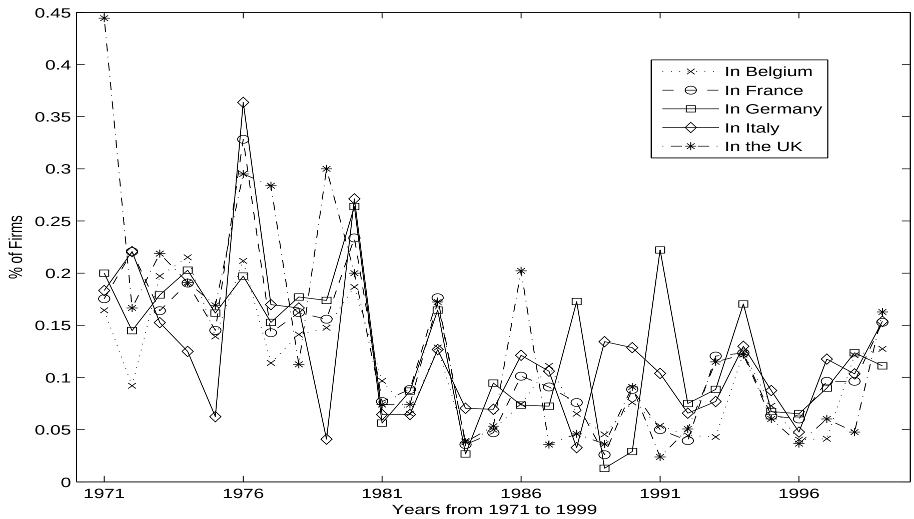
[15] I report size, a motor power index, fuel efficiency and "comparable price". The latter is the ratio of nominal price over nominal GDP per capita.

3.3 Entry/Exit Behavior

This section discuss the assumption about entry/exit of firms and models. In general this is important in the sense that large movements in exchange rates can change the relevant players or models and consequently might be a composition effect as highlighted by Rodriguez-López (2008).

To address the entry/exit of firms I would need a benchmark to deal with mergers, entry of new firms and exit of incumbents, in each market at every time period. I argue that the average percentage of new firms is low, with small firms being absorbed by bigger players. The percentage of new firms among total firms across the 30 years is less than 7%. Weighting by market shares, the relevance of new firms is even lower. Figure 4 presents the evolution of the number of new firms.

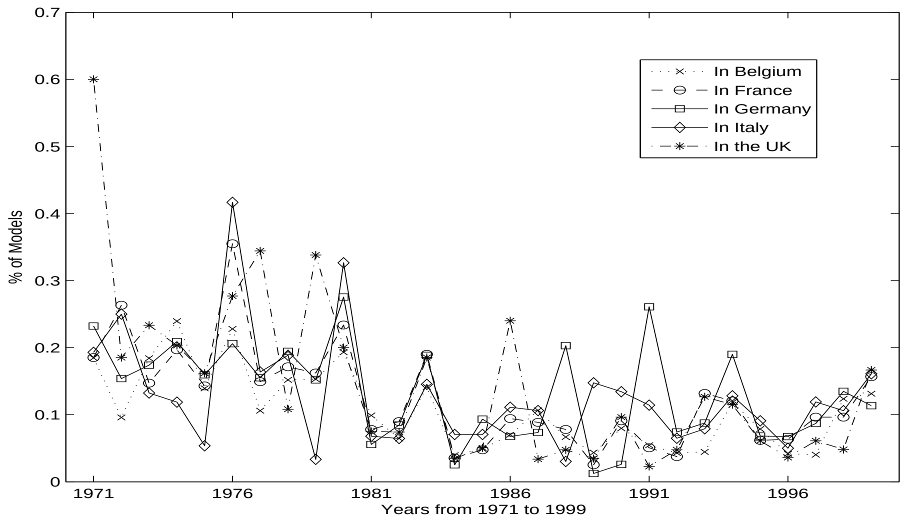
Figure 4: **New firms across Europe.**



Similarly, to deal with entry/exit of models I need to predict which incumbent model exits and the characteristics of the new entering model, which is prohibitive when the characteristics are multidimensional as in this case. I argue that new models are not a big share of the market. Figure 5 shows the ratio between new models and total number of models in each market, and the average percentage of new models across the 30 years is about 5%.

For the forward simulation I consider fixed characteristics as well as fixed models in each market. Hence I know that the results that I find are not contaminated by this composition effect. None of the previous structural empirical work in cars had controlled for this fact, so I think this is an improvement.

Figure 5: **New models across Europe.**



4 Results

This section presents the empirical results of estimating the model in the European car market. The first subsection presents the demand results. The second presents the results for the supply side of the industry. Some impulse-response are presented to evaluate the economic sense of the policy functions. Finally I present the structural estimates and their implications.

4.1 Demand Estimation

This section presents the estimates of the demand for differentiated products in the European car market, using the general demand framework developed by Berry, Levinsohn and Pakes (1995). This framework considers heterogenous consumers, controls for price endogeneity and does not need a sequential nested decision.

One of the most important features that I have to match is that domestic car producers have an extremely dominant position in the European car market, as presented in data section. Roughly speaking, domestic cars are quite similar to foreign cars based on observed characteristics, but their market shares are large. Therefore, any demand estimation should consider some sort of "home bias" and unobserved characteristics in order to match these market shares.

Using a nested logit estimation, Goldberg and Verboven (2001) found that domestic producers face two advantages: i) a fixed positive effect on demand and ii) a systematic more inelastic demand. Notice that one of the considered nest is the decision between a domestic and foreign car. The latter nest provided them a elasticity parameter by car's origin that granted a domestic advantage at price elasticity level besides the fixed effect (after controlling for other characteristics).

BLP technique does not impose any arbitrary decision nest[16], hence my price elasticities are robust to those considerations. As I present below, this new evidence suggests that the home bias is totally captured by a fixed effect and there are no particular price-elasticity advantages for domestic producers in their domestic markets.

As presented in the theoretical demand, the utility function is given by:

$$U_{ijt} \quad = \quad \alpha'_{1i}[X_{jt} \;\; home_{jt}]' + \alpha_{2i}(y_i - p_{jt}) + \xi_{jt} + \varepsilon_{ijt} \tag{25}$$

where X_{jt} is the vector of observable characteristics: size, motor power and fuel efficiency. Also includes the set of dummies (segment, market, year, brand, firm, and location of plants); I explicitly consider the home bias preferences through the dummy variable $home_{jt}$, which is 1 if the destination market is the same country as the brand nationality. p_{jt} is the real price of product j in market t, measured as nominal price over nominal GDP per capita.[17] Notice that in general there are no restrictions about which coefficients can vary across consumers. After trying several specifications, I present only the statistically significant coefficients.

BLP (1995) suggested instruments to control for endogeneity of prices because of the potential correlation between unobserved characteristics ξ_{jt} and price p_{jt}. I closely follow the instruments suggested by BLP, so I use the sum of the competitors' characteristics, the sum of the other own product's characteristics, the number of competitors and the number of the other own products, and their powers as well. These instruments are very strong in this case, with a nice predictive power over prices.

Table 4 presents the demand estimates that will be used in the next sections.

Notice that once country specific price and home bias coefficients were considered, the random unobserved heterogeneity only is significant in the price coefficient ($\sigma_p > 0$).

In this setting the own price elasticity of product j is given by:

$$\eta_{jt} \equiv \frac{\partial s_{jt}}{\partial p_{jt}} \frac{p_{jt}}{s_{jt}} \quad = \quad \frac{p_{jt}}{s_{jt}} \int \alpha_i s_{ijt}(1 - s_{ijt}) d\Phi(v_i)$$

Notice that the home bias effect only enters through the individual share $s_{ijt} = s(p_{jt}, x_{jt}, home_{jt}, \xi_{jt}, \alpha_i)$.

Figure 6 presents the distribution of the own elasticity estimates.

[16] Cardell (1997) formally shows that the nested logit can be written as a special case of the mixed logit. An interesting debate about this two settings can be found in Wojcik (2000) and the reply by Berry and Pakes (2001).

[17] This solves the problem due to differences in inflation and income between markets.

Table 4: **Demand Estimates.**

Linear BLP Parameters α	**Coef**	s.d.	t-test
Price-Belgium	**-1.86**	(0.55)	-3.40
Price-France	**-4.09**	(0.97)	-4.22
Price-Germany	**-3.25**	(0.85)	-3.82
Price-Italy	**-2.03**	(0.62)	-3.26
Price-UK	**-1.28**	(0.63)	-2.05
Home-Bias-France	**1.75**	(0.09)	19.07
Home-Bias-Germay	**1.33**	(0.18)	7.40
Home-Bias-Italy	**2.53**	(0.06)	39.01
Home-Bias-UK	**1.28**	(0.10)	13.23
Inverse Power	**-1.11**	(0.11)	-9.70
Size	**0.77**	(0.25)	3.10
Liters per Km	**-1.41**	(0.23)	-6.09
Non-Linear Parameters σ	**Coef**	s.d.	t-test
Std Dev on Price Coeff.	**0.68**	(0.35)	1.93
GMM Obj. function	**286.46**		

Figure 6: **Distribution of Own price elasticities.**

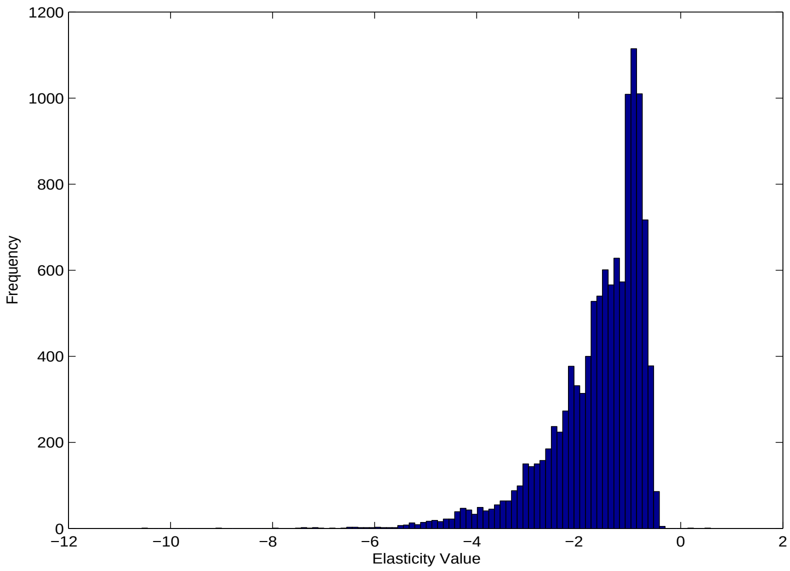


Table 5: **Estimated Average Own Price Elasticities.**

	Belgium	France	Germany	Italy	UK
$\frac{\partial \log(s_i)}{\partial \log(p_i)}$	-1.09	-2.79	-1.92	-1.53	-0.83

Recall the assumption that every producer knows the demand function when setting car prices in each market. Optimal pricing policy heavily relies on the marginal effects of changes in prices, so it is very relevant whether domestic producers have an elasticity advantage in their domestic market. I namely define an elasticity advantage if a domestic producer faces systematically a more inelastic demand than their foreign competitors.

In order to identify any advantage at price elasticity level, first I cluster the elasticities by market destination so all producers face the same set of consumer's parameters.[18] In each market, I aggregate by nationality so I can compare the elasticities of domestic and foreign producers.

The five figures in appendix C strongly suggest that domestic producers do not face a systematic less elastic demand, since domestic's elasticities are in the range of the other producers' elasticities. This is a robust fact when replicating the analysis by car segment.[19] Notice that the absolute values of my estimates are smaller than the nested logit estimates of Golberg and Verboven (2001), especially for the UK. In the usual static approach (that exploits first order conditions) there is a link between demand elasticities and markups. This link is not straightforward in a dynamic framework. Basically, the issue behind these estimates is how large is the decrease in revenues after a price increase. A price increase (due to a depreciation for example) would imply a large decrease in quantity based on the usual larger elasticities (around 5). These smaller price elasticities predict a quite smaller lost in revenues after an adverse change in the relevant nominal exchange rate. I come back to this issue in the result section when presenting the policy function estimates.

Another important feature of these estimates is the fact that the fixed effects of home bias are quite large. To illustrate this point, table 6 reports the predicted market shares, assuming no home bias at all in the five markets, i.e., replacing zero in the home bias coefficient in all the five markets while keeping all the other characteristics fixed (including the unobservable characteristic ξ). The reduction of domestic shares are quite large comparing with table 2 supporting the idea that the large domestic dominance is not due to the (un)observed characteristics only.

Finally, some caveats about these demand estimates. First, I can ac-

[18] Recall that price and home bias coefficients are market specific.

[19] Although I do not report the all 25 figures.

Table 6: **Predicted Market Share with No Home Bias.**

Brand's Nationality	Belgium	France	Germany	Italy	UK
American	9.7	13.8	16.1	12.0	33.3
French	28.2	**30.6**	15.8	36.7	20.4
Germans	19.9	18.6	**17.6**	21.0	10.7
Italians	6.9	14.9	7.8	**11.3**	5.1
British	13.4	12.9	28.1	11.7	**12.5**
Japanese	17.3	5.2	11.6	1.9	12.6
Others	4.6	4.1	3.0	5.4	5.5

count and identify these large domestic fixed effect, but I can not tell the underlying reasons why this is the case. The home dummy might capture several phenomena such as "nationalism", network effects, replacement availability, any kind of asymmetric information about the products, historical arguments or (most likely) a mix of all reasons above.

Also, these estimates are conditional on the characteristics and models available for each market since 1970. These parameters just rationalize the options taken by the consumers, given the choice set they faced, so it cannot account for regulations or any constraint[20] that play against foreign cars changing the choice set.

4.2 Transition Probabilities

This subsection presents the estimation of the transition probabilities. These processes determine the evolution of the state variables, which in this case are independent of the endogenous control variables (prices). The state variables of the model are: exchange rates, nominal wages in the manufacturing sector (or car sector if available) and nominal GDP per capita in the buying markets. Exchange rates are crucial to express the profits and costs in the same currency. Nominal wages are the source of nominal variation in the costs. Recall that the comparable price used in the demand side is given by the ratio between the nominal price and the nominal GDP per capita, both in destination market currency.[21] As argued above, I decide to exclude car's characteristics as state variable, so characteristics remain fixed over the forward simulations.

I assume that all state variables follow a first order Markov process. The following sections present the actual estimates for these state variables.

[20]Such as the quotas faced by Japanese cars in Italy.

[21]This ratio controls for two country-specific dynamics such as inflation rate and consumer's income.

4.2.1 Exchange Rates

I assume that the nominal exchange rate follow a first order autocorrelated process, $AR(1)$, considering correlated contemporary shocks across countries (as in the seemingly unrelated regressions, SUR). All the estimations consider the log of the nominal exchange rates.

The following time series are the ratio between the local currency and the American dollar. Hence the equation for currency of country $s = \{\text{Belgium, France, Germany, Italy, UK, Japan}\}$ at time t is given by:

$$e_{s,t} = \alpha_s + \rho_s e_{s,t-1} + u_{s,t} \tag{26}$$

where the shocks $u_{s,t}$ are correlated among countries but not correlated across time.

$$cov(u_{s,t}, u_{r,t}) = \sigma_{s,r} \neq 0 \quad \forall s, r \quad \text{and} \quad cov(u_{s,t}, u_{r,p}) = 0 \quad \forall t \neq p \tag{27}$$

In the BBL estimation I use the ratio between the producer's currency and the selling market currency, so the dollar as denominator do not matter much.

The process of integration towards a common currency shall be mentioned. First, the calendar for the launch of the Euro was set in the Maastricht treaty, which was signed in February 1992, as a consequence of previous treaties and negotiations in the late 80s (Single European Act (SEA), 1987). The Euro was introduced in 1999, hence after the 4th quarter of 1998 there is no variation between 4 out of 6 of my considered currencies. Hence I estimate five alternative subsamples.[22] There are not big differences among the estimates, however I see a slight decline in the inertia over the years. I select the model based on the quarters just before the launch of the Euro as the most appropriate process to consider (1971q1 to 1998q4).

The estimates are going to be estimated with quarterly data but all the forecasts used in the forward simulation stage are yearly.[23] To compare the degree of inertia of the series I compare the *"absorbing period"* $\mathcal{T}$ which is the number of periods needed to reduce a shock to a 10% of its initial magnitude, i.e, $\rho^{\mathcal{T}} = 0.1$.

As a not surprisingly result, I find a huge autocorrelation, that might lead to consider a non-stationary series. Although BBL technique does not require to the state variables to be stationary, it turns out that using extended quarterly data (from 1971q1 until the 2008q2) I can not reject a stationary process ($\widehat{\rho}_s < 1$) with a huge persistence.[24]

The detailed estimates are presented in table 7.

---

[22] i) From 1971q1 to 1989q4; ii) From 1990q1 to 2008q2; iii) From 1981q1 to 1998q4; iv) From 1971q1 to 1998q4; v) From 1971q1 to 2008q2.

[23] Appendix H describes the procedure to use these estimates for yearly forecast.

[24] For a discussion on the lack of power in unit root tests, see Hamilton (1994).

Table 7: **Transition Probability estimates for Nominal Exchange Rates.**

		Quarterly Estimates	Yearly Est.	$\mathcal{T}$
Belgian	ρ	0.98***	0.93	33
Franc	α	0.06*	0.23	
French	ρ	0.99***	0.96	54
Franc	α	0.02	0.07	
German	ρ	0.98***	0.91	26
Mark	α	0.01	0.04	
Italian	ρ	0.98***	0.92	28
Lira	α	0.15**	0.60	
British	ρ	0.97***	0.89	19
Pound	α	-0.01	-0.05	
Japanese	ρ	0.98***	0.91	24
Yen	α	0.12*	0.44	

$*$ significant at 5% ; $**$ significant at 1% ; $***$ significant at 0.1%

I also want the correlation matrix of the residuals, since I need to draw simulations of the random vectors u. During these decades I observe an integration process between these European countries that lead to an almost perfect correlation between currencies. Of course after the launch of Euro the correlation is perfect, since the currencies of Belgium, France, Germany and Italy just disappeared. The estimated correlation matrix for the selected period is presented in table 8.

Table 8: **Correlation Matrix of Exchange Rate Shocks.**

Yearly	Bel	Fra	Ger	Ita	UK	Jap
Bel	1.00					
Fra	0.93	1.00				
Ger	0.97	0.91	1.00			
Ita	0.81	0.84	0.79	1.00		
UK	0.66	0.65	0.65	0.70	1.00	
Jap	0.62	0.60	0.62	0.45	0.46	1.00

Among the countries that adopt the Euro, the Italian currency has a quite lower correlation than the others. The UK did not adopt the Euro and kept its currency showing an intermediate level of correlation. As expected, the Japanese Yen is the less correlated currency. Using this set of estimates I can draw alternative paths of nominal exchange rates in the forward simulation stage.

4.2.2 Nominal Wages and Nominal GDP per capita

Now I turn to the transition probabilities of the nominal wages, W, and the nominal GDP per capita, Y. I consider both GDP per capita and wages in the manufacturing sector (or car sector if available) to be correlated within each country (Belgium, France, Germany, Italy, and the UK). Furthermore, I assume segmented labor markets and therefore I rule out correlation between countries through the random term v_s.

Using the log of the variables, the estimated model is the following $VAR(1)$ system:

$$\begin{bmatrix} W_{s,t} \\ Y_{s,t} \end{bmatrix} = \lambda_0 + \lambda_s' \begin{bmatrix} W_{s,t-1} \\ Y_{s,t-1} \end{bmatrix} + \begin{bmatrix} v_{1,s,t} \\ v_{2,s,t} \end{bmatrix} \tag{28}$$

where $E(v_{1,s,t}v_{2,r,p}) = \kappa \neq 0$ if and only if $s = r$ and $t = p$.

The estimates I present in table 9 are based on yearly data between 1971 and 1999.[25]

Table 9: **Transition Probability estimates for Nominal Wages and GDP per capita.**

	GDP Equation			**Wage Equation**			**Correlation**
	GDP_{t-1}	$Wage_{t-1}$	Cons.	GDP_{t-1}	$Wage_{t-1}$	Cons.	κ
Belgium	0.95***		0.68***	0.07***	0.84***		0.35*
France	0.65***	0.30***	2.93***	-0.25***	1.19***	2.27***	0.59***
Germany	0.95***		0.58***		0.95***	0.19***	
Italy	0.69***	0.28***	2.71***	-0.19***	1.13***	2.04***	0.33*
UK	0.96***		0.45***	0.02***	0.94***		0.42**
Japan	-	-	-		0.90***	1.35***	

Not surprisingly, all the process are extremely autocorrelated. It implies a slow adjustment given a shock. Similarly for most of the countries, the shocks on nominal wages are correlated with the shocks on nominal GDP, captured by the country specific parameter κ. Germany is the only country where there is no significant wage-GDP correlation.

4.3 Policy Functions

This section describes the policy functions and presents the estimates. The aim of this stage is to retrieve the optimal decision function from the observed behavior. I assume agents have taken their optimal decisions based

[25] Quarterly data is not available for all the relevant years and countries.

on observable state variables consistent with Markov perfect equilibrium, hence I estimate the relationship through a reduced form using actual data.

Remember that the BBL approach uses the transition probabilities to simulate several paths of future scenarios. Given those alternative sequence of state variables, I compute the optimal response using the estimated policy functions in each scenario.

Basically, I want to predict future car prices based only on fixed car's characteristics and simulated macroeconomic variables. My dependent variable is nominal prices in destination currency and the states variables include car's characteristics and macroeconomic variables of the five destinations market (Belgium, France, Germany, Italy and the UK). I aggregate the 31 firms into 6 nationalities (American, French, German, Italian and Japanese) so we should think of 6 players meeting in 5 different markets.

I have emphasized the strong evidence of "Pricing to Market" behavior, especially important in differentiated products. To account for "pricing to market" in the European car industry, I allow different policy functions in each market/producer combination, so the Markov perfect equilibrium is not assumed to be the same. Hence each producer's policy function has different parameters in each different market. I estimate each combination of the 6 firm's nationalities over the 5 destination markets. There is no free lunch and the cost of having producer/market estimations is the reduction in the sample that limits more flexible functional forms in the estimation.[26]

From the initial 11,549 observations I must restrict the sample for various reasons. First, I only use those that belong to the 6 nationalities.[27] Second, I need information of at least two consecutive periods in order to estimate the lagged price coefficient. Third, I only use those cars produced in domestic locations. Although most of the models were made in the domestic headquarter country, some firms have production in different locations. I discard the other location's cars because do not have enough observations to avoid the strong assumption of a common policy function and cost parameters with the headquarter's production. The exception is given by the American cars that are made in the UK (for the British market) and in Germany (for the rest of the markets). The available number of observations for each estimation is given in table 10.

The policy functions should have a flexible functional form in order to capture the unknown relationship between states and control variables. I do not have any structural interpretation for these estimates and only through the second stage estimates I will have structural parameters. Of course the considered explanatory variables must have an underlying economic reason to be part of the relevant state variables for these players in

[26]Exploring policy functions that are asymmetric or a S-s function is totally desired but requirements on the number of observations are prohibitive.

[27]I leave out the models from the Netherlands, Czechoslovakia, Sweden, Spain, Korea, Russia, Yugoslavia.

Table 10: **Sample for Policy Function Estimation.**

Nation/Market	Belgium	France	Germany	Italy	UK	Total
American	211	175	204	165	174	929
French	463	462	413	418	390	2,146
Germans	296	286	301	280	252	1,415
Italians	355	325	279	404	197	1,560
British	104	94	34	69	140	441
Japanese	515	272	416	55	405	1,663
Total	1,944	1,614	1,647	1,391	1,558	8,154

this particular pricing decision. I choose to have all the states variables related to own production costs. Although this set can be arbitrarily extended, I tried the average of all the past own prices and all competitor's prices (also averaging the same segment only). I did the same with the products' characteristics, competitor's wages and competitor's exchange rates too. Many of these variables were quite collinear with the other state variables. None of these attempts made sense neither statistically nor economically, so I kept the minimum set of variables directly related to own producing costs.

I have 30 combinations for the six nationalities in each of the five markets. Denote m the market of destination and denote s the country of production which most of the cases is the same as the head quarter country or nationality f.[28]

Hence, for a given car model in market m, produced in market s at time t, I have:

$$\begin{aligned}\log(p_{jt}^m) \;=\;& \alpha \log(p_{j,t-1}^m) + \beta_1 \log(e_{mt}/e_{st}) + \beta_2 \log(e_{mt}/e_{st})^2 \\ & + \beta_3' \log(e_{mt}/e_{st}) \cdot \log(X_{jt}^m) + \gamma_0 \log(X_{jt}^m) + \gamma_1 \log(W_{st}) \\ & + \gamma_2' \log(X_{jt}^m) \cdot \log(W_{st}) + \lambda_1 \log(Y_t^m) + \lambda_2' Dummies + \varepsilon_t\end{aligned} \quad (29)$$

where the dependent variable is the log of the nominal price of model j in destination m currency at time t, p_{jt}^m, highlighting that I want to explain a nominal phenomenon. The explanatory variables I consider are:

- The ratio of nominal exchange rates terms (e_{mt}/e_{st}) that considered polynomials and product with the characteristics X_{jt}^m that are model specific.
- The characteristics X_{jt}^m and the nominal wage W_{st} in the producer country s. These terms are a measure of nominal cost of production.

[28]Except for American firms, who produced in Germany and the UK.

- The lagged price p^m_{jt-1} which represents the price stickiness in a reduced form. Notice that this estimate can not be interpreted as the adjusting cost parameter directly.
- The nominal GDP per capita,Y^m_t in the destination market m at time t. This captures the income effect of the consumers in each market m. Recall that the real price consider in the demand is the ratio p^m_{jt} over Y^m_{jt}.[29]
- The dummies per firm and market segment (compact, subcompact, standard, intermediate and luxury cars).

In order to give us a sense of the price stickiness that I observe in the policy function, table 11 present the estimated coefficients $\widehat{\alpha}$, which are large, significant and origin-destination market specific.

Table 11: **Lagged Price Estimated Coefficient.**

	Belgium	France	Germany	Italy	UK	Producer Av.
American	0.53	0.64	0.65	0.42	0.42	0.53
French	0.85	0.80	0.75	0.71	0.67	0.76
Germans	0.70	0.74	0.86	0.71	0.70	0.74
Italians	0.63	0.70	0.71	0.77	0.57	0.67
British	0.56	0.67			0.30	0.51
Japanese	0.75	0.50	0.64		0.77	0.67
Market Av.	0.67	0.67	0.72	0.65	0.57	**0.66**

These coefficient are not meant to be interpreted as a meaningful economic parameters.[30] The degree of fitness is quite good with R-squared above .95 although the statistic significance are quite low in general. This is expected given the high collinearity of many of these variables and the high degree of autocorrelation of the series. One way to evaluate them is through the implications for forecasting.

The forecasts are useful for the structural second stage estimation as long as their economic implications are reasonable. I then rule out pass-through estimates that either predicts overshooting or negative pass-through for exchange rates and wages. Hence I might have zeros pass-through in some very particular cases. To ensure that policy functions imply sensitive economic results, I stress the importance of Impulse Response exercises, since these forward simulation are the key ingredient to identify the deep parameters that rationalize the optimal behavior.

[29]This is very collinear with nominal domestic wages at the destination market. This fact does not allow us to include a term that represents domestic components in the cost function.

[30]The entire set of 13 regressors for each of the five markets for each of the six producers is available upon request.

4.4 Checking the Policy Functions: Impulse-Response Experiments

This section discuss the results and the criteria to evaluate the estimated policy functions. Recall that the aim of these estimates is to have a good predictive power to feed the forward simulation second stage.

From a pure game theory point of view, the optimal policies estimated here are just statistical representations of the true theoretical policy functions, that only can be found solving the theoretical game. Under this point of view, any real counterfactual exercise only can be done with those theoretical policy functions. Notice that there is no formal concept of price equilibrium along the temporal profile of responses.

Instead, the following impulse-response exercises show the forecasts using the estimated policy functions, assuming that the policy functions remain the same. This exercise is a graphical way to present the statistical properties and economic sense of the predictions.

One key prediction for the second stage is to obtain reasonable price ratios with respect the the nominal GDP per capita in each market. Recall that that nominal GDP per capital follows its own AR(1) process and therefore any miss-specification will lead the price ratio directly to infinity or zero. I ensured that selected specifications yield sensitive forecast for these ratios.

Also an important forecast to consider is the response to a shock in the nominal state variables. I evaluate the policy functions under different paths of the state variables to asses the changes in price, demand and revenue for each player. Since I have a fully structural demand, I evaluate the implications of the price change on demand and revenues. Recall that the elasticity patterns in the demand estimation consider not only the change in relative prices but also the characteristics of each car.

Using the estimates of each policy function, I simulate two different paths under two different scenarios. The benchmark keeps all the state variables in their long run value, whereas the other initially perturb a given state variable in 10% increase (I focus on exchange rate and wage perturbations). After the initial perturbation[31] , the state variable follows its own AR(1) process until getting closer to their steady-state.[32] I simulate the exercise for 40 periods ahead.

Notice that these predictions are based on the best reduced form estimations taken from the data, so these predictions are only the best statistical responses.

[31]The shocks are uncorrelated to clarify the presentation, during the forward simulation stage I draw the shocks using the estimated correlations in the transition probabilities.

[32]The existence of steady-state is not necessary for the estimation under BBL technique. However, it simplifies this exercise because otherwise the reaction are determined by the initial conditions. Based on yearly data I do find stationary processes for the state variables.

4.4.1 Exchange Rate Depreciation

This subsection graphically analyzes the impulse-response experiments after a 10% nominal depreciation of each of the nominal currencies.

Although the reaction is symmetric between a depreciation of the destination currency and an appreciation of the origin currency, the temporal profile of the reaction will be different because of the different speed of adjustment of each currency.

Also, the shock affects differently to domestic and foreign producers. For example a depreciation of the French Franc may change the price of all the French cars outside France. The depreciation allows to the French producers to cut prices abroad keeping markups constant. On the other hand, only Foreign producers are affected in France. The depreciation might force the foreign producers to increase their prices since their revenues are less valuable in producer's currency. Because French producers have costs in this depreciated currency, they do not change their prices domestically. I denoted these two effects as *International effects* when domestic producers can sell cheaply abroad and *Domestic effects* when foreign competitors are more expensive.

As special case I have Belgium where there are no domestic producers, hence all the cars are more expensive in Belgian Franc after a domestic depreciation. Similarly, since I do not consider the Japanese domestic market, a Japanese Yen depreciation implies lower prices all across Europe.

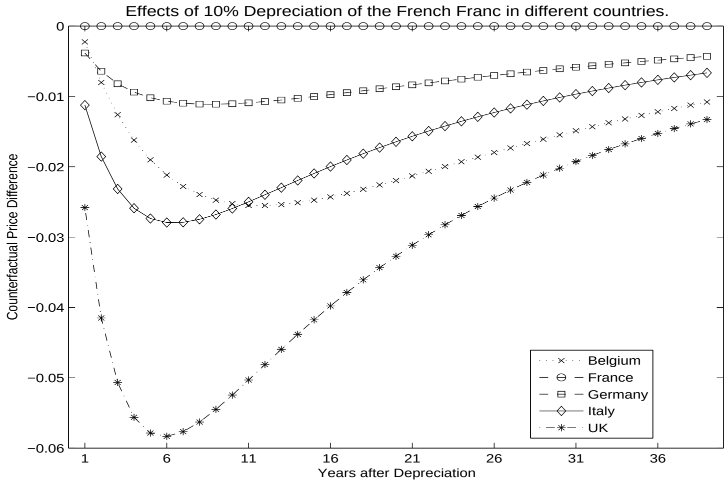
As an example, I present the figures for the French franc case. The entire set of figures for all the responses after a 10% depreciation of each currency in each separate market is in appendix D and E. Appendix F presents the 90% confidence intervals for each response based on a bootstrapping of 1000 draws of each policy estimation. I refer to these figures whenever I claim that the response are not statistically significant.

Figure 7 presents the reaction of French producers outside France. The evidence remarks the heterogeneity in responses, both in size and temporal profile of the price change. The price change is close to 6% in the UK, while only 1% in Germany. Notice also the delay of six periods to reach the peak of reaction, even though there is a unique initial shock and afterwards each state variable follows its own process. Also notice that I do not observe a full pass-through and after a 10% depreciation, the prices respond partly.

Figure 8 presents the reaction of foreign producers in France after a depreciation of the French Franc. Since their revenues are smaller in terms of their cost's currency, foreign producers increase their price. French producer's price remain the same since their cost and revenues currencies have been not affected by the depreciation.

The price increases and temporal profile are quite similar among producers (about 6% and similar speed of reduction), except by Japanese cars that increase only 1% and remains almost flat along the simulations.

Figure 7: **Reactions in Europe after a 10% depreciation of the French Franc.**



Using my point estimates of the demand system, I compute the consequences in the traded quantity as well. Notice that the depreciation of one currency changes all players demand. Even though some price may remain constant, the change of any competitor's price may imply a change on demand. I present the percentage responses in the second panel of figure 8. The reactions in demand after the price increase stress a heterogenous pattern of substitution among French consumers. Domestic cars almost do not change, even though they are relatively cheaper after the depreciation, highlighting that many consumers prefers the outside good. Losses in demand are close to 20%, based on the estimated elasticities between 2 and 3. The net result in revenues is just the sum of these two percentage responses. In short, a 10% depreciation in the French Franc leads to a reduction in revenues of about 20%. Notice using previous elasticities close to 5, the predicted losses would be close to $40 - 50\%$.

4.4.2 Wage Increase Experiment

This subsection presents the price reactions of a 10% increase in producers' nominal wages, using the estimated policy functions and transition probabilities. This wage increase only affects the costs of producer at the time[33] and it implies a price increase in the domestic market and abroad. Figure 9 presents the percentage responses in price increases and appendix G presents the figures for the rest of European wages.

In general there are no big differences in the magnitudes of the price

[33]Except for American cars that are made in Germany and the UK.

Figure 8: **Reactions in France after a 10% depreciation of the French Franc.**

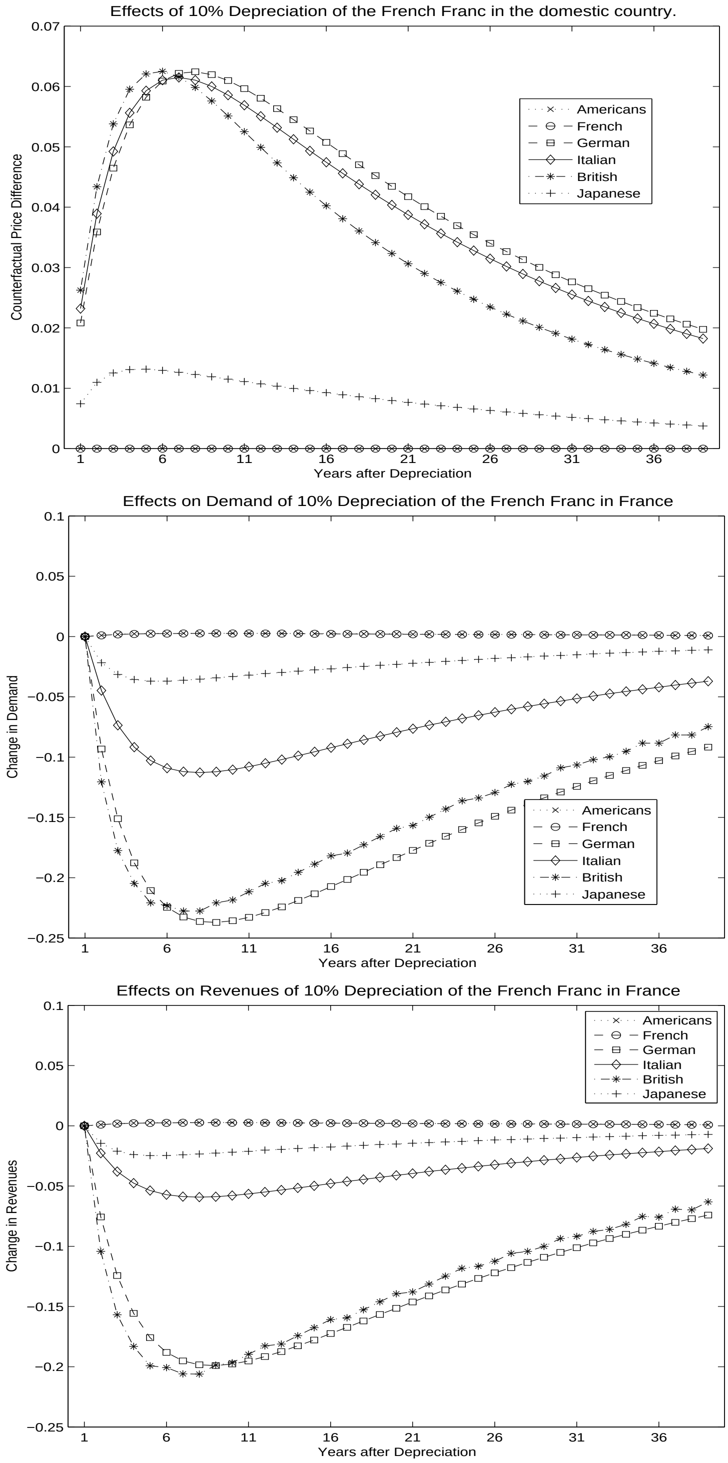
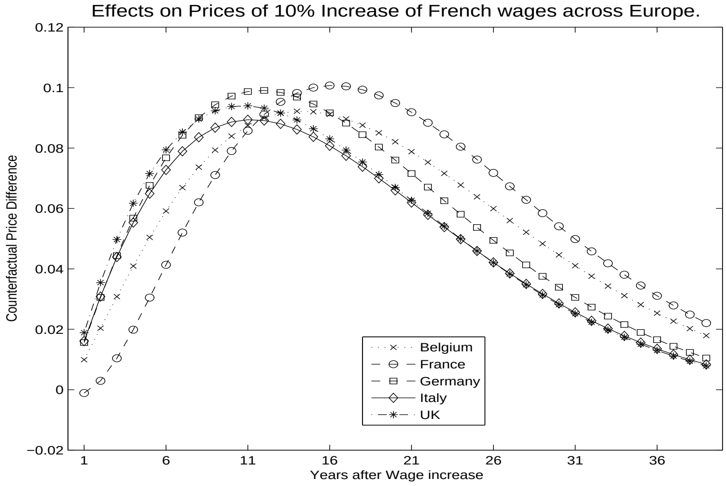


Figure 9: **Reactions after a 10% increase in French wages across Europe.**



increases, but in the temporal profile I observe some countries with a longer delay in the cost pass-through.

Recall that all the policy functions, transition probabilities and demand estimates were taken directly from the data and did not impose any optimality condition. The BBL second stage assumes that producers were optimizers and estimate the cost parameters that make this behavior optimal, i.e., search over the structural parameters that rationalize the previously estimated behavior.

4.5 Structural Cost Parameters

This section analyzes the estimated structural cost parameters in the European car market. The second stage search over the cost parameters that rationalize the behavior found in the data (captured through the first stage estimates). Using these parameters I identify the size of the destination wage component and the size of the adjustment cost component over the total cost.

I assume the following cost function for firm f and product $j \in \mathcal{F}_{jm}$:

$$\begin{aligned} C_{jt}^{m} \;=\; & \underbrace{\nu_0 \cdot q_{jt}^m + \nu_j \cdot [q_{jt}^m]^2}_{\text{Car's Characteristics}} + \underbrace{\nu_{w1} \cdot W_{ft} \cdot q_{jt}^m + \nu_{w2} \cdot W_{ft} \cdot [q_{jt}^m]^2}_{\text{Producing Wage Cost}} \\ & + \underbrace{\nu_{w3} \cdot e_{fmt} \cdot W_{mt} \cdot q_{jt}^m + \nu_{w4} \cdot e_{fmt} \cdot W_{mt} \cdot [q_{jt}^m]^2}_{\text{Destination Wage Cost}} \\ & + \underbrace{\Psi_m \cdot e_{fmt} \cdot |p_{jt}^m - p_{jt-1}^m|}_{\text{Price Adjustment Cost}} \end{aligned} \quad (30)$$

where vector ν includes the production cost parameters and Ψ is the vector price adjustment cost. The latter the structural parameters are indexed by m since they are destination market specific. q_{jt}^{m} is the quantity of product j sold in market m, and $W_{gt}, g \in \{m, f\}$ is the nominal wage in destination country m or source/producer's country s. e_{fmt} is the nominal exchange rate between country f and m. The quadratic terms ensures point estimates since the minimization procedure can achieved a global minimum.

The first component is a fixed effect per model, so it represents the production cost related to the characteristics of each car, which remain fixed during the forward simulations.

The second and third components are the the nominal labor cost, which distinguish between wages where the product was made and wages where the car was sold (if different from producing country). Those are the main nominal component in the marginal cost.

The last component represents the price adjustment cost, which is independent of the quantity q_{jt}^{m}. I also consider an alternative cost function given by $\Psi_{fm} \cdot |\log(p_{jt}^{m}) - \log(p_{jt-1}^{m})|$. The estimation looks for the price adjustment cost that is consistent with the actual price stickiness.

As discussed in the entry-exit section, I ensure the same competitors over time. To do so I keep the firms and models that were traded in 1985, which is in the middle point of my sample.[34] For these models I simulate 1,000 different paths of state variables, each path involving 40 periods of time.

Table 12 presents the car models I consider in the forward simulations with no entry or exit of models. As we can see there are few British cars in the sample and they eventually disappear in the 90's, making impossible to have reliable cost estimation for British producers.

Table 12: **Models considered in Forward Simulations.**

	Belgium	France	Germany	Italy	UK	Total
American	9	8	9	7	6	39
French	19	18	16	18	16	87
Germans	10	10	10	10	8	48
Italians	13	16	7	19	5	60
British	4	5	0	5	6	20
Japanese	29	15	20	0	20	84
Total	84	72	62	59	61	338

Some important remark of the cost estimates. First, I can not identify any fixed cost of the firm, such as an investment in a new plant.The

[34] I have the estimates for other years and are they very similar.

estimation procedure cancel out these terms leaving the variable cost estimates unaltered. Second, I account for the differences among countries at demand and supply level. The demand consider consumer heterogeneity and the optimal policies are market-firms' specific, hence the equilibrium beliefs and cost parameters are market-firms' specific as well.

4.5.1 Cost Share by Components.

This section presents the cost parameters implications in order to explain degree of incomplete exchange rate pass-through and the adjustment cost consistent with the observed price stickiness. For simplicity, I present the share of each component over total cost in order to provide an order of magnitude of my estimates. The same charts for the alternative specification are presented in the appendix I, which are qualitatively the same.[35]

The shares of each component is given by the following decomposition:

$$\text{Share of Local Production Cost} = \frac{\nu_0 \cdot q_{jt}^m + \nu_j \cdot [q_{jt}^m]^2 + \nu_{w1} \cdot W_{ft} \cdot q_{jt}^m + \nu_{w2} \cdot W_{ft} \cdot [q_{jt}^m]^2}{C_{jt}^m}$$

$$\text{Share of Destination Wage Cost} = \frac{\nu_{w3} \cdot e_{fmt} \cdot W_{mt} \cdot q_{jt}^m + \nu_{w4} \cdot e_{fmt} \cdot W_{mt} \cdot [q_{jt}^m]^2}{C_{jt}^m}$$

$$\text{Share of Price Adjustment Cost} = \frac{\Psi_m \cdot e_{fmt} \cdot |p_{jt}^m - p_{jt-1}^m|}{C_{jt}^m}$$

Table 13 presents the share of each component for each producer's nationality. Naturally, the destination market component appears in the exported cars only. The adjustment cost component is virtually zero for the domestically sold cars of the American and German producers.

Based on the tables, I conclude the following insights. First, the destination market wage component in table 13 may explain the incomplete degree of exchange rate pass-through. Roughly speaking the destination wage components contribute to one third of the costs and therefore I should not expect to have full pass-through.Goldberg and Verboven (2001) find destination cost about 40% for the European car market, hence my estimates are along the same lines for most producers. Still the foreign component for Italian producers seems too high to be plausible.

Second, the adjustment cost component seems small and sometimes not economically significant. My estimates in table remark that these terms are larger for Italians and Japanese producers, whereas almost nonexistent for German producers. The adjustment cost component seems more important

[35] In general I found plausible results for most producers, except for British producers. Only five cars per market were not enough to identify the cost parameters, which yields negative markups for all models (with some noticeable outliers). Thus I do not report the unreliable British results. Perhaps the small elasticities in the demand estimation can also be the source of the failure of the estimation for this producers.

Table 13: **Different Components (%) over Total Cost in 1985.**

Exports	Local Cost	Destination Cost	Adjustment Cost
American	83.17	16.68	0.15
French	77.91	20.11	1.98
German	62.10	37.58	0.31
Italian	35.33	59.17	5.50
Japanese	60.12	28.91	10.97
Sold Domestically	Local Cost		Adjustment Cost
American	100.00		0.00
French	97.42		2.58
German	100.00		0.00
Italian	88.59		11.41

Table 14: **Adjustment Cost Share by Destination Market.**

	Belgium	France	Germany	Italy	UK
American	0.0	0.4	0.0	0.0	0.0
French	0.0	2.2	0.0	7.4	0.1
German	0.1	0.0	0.0	0.8	0.1
Italian	12.9	1.9	0.0	10.2	2.1
Japanese	0.0	1.4	3.8	-	37.2

Table 15: **Ratio of Adjustment Cost Parameters:** Ψ_{fm}/Ψ_{ff}**.**

	Belgium	France	Germany	Italy	UK
American	0.07	93.38	1.00	0.22	11.04
French	0.00	1.00	0.00	1.78	0.08
German	3.57	0.00	1.00	1.31	1.49
Italian	0.37	0.02	0.02	1.00	0.23
Japanese	0.00	0.25	1.00	-	14.28

in exports but recall that most of the cars are sold domestically, so these calculations have a bigger denominator.

To compare this conclusion with the related literature, my price adjustment cost represents at most 3% of total revenues, roughly speaking.[36] Nakamura and Zerom (2008) found that adjustment cost represents 0.23% of total revenues in the coffee industry, using a different dynamic approach. Using a static framework, Goldberg and Hellerstein (2008) estimates are less than 1% of revenues in the beer industry. Notice that most papers have weekly data based on scanner data whereas this paper presents yearly data.

Third, there is a clear heterogeneity in the estimates of tables 14 and 15. Adjustment cost seemed to be market specific for each producer nationality. Comparing the ratio of coefficients and the relative importance of the cost share. Something that is destination-origin specific might matter. To justify such practice I could have some conjectures based on bilateral country relationships like the average of relative inflation, exchange rate volatility or any other characteristic that is pair-country-specific. None of the previous literature in this topic has explored this dimension. An interesting research question would be to explore the covariates that explain this cost share, however the 25 estimates are too few to do serious econometrics.

Table 16: **Implied Markups in 1985.**

	Mean	Std Dev
American	71%	35%
French	83%	31%
German	61%	47%
Italian	74%	37%
Japanese	67%	42%

Fourth, table 16 presents the implied markups for year 1985, i.e., the markups that rationalize the behavior described by the policy functions.[37] Going back to the figures of the policy function impulse-response exercises, we observed that revenues could drop by 20% because of a not unfrequent 10% depreciation, therefore it is not surprisingly that to rationalize that behavior the markups should be large enough. A smaller markup would not survive to the usual exchange rate shocks. In general I compute quite higher markups than the previous usual static approach, but also with a huge dispersion (with some noticeable outliers). Actually, larger demand

[36] Assuming an adjustment cost of 10% of total cost and a markup of 70%.

[37] I do not consider the few models with markups greater than 100% and the British estimates which were based on 5 models).

elasticities would imply larger markups to sustain larger decrease in revenues.

Notice that I need fewer assumptions than the standard static approach, since the policy function is estimated and does not rely on first order conditions of Bertrand competition. Also this paper can not identify fixed cost, which might be really important in this industry, for example investment in new plants, development of new models or technology. Therefore, without those fixed costs I can not say much about the entire industry profitability.

5 Future Research

Several extensions and related research questions arise after these results. Some of them are related to consider more complex policy functions, such as, asymmetric responses, threshold models, or any other semiparametric technique. If we take seriously the remarked pricing to market behavior that request to have producer-market specific estimations, the number of observations does not allow me to go further. An eventual improved/updated data set would be the way to go in this direction. Along the same lines, a focus on the possible structural break due to Euro adoption is also an interesting question. Again, splitting the sample into two time periods have strong implications for the degree of freedom in the policy function estimations. This structural break could be done at policy function level but also at cost function level.

Another possible extension is to determine some explanatory variables for the estimated price adjustment costs. In this case I have at most 25 observations but it seems interesting to shed light on the possible causes of this market specific price adjustment penalties.

6 Conclusions

The aim of this paper is to extend the structural estimation in the European car market to study cost parameters that rationalize i) the observed degree of exchange rate pass-through and ii) the timing in the price adjustment dynamics. I consider an international multi-product oligopoly model in which the forward looking firms set optimal prices taking into account the cost of repricing.

I estimate a fully structural model of demand and supply for differentiated products following the methodology for dynamic games developed by Bajari, Benkard and Levin (2007). My demand estimates highlight the consumer heterogeneity that enhances pricing to market behavior. Consumers have different degree of substitution among international producers, and producers have market specific pricing policies.

On the supply side, I explain incomplete pass-through by a sizable third of the total costs which are denominated in destination currency (destination wage component). Additionally, there is no need of huge adjustment costs to rationalize the large degree of inertia in prices. Intuitively, an economic environment in which wages, GDP and exchange rates are very autocorrelated with persistent shocks, just small adjustment costs can rationalize the actual autocorrelated and persistent car prices. My estimates show that less than 10% of total cost can generate the large observed price stickiness. Surprisingly, my estimates of adjustment cost seem to be market-specific adding a new dimension of heterogeneity to the pricing to market behavior, which has not been explored before.

As a venue of future research I highlight exploring more complex policy functions (threshold models, asymmetric responses, etc), analyzing structural breaks and searching for explanatory variables of the price adjustment costs. Unfortunately, those tasks would require an extended/updated data set to be done in a proper way.

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APPENDIX SECTIONS

A Nationalities.

This appendix section presents the two criteria to classify the nationality of each car model. First I use the brand's history to assign a nationality, regardless the change in property (acquisition or merger with other firms). The demand side estimation use this criterium as the most likely perception for European consumers.

Table 17 shows in detail the nationality considered for each brand. Table 18 and 19 present the market shares and the share of total models available under this criterium.

Table 17: **Nationality based on brand's history.**

Country	Brand Name	Country	Brand Name
Czech R.	Škoda	Japan	Daihatsu
France	Citroën		Honda
	Peugeot		Mazda
	Renault		Mitsubishi
	Talbot		Nissan-Datsun
	Talbot-Hillman-Chrysler		Subaru
	Talbot-Matra		Suzuki
	Talbot-Simca		Toyota
Netherlands	DAF	US	Ford
Germany	Audi	Korea	Daewoo
	BMW		Hyundai
	MCC		Kia
	Mercedes	Spain	Seat
	Princess	Sweden	Saab
	Volkswagen		Volvo
Italy	AlfaRomeo	UK	Opel-Vauxhall
	Autobianchi		Rover
	Fiat		Rover-Triumph
	Innocenti		Triumph
	Lancia	Yugoslavia	Yugo

The supply side consider another definition of nationality to construct the profit function, since I need to express firm's revenues in firm's head-quarter currency. Table 20 presents the assignation between firms and nationalities based on historical nationality of the headquarters location.

Table 18: **Available models across Europe by nationality of the brand**

Brand's Nationality	Belgium	France	Germany	Italy	UK	Total
American	130	126	126	123	126	631
French	566	561	509	509	502	2647
German	338	325	347	317	293	1620
Italian	408	379	340	478	242	1847
British	329	274	224	229	364	1420
Japanese	629	377	533	136	523	2198
Others	273	223	204	235	251	1186
Total	2,673	2,265	2,283	2,027	2,301	11,549

Table 19: **Shares of cars by nationality of the brand.**

	% of Sold Cars	% of Models
USA	11.57	5.46
France	28.02	22.92
Germany	18.12	14.03
Italy	16.23	15.99
UK	15.29	12.30
Japan	7.66	19.03
Korea	0.39	2.43
Sweden	1.53	4.80
Spain	0.80	2.14
Yugoslavia	0.03	0.24
Netherlands	0.20	0.24
Czech Republic	0.16	0.42

Firms never change the assigned nationality even though a brand could change due to mergers or acquisitions. Along the same lines, table 21 and 22 presents the market shares and the share of total models available in each market for each nationality and each destination market.

Table 20: **Nationality based on firms' headquarter.**

Nationality	Firm	Nationality	Firm
France	Peugeot	Italy	AlfaRomeo
	Renault		DeTomaso
	TalbotMatra		Fiat
	TalbotSimcaHillmanSunbe		Lancia
Germany	BMW	Korea	Daewoo
	Daimler		Hyundai
	Mercedes		Kia
	VW	Netherlands	DAF
Japan	FujiHI (aka Subaru)	Spain	Seat
	Honda	Sweden	Saab
	Mazda		Volvo
	Mitsubishi	UK	Rover
	Nissan	US	Ford
	Suzuki		GeneralMotors
	Toyota	Yugoslavia	Yugo

Table 21: **Models available across Europe by firms' headquarter.**

HQ's Nationality	Belgium	France	Germany	Italy	UK	Total
American	321	273	292	258	315	1,459
French	532	528	475	481	480	2,496
Germans	426	413	420	411	376	2,046
Italians	442	412	374	506	264	1,998
British	132	122	54	84	167	559
Japanese	629	377	533	136	523	2,198
Others	281	439	17	28	28	793
Total	2763	2564	2165	1904	2153	11549

Table 22: **Shares of cars by firms' headquarter.**

	Share of Sold Cars	Share of Models
USA	22.12 %	12.63 %
France	26.64 %	21.61 %
Germany	19.56 %	17.72 %
Italy	17.61 %	17.30 %
UK	4.37 %	4.84 %
Japan	7.66 %	19.03 %
Korea	0.39 %	2.43 %
Sweden	1.37 %	3.80 %
Spain	0.06 %	0.15 %
Yugoslavia	0.03 %	0.24 %
Netherlands	0.20 %	0.24 %

B Computing BLP

This appendix section presents the details on the demand estimation. Berry, Levinsohn and Pakes (1995, hereafter BLP) developed the procedure to estimate a random coefficient model as a demand system for differentiated products with aggregated data. The optimization problem is:

$$\widehat{\theta} = \arg\min_{\theta} \parallel s(x_{\cdot,t}, p_{\cdot,t}, \xi_{\cdot,t}, \theta) - \mathbf{Sh} \parallel$$

where $s(\cdot)$ is the predicted shares of the model and **Sh** are the observed shares in the data. The minimization problem is far from trivial since ξ's are not observable and all variables enter in a non-linear fashion.

Berry (1994) and BLP (1995) developed an iterative process, in which the problem is linearized in ξ. Then, the minimization is straightforward through a GMM procedure based on suitable instruments. Also BLP have suggested a set of instruments that may apply in general cases. These instruments are based on the number and characteristics of competitors.

Using previous notation, want to estimate a parameter $\theta = [\Sigma, \beta]$. β are linear parameters and Σ is the cholesky decomposition of a variance covariance matrix of the parameters β.

If parameter β has dimension K, its K by K var-cov matrix $V = \Sigma\Sigma'$ would have at most $(K+1)K/2$ unknowns. Usually most covariances are set to zero for simplicity.

This procedure is summarized as a three step procedure:

I) First given some Σ, I find a vector $\delta(\Sigma)$. It uses a non linear procedure that involves computation of simulated integrals.

II) Secondly, using $\delta(\Sigma)$ I estimate $\beta(\delta(\Sigma)) = \beta(\Sigma)$ in a linear way.

III) Finally, I have a GMM objective function G. Since the GMM objective function G can be expressed as $G(\Sigma, \delta, \beta) = G(\Sigma)$, it is a function of Σ only. The final stage is to find $\widehat{\Sigma}$ that minimizes $G(\Sigma)$.

The basic data consist in: $\mathbf{Sh}_{N\times 1}$ vector of actual markets shares, $X_{N\times K}$ vector of the K characteristics of each product. Let $Z_{N\times J}$ be a vector of the J instruments for each product ($J > K$). $v_{R\times K}$ is a fixed vector of random draws of a multivariate standard normal. Each row i is a random draw of dimension K that represent a *simulated consumer*:

$$v_i \sim N(0, \mathbf{I}_K)$$

where $\mathbf{I}_K$ is an identity matrix of dimension K.

Constructing $\delta(\Sigma)$: I need to find the "mean utility" vector $\delta(\Sigma)$. Given matrix $\Sigma_{K\times K}$ and fix random draws v, I multiply v to construct $\widetilde{v}$ for all simulated consumers:

$$\widetilde{v}_{R\times K} = v_{R\times K} * \Sigma'_{K\times K}$$

Hence, $\widetilde{v}_i$ (the i^{th} row of $\widetilde{v}$) is a $1 \times K$ vector of multivariate normal distribution with variance-covariance $V = \Sigma\Sigma'$.[38]

Next, I choose an arbitrary initial value of δ, say δ_0. I construct the consistent vector s of predicted shares, simulating the integral. It yields:

$$s_j(\widetilde{v}(\Sigma), X_{N\times K}, \delta) = \frac{1}{R}\sum_{i=1}^{R}\left[\frac{\exp(\delta_j + X_{j,\cdot}\widetilde{v}'_{i,\cdot})}{1 + \sum_{h=1}^{H_j}\exp(\delta_h + X_{h,\cdot}\widetilde{v}'_{i,\cdot})}\right] \tag{31}$$

To find the right value of δ, I need to solve the N by N non linear system between predicted and actual shares:

$$s(\delta, \Sigma) = \mathbf{Sh} \tag{32}$$

Instead, Berry (1994) suggested the recursive procedure that converges to an unique δ, given Σ. Given any initial value of δ^0, the δ of round $h+1$ will be:

$$\delta^{h+1} = \delta^h + \log(\mathbf{Sh}) - \log(s(\delta^h))$$

where each of the vectors have dimension N by 1. Uniquely, I find $\delta(\Sigma)$ that matches the best my predicted and actual shares.

[38]Recall that in general:

$$\nu \sim N(0, \mathbf{I}(K)) \Rightarrow \Sigma\nu \sim N(0, \Sigma\Sigma')$$

Estimating $\beta(\Sigma)$: This step is just a simple instrumental variables estimation (IV). For a given Σ (the non-linear parameters) I compute β (the linear parameters) using the linear regression:

$$\delta(\Sigma) = X\beta + \varepsilon \tag{33}$$

with the moment condition that $E(Z'\varepsilon) = 0$. The usual IV procedure lead us to:

$$\widehat{\beta}(\Sigma) = \left(X'Z(Z'Z)^{-1}Z'X\right)^{-1} X'Z(Z'Z)^{-1}Z'\delta(\Sigma) \tag{34}$$

where the weighting matrix used was $W_T = (Z'Z)^{-1}$.

Searching for $\widehat{\Sigma}$: Given Σ and the previous steps, I construct the residual $\varepsilon_{N\times 1} = \varepsilon(\Sigma)$, as follows:

$$\varepsilon(\Sigma) = \delta(\Sigma) - X\widehat{\beta}(\Sigma)$$

Hence finally, $\widehat{\Sigma}$ is given by:

$$\widehat{\Sigma} = \arg\min_{\Sigma\in\Theta} \varepsilon(\Sigma)'Z(Z'Z)^{-1}Z'\varepsilon(\Sigma)$$

where Θ is the set of feasible cholesky decompositions of a positive definite matrix.

To compute the standard errors for these estimates, I follow the standard formulae for GMM estimates.[39]

C Elasticity Advantage Assessment.

This appendix section presents evidence to test whether there is any elasticity advantage in the European car market for domestic producers in their domestic markets. I consider an elasticity advantage if a producer faces systematically a more inelastic demand.

The following figures present the elasticities faced by producers of different nationalities in each of the five analyzed markets. The closer the elasticities to the top of the figure implies a more inelastic demand.

In general terms I found no evidence of any elasticity advantage for domestic manufacturers since the domestic's lines are always in the range (or below) of the other producers' elasticities. This is a robust fact when replicating the analysis by car segment.[40]

[39] See McFadden and Newey (1994) for further details.

[40] Although I do not report the all 25 figures.

Figure 10: **Own price elasticities by nationality in Belgium.**

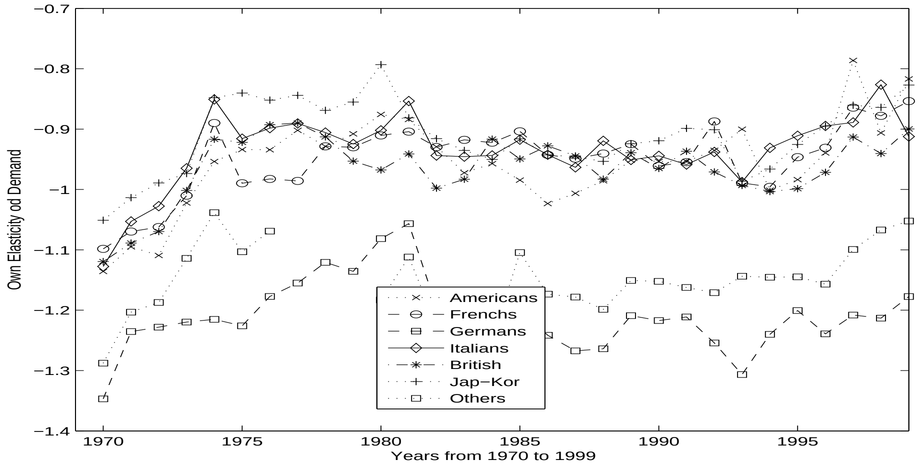


Figure 11: **Own price elasticities by nationality in France.**

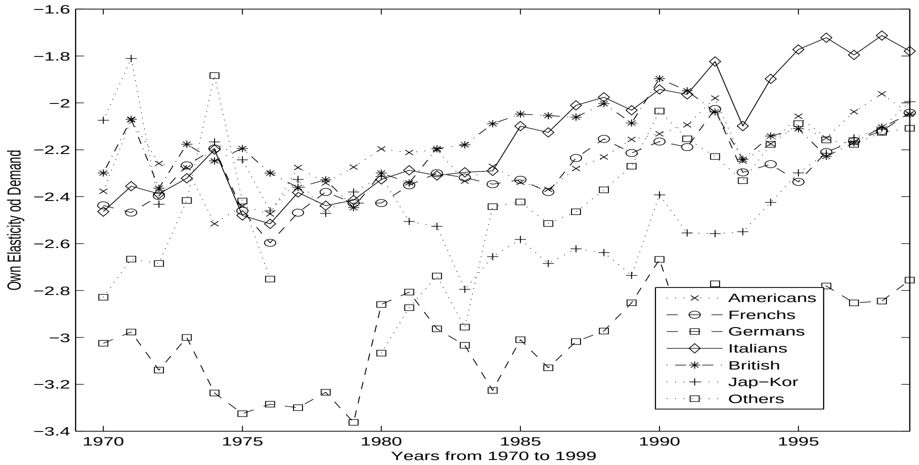


Figure 12: **Own price elasticities by nationality in Germany.**

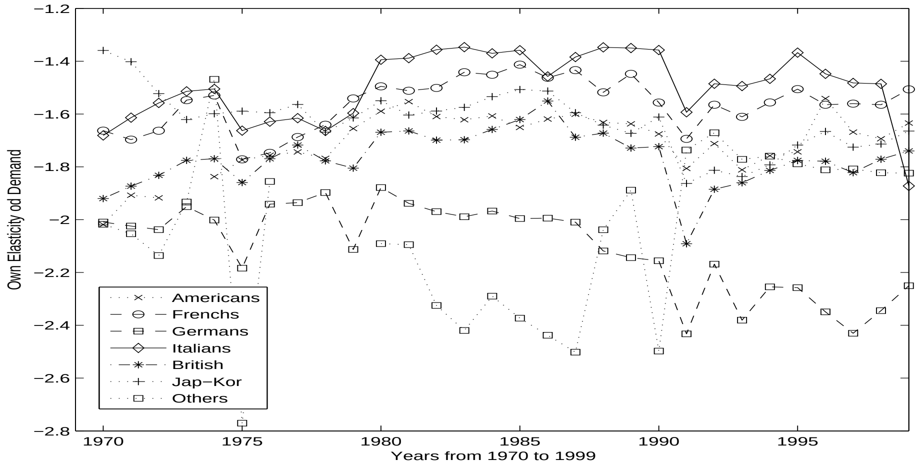


Figure 13: **Own price elasticities by nationality in Italy.**

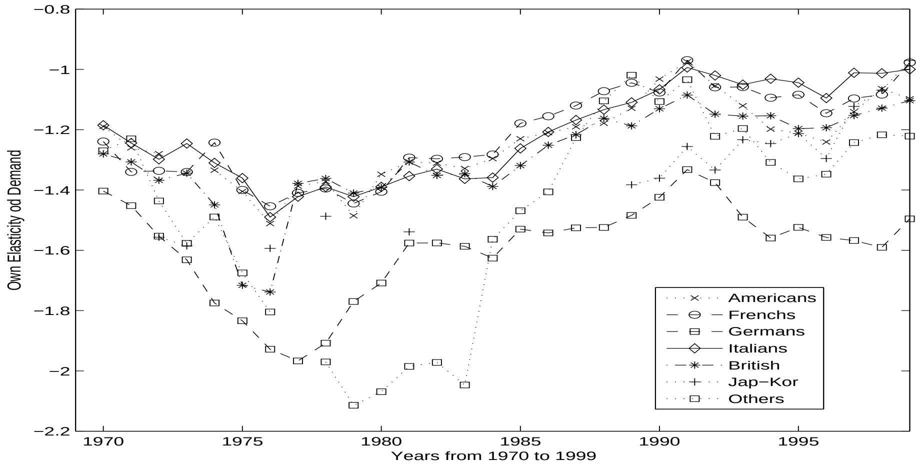
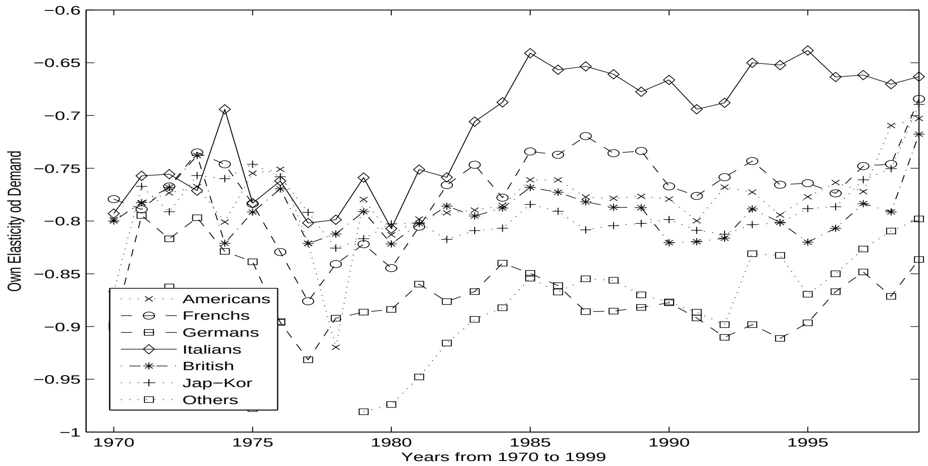


Figure 14: **Own price elasticities by nationality in the UK.**



D International Effects of Exchange Rate Depreciation.

This appendix presents the impulse response exercises after a 10% depreciation of each of the relevant European currencies as explained in section 4.4. Each figure presents the percentage difference between the paths of steady state values and the variables after an initial shock. For 40 periods, I present the convergent path predicted by the AR(1) transition probabilities towards the steady state scenario, which of course should close the initial gap.

This section presents the international effects in all the European markets. Basically, a domestic depreciation allows to domestic producers to sell cheaper than foreign competitors abroad. Demand for all producers may be affected since the consumers' ranking may change abroad.

Recall that in the year 1985 i) there are no British cars in neither Germany nor Italy, ii) there are no Japanese cars in Italy.

Figure 15: **Reactions in Europe after a 10% depreciation of the Belgian Franc.**

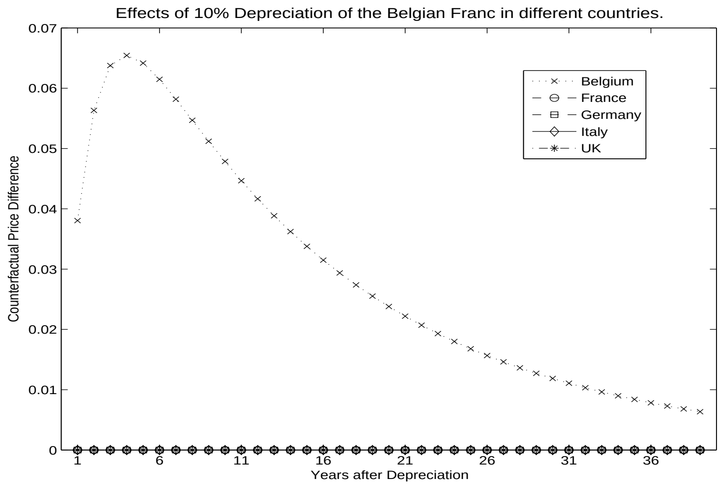


Figure 16: **Reactions in Europe after a 10% depreciation of the French Franc.**

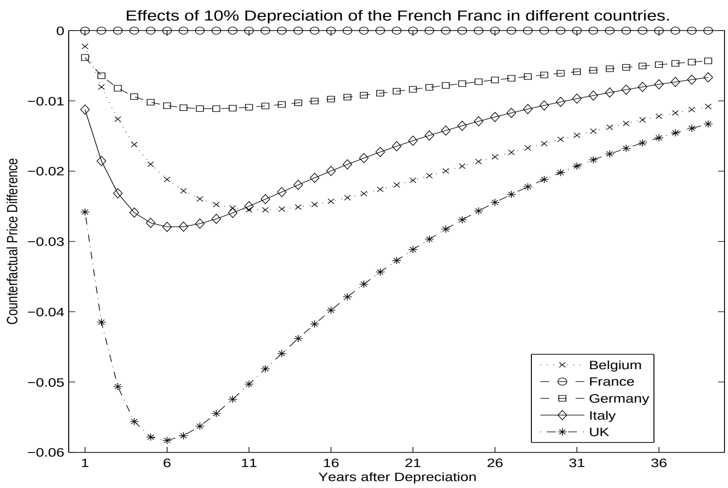


Figure 17: **Reactions in Europe after a 10% depreciation of the German Mark.**

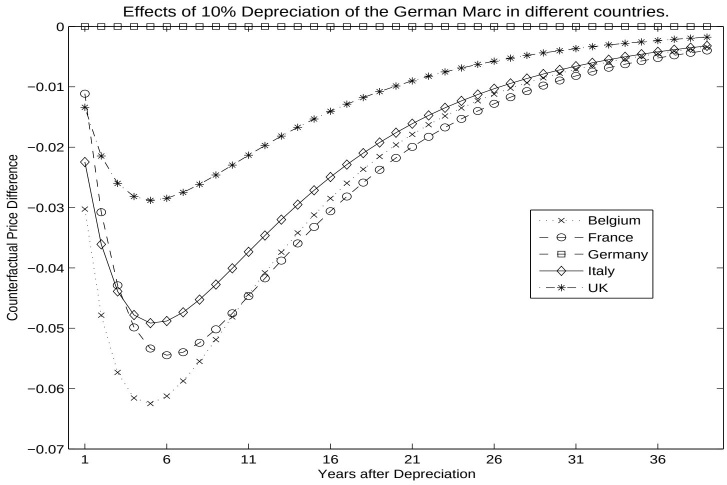


Figure 18: **Reactions in Europe after a 10% depreciation of the Italian Lire.**

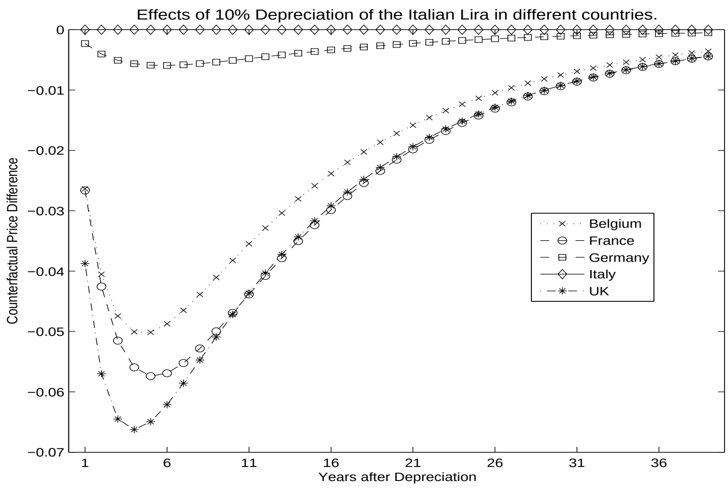


Figure 19: **Reactions in Europe after a 10% depreciation of the British Pound.**

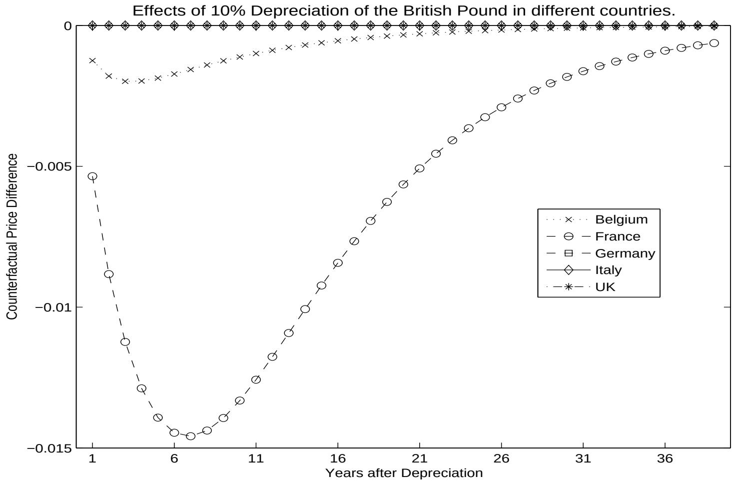
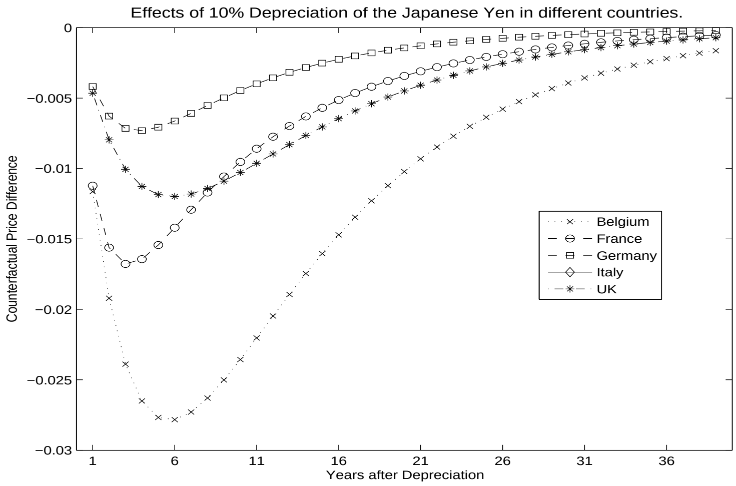


Figure 20: **Reactions in Europe after a 10% depreciation of the Japanese Yen.**



E Domestic Effects of Exchange Rate Depreciation.

This appendix presents the impulse response exercises after a 10% depreciation of each of the relevant European currencies as explained in section 4.4. Each figure presents the percentage difference between the paths of steady state values and the variables after an initial shock. Along 40 periods, I present the convergent path predicted by the AR(1) transition probabilities towards the steady state scenario, which of course should close the initial gap.

This section presents the effects in the domestic market only. A domestic depreciation does not affect domestic producers through cost but makes all the foreign competitors more expensive. Demand for all producers may be affected since the domestic consumers' ranking may change. This exercises is extended to compute the path of demand and revenues of each producer in the market whose currency has depreciated.

Recall that in the year 1985: i) there were neither American nor British cars made in Germany, ii) there were neither Japanese nor British cars made in Italy and iii) American cars sold in the UK were made also in Great Britain.

Figure 21: **Reactions in Belgium after a 10% depreciation of the Belgian Franc.**

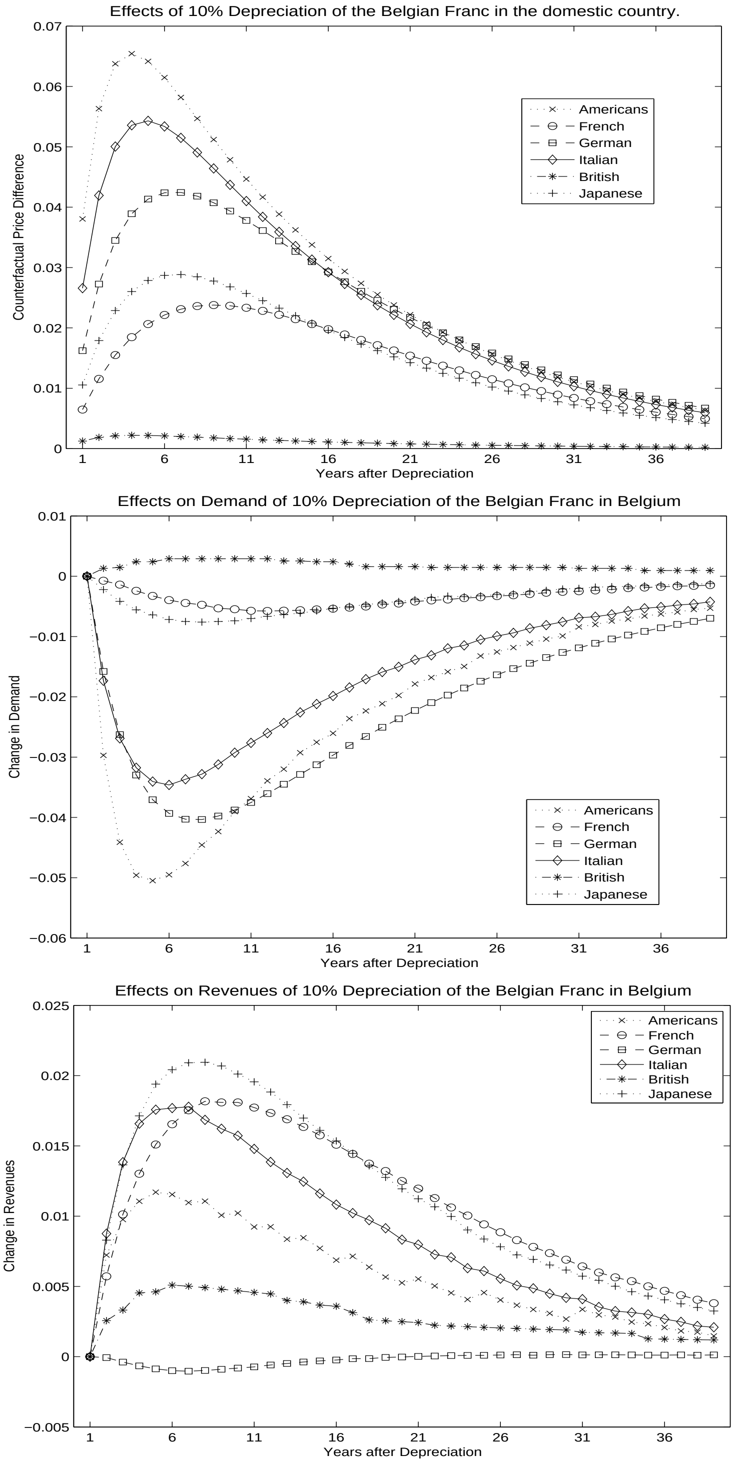


Figure 22: **Reactions in France after a 10% depreciation of the French Franc.**

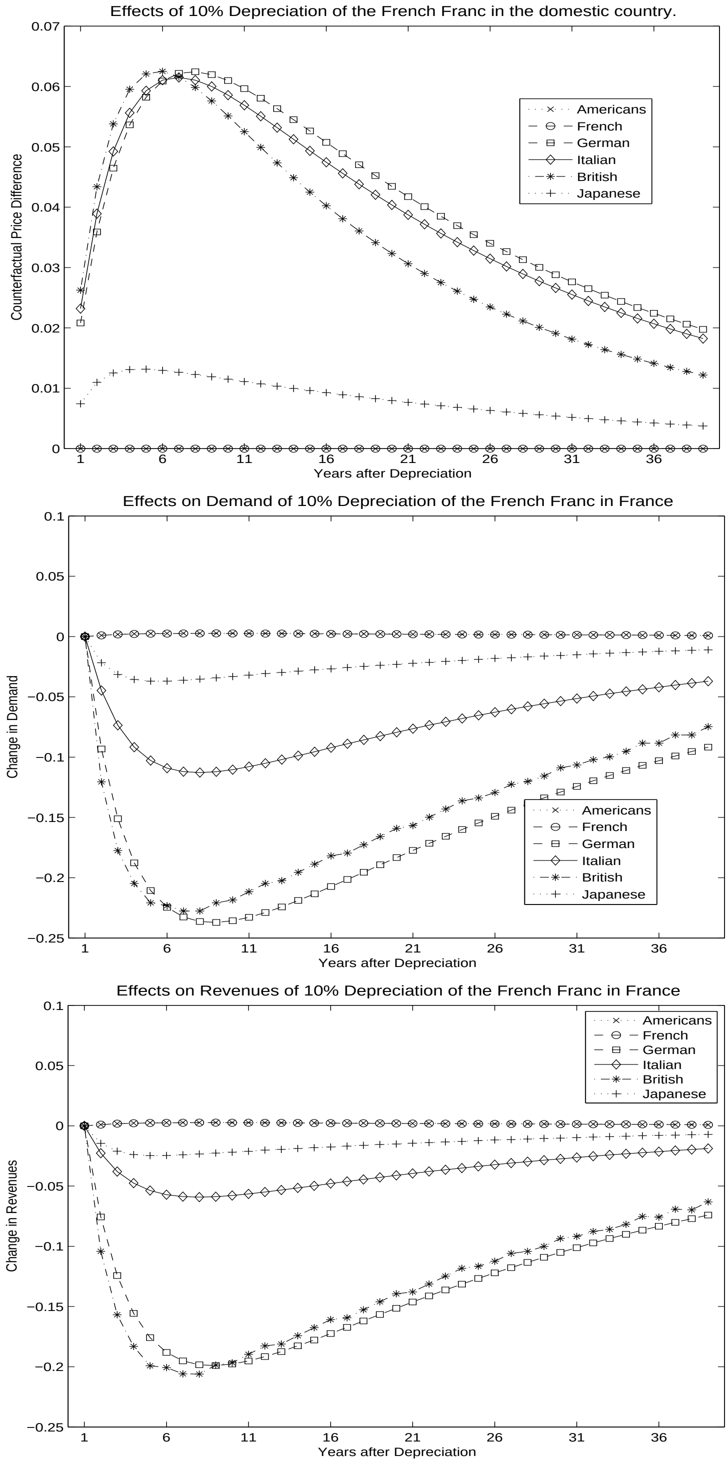


Figure 23: **Reactions in Germany after a 10% depreciation of the German Mark.**

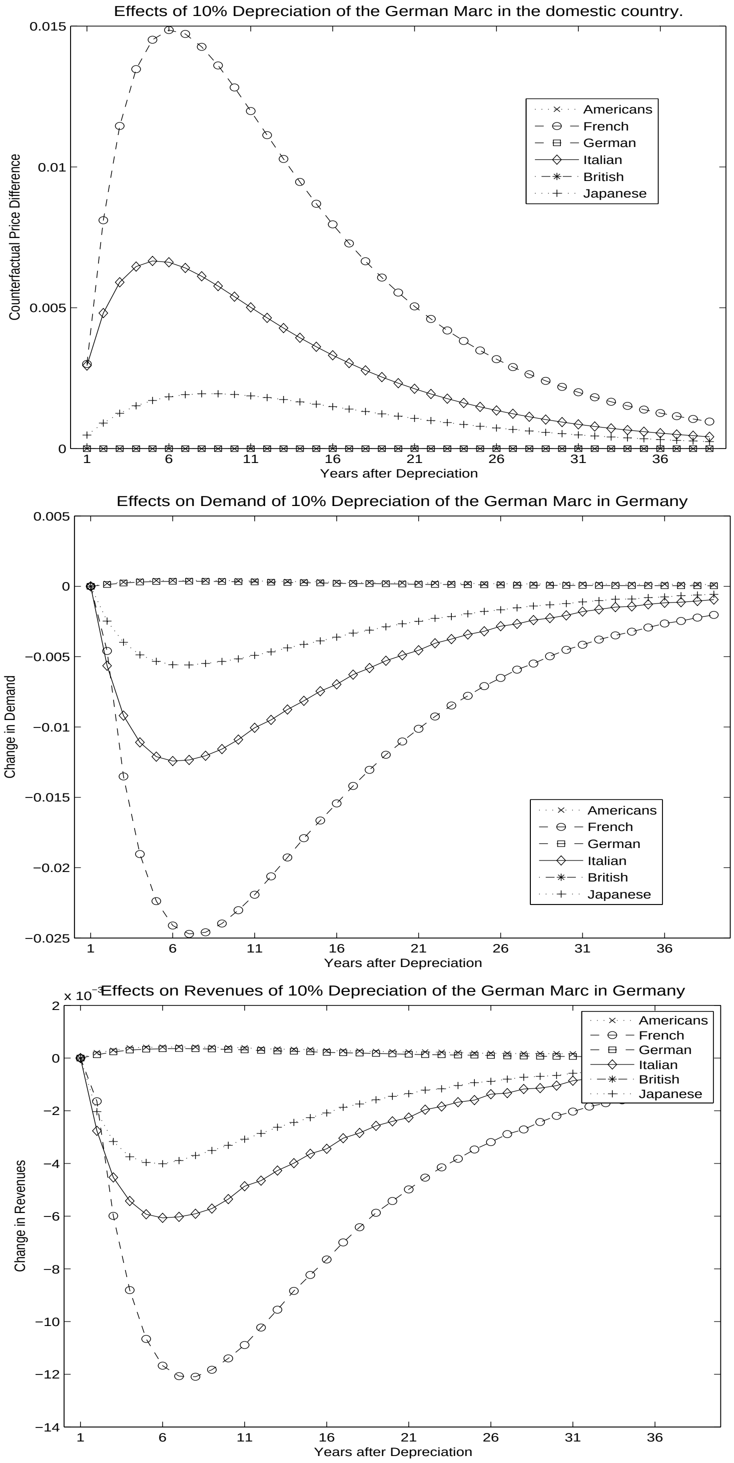


Figure 24: **Reactions in Italy after a 10% depreciation of the Italian Lire.**

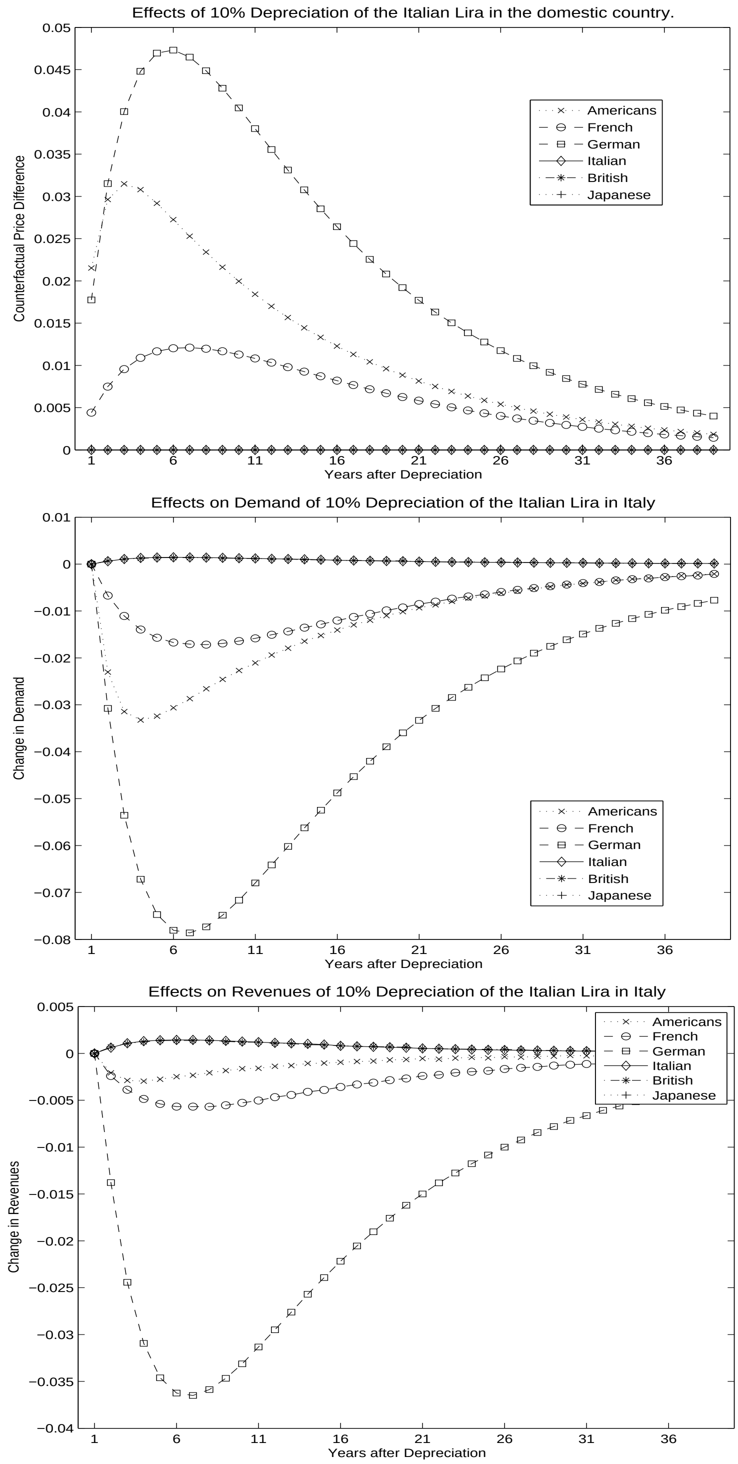
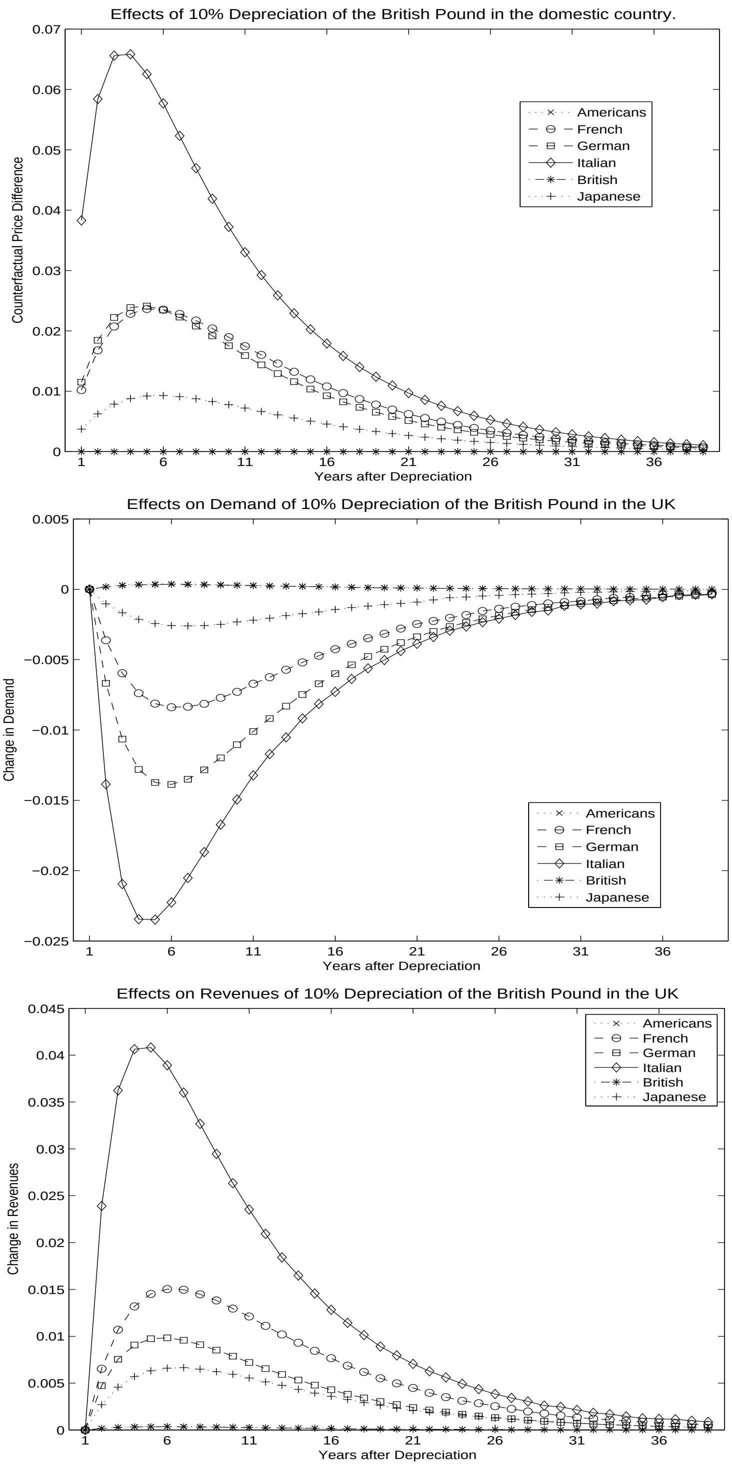


Figure 25: **Reactions in the UK after a 10% depreciation of the British Pound.**



F Confidence Intervals for the Policy Function.

This appendix presents the confidence intervals of the impulse response exercises after a 10% depreciation of each of the relevant European currencies as explained in section 4.4. Each figure presents the bootstrapping exercise for each price panel in the appendix section of both: i) the international effects on domestic producers after a domestic depreciation and, ii) the domestic effects on foreign producers after a domestic depreciation.

Recall that i) there are no British cars in Germany and American cars were made in Germany, ii) neither British nor Japanese cars were sold in Italy and iii) American cars were made in the UK.

F.1 Confidence Interval for the International Effect of a Domestic Depreciation.

Figure 26: **Confidence Interval for Price reactions in Europe after a 10% depreciation of the Belgian Franc.**

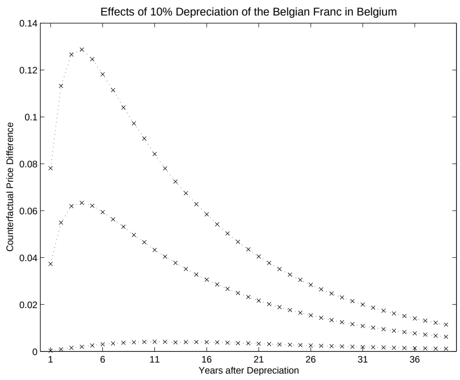


Figure 27: **Confidence Interval for Price reactions in Europe after a 10% depreciation of the French Franc.**

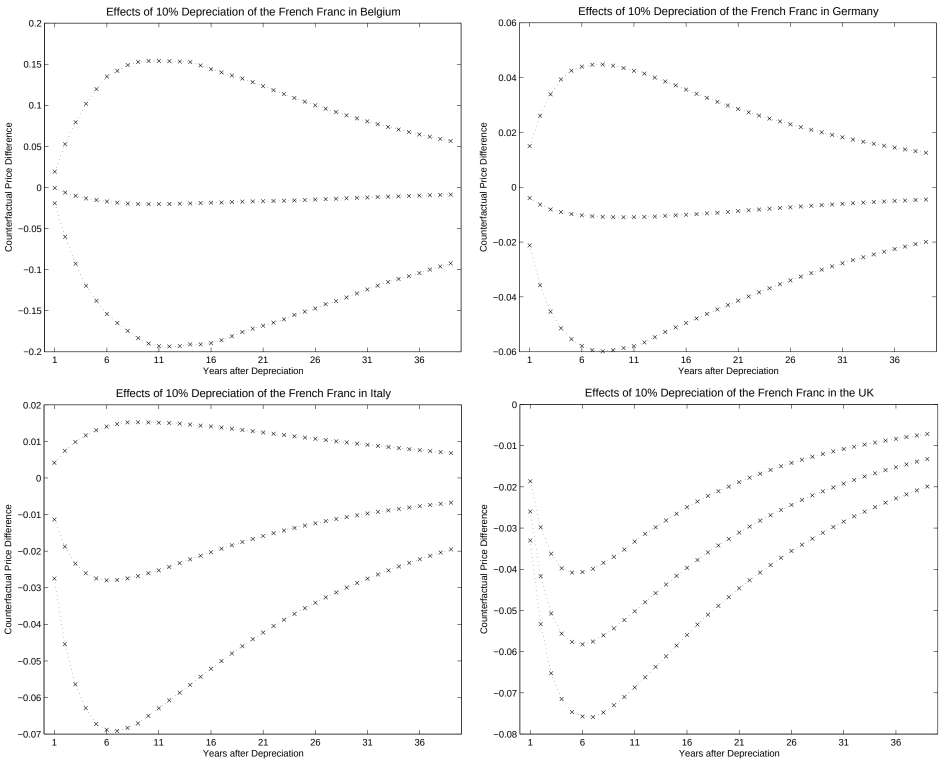


Figure 28: **Confidence Interval for Price reactions in Europe after a 10% depreciation of the German Mark.**

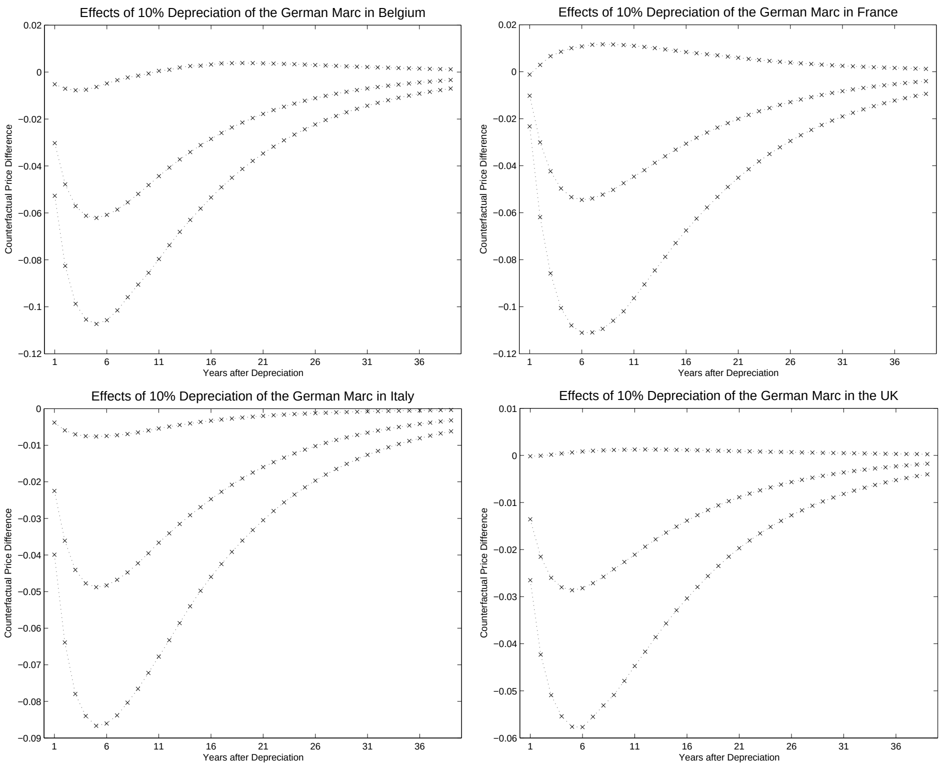


Figure 29: **Confidence Interval for Price reactions in Europe after a 10% depreciation of the Italian Lire.**

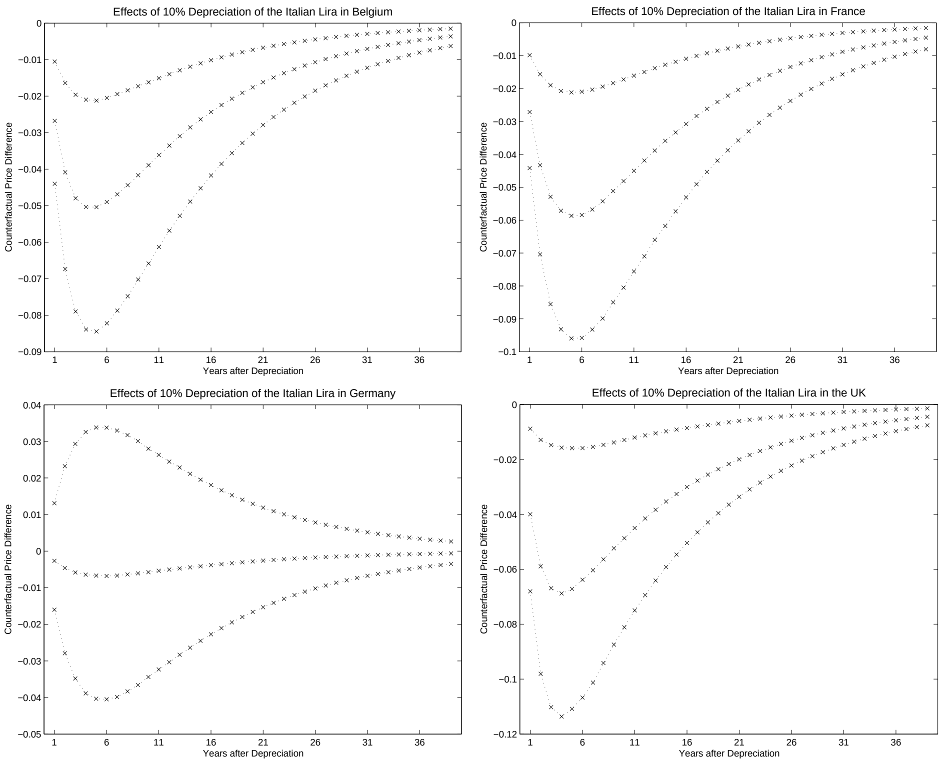


Figure 30: **Confidence Interval for Price reactions in Europe after a 10% depreciation of the British Pound.**

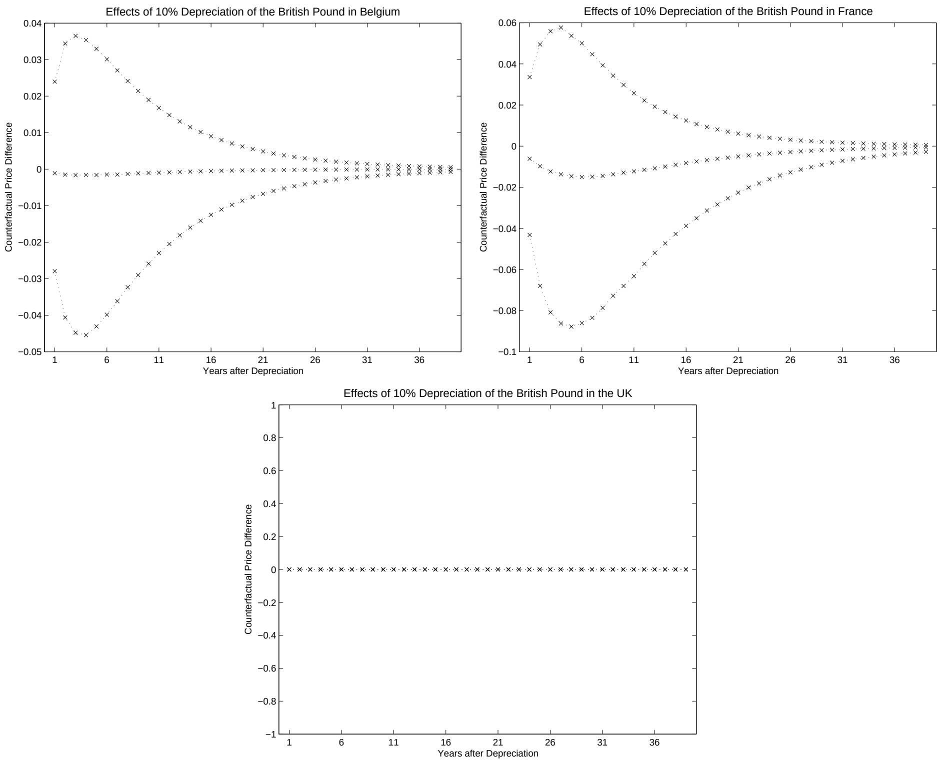
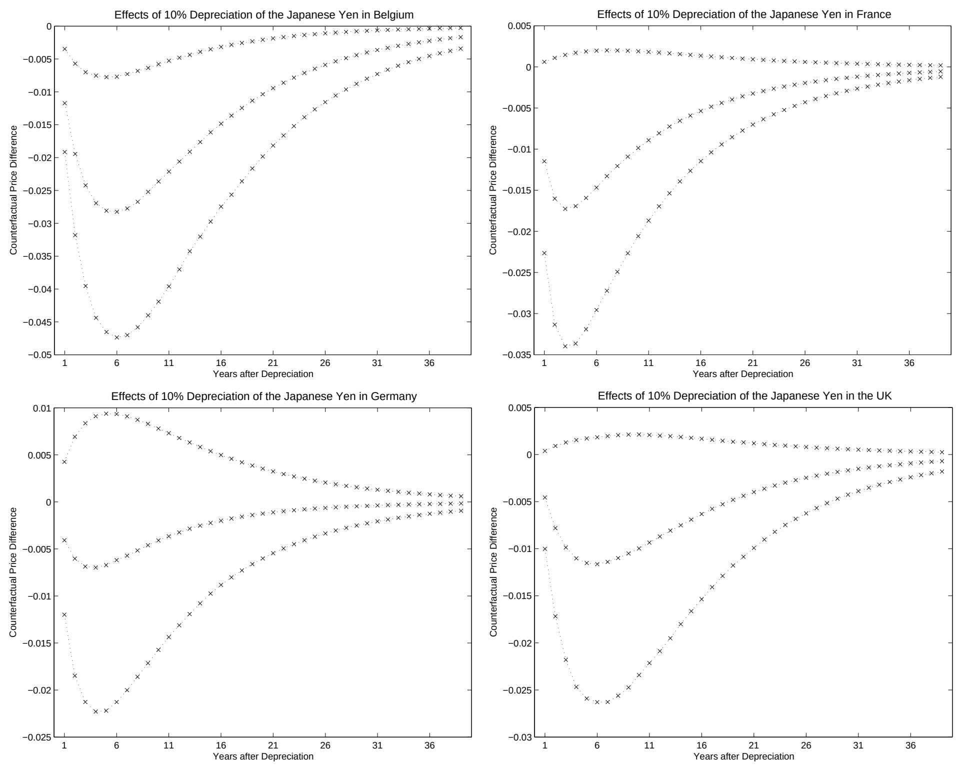


Figure 31: **Confidence Interval for Price reactions in Europe after a 10% depreciation of the Japanese Yen.**



F.2 Confidence Interval for the Domestic Effect of 10% Domestic Depreciation.

Figure 32: **Confidence Intervals for Reactions in Belgium after a 10% depreciation of the Belgian Franc.**

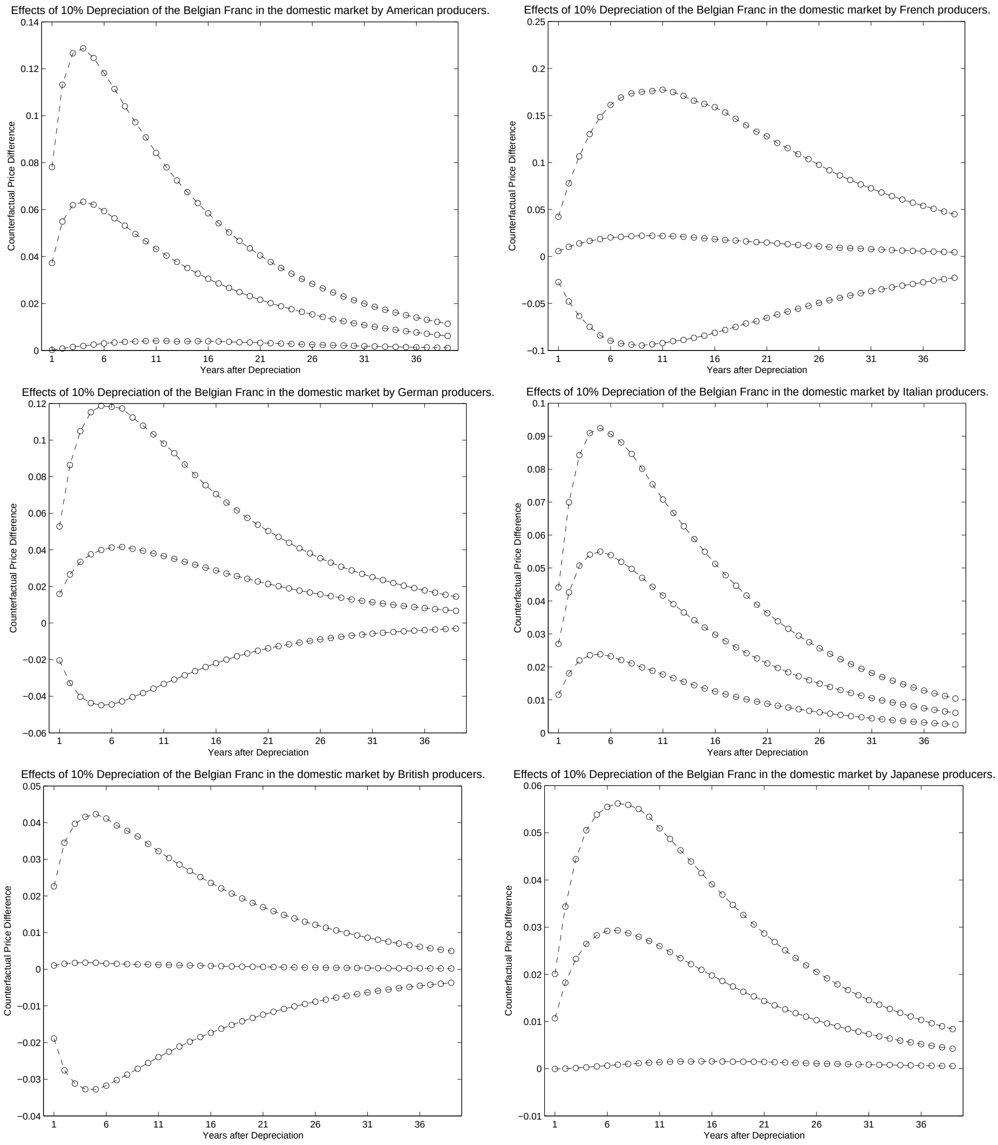


Figure 33: **Reactions in France after a 10% depreciation of the French Franc.**

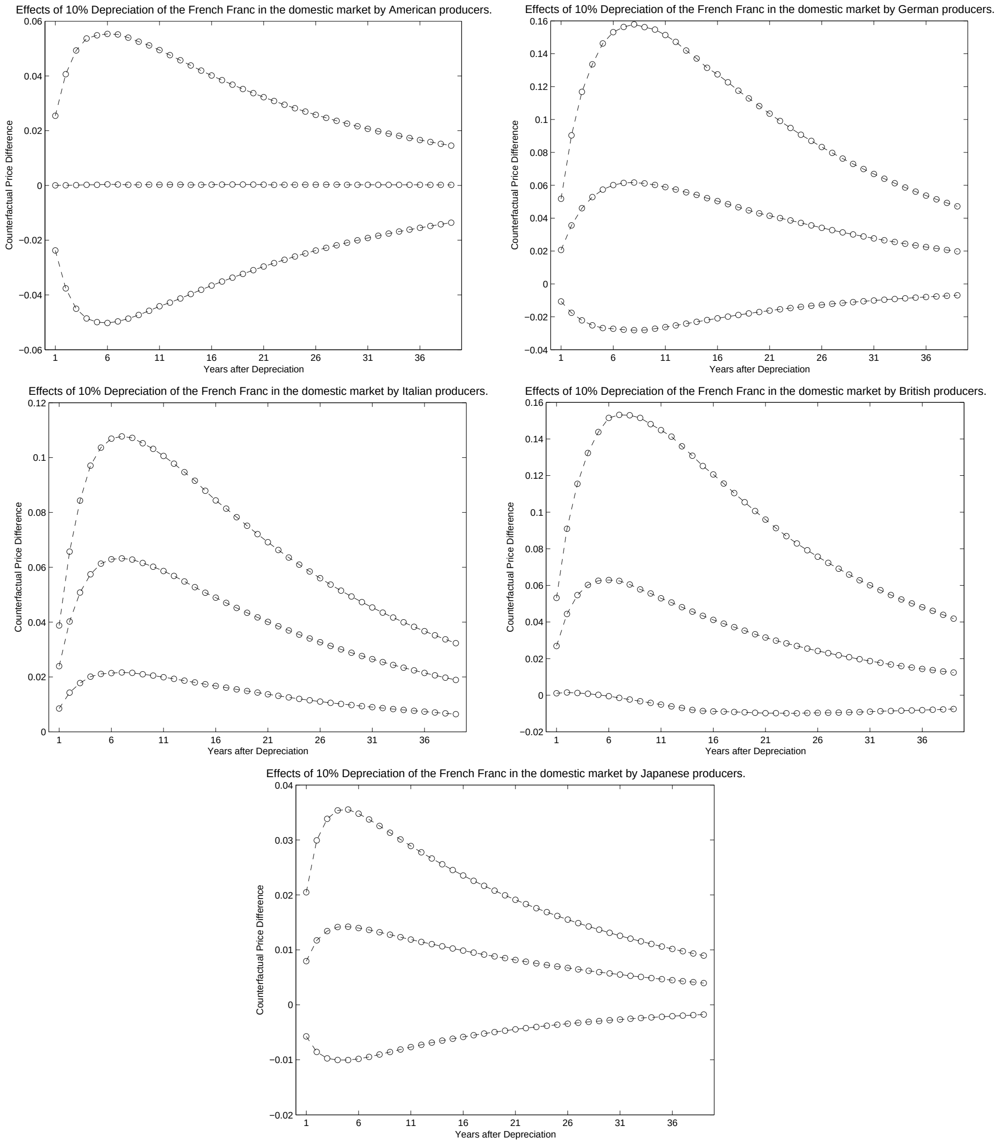


Figure 34: **Reactions in Germany after a 10% depreciation of the German Mark.**

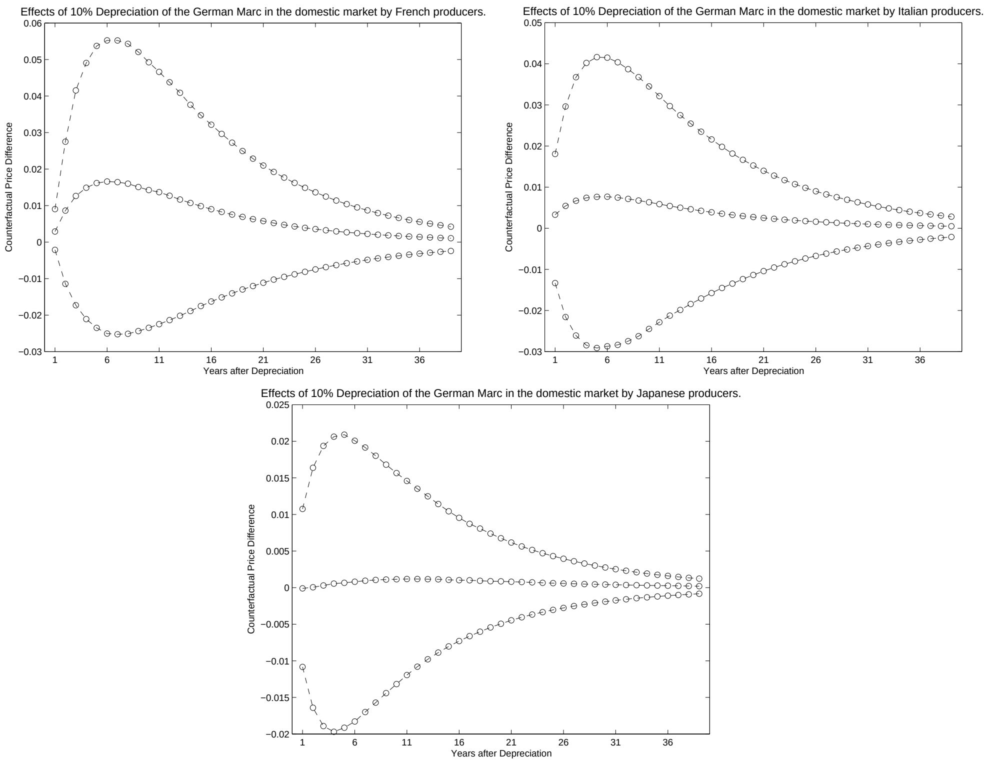


Figure 35: **Reactions in Italy after a 10% depreciation of the Italian Lire.**

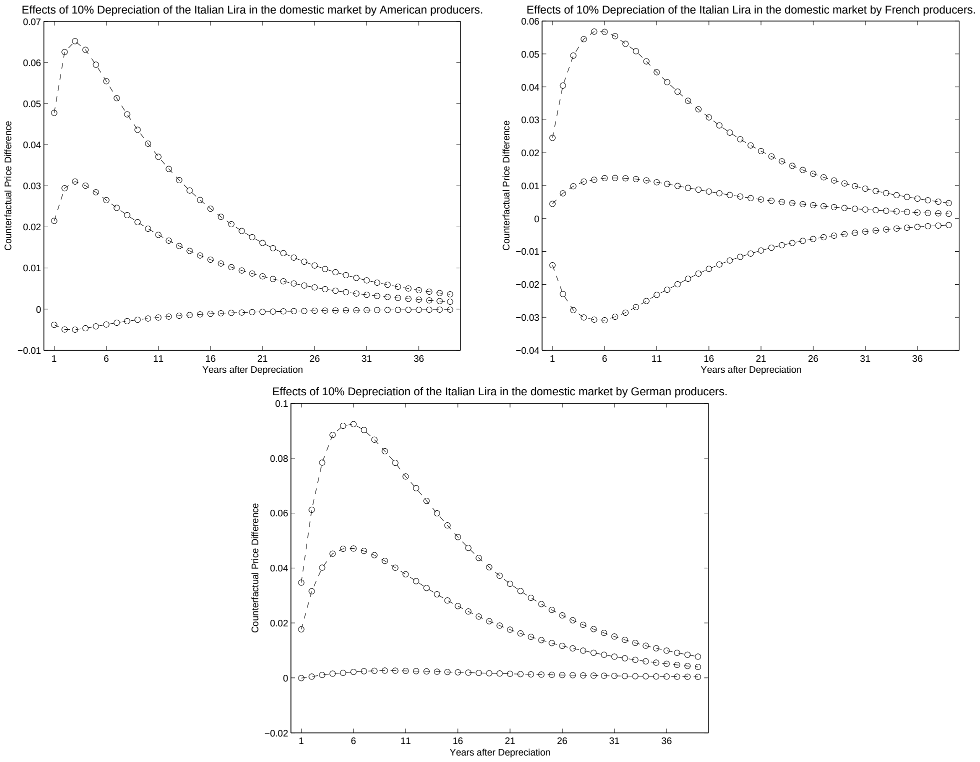
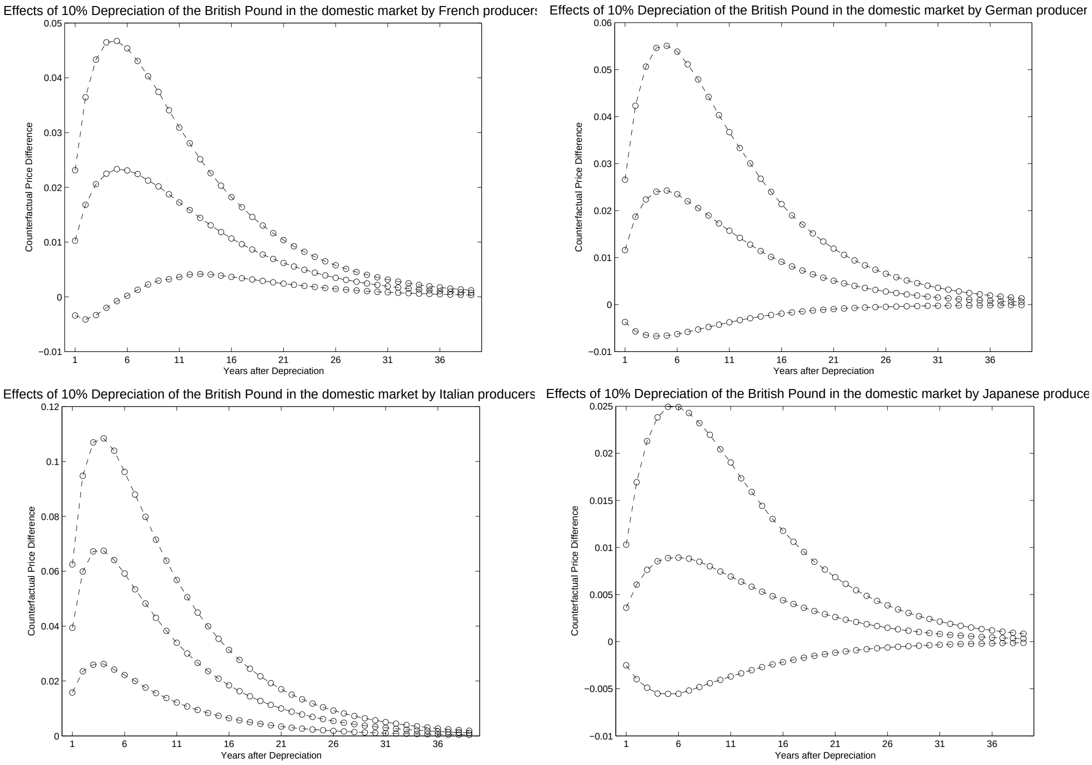


Figure 36: **Reactions in the UK after a 10% depreciation of the British Pound.**



G Impulse Response Exercise of a 10% Domestic Wages Increase.

This appendix presents the impulse response exercises after a 10% increase of each of the relevant European wages as explained in section 4.4. Each figure presents the percentage difference between the paths of steady state values and the variables after an initial shock. Along 40 periods, I present the convergent path predicted by the AR(1) transition probabilities towards the steady state scenario, which of course should close the initial gap.

This section presents the effects in each of the destination markets. Recall that there is no Belgian producer and I do not analyze the Japanese domestic market.

Figure 37: **Reactions across Europe after a 10% increase in French wages.**

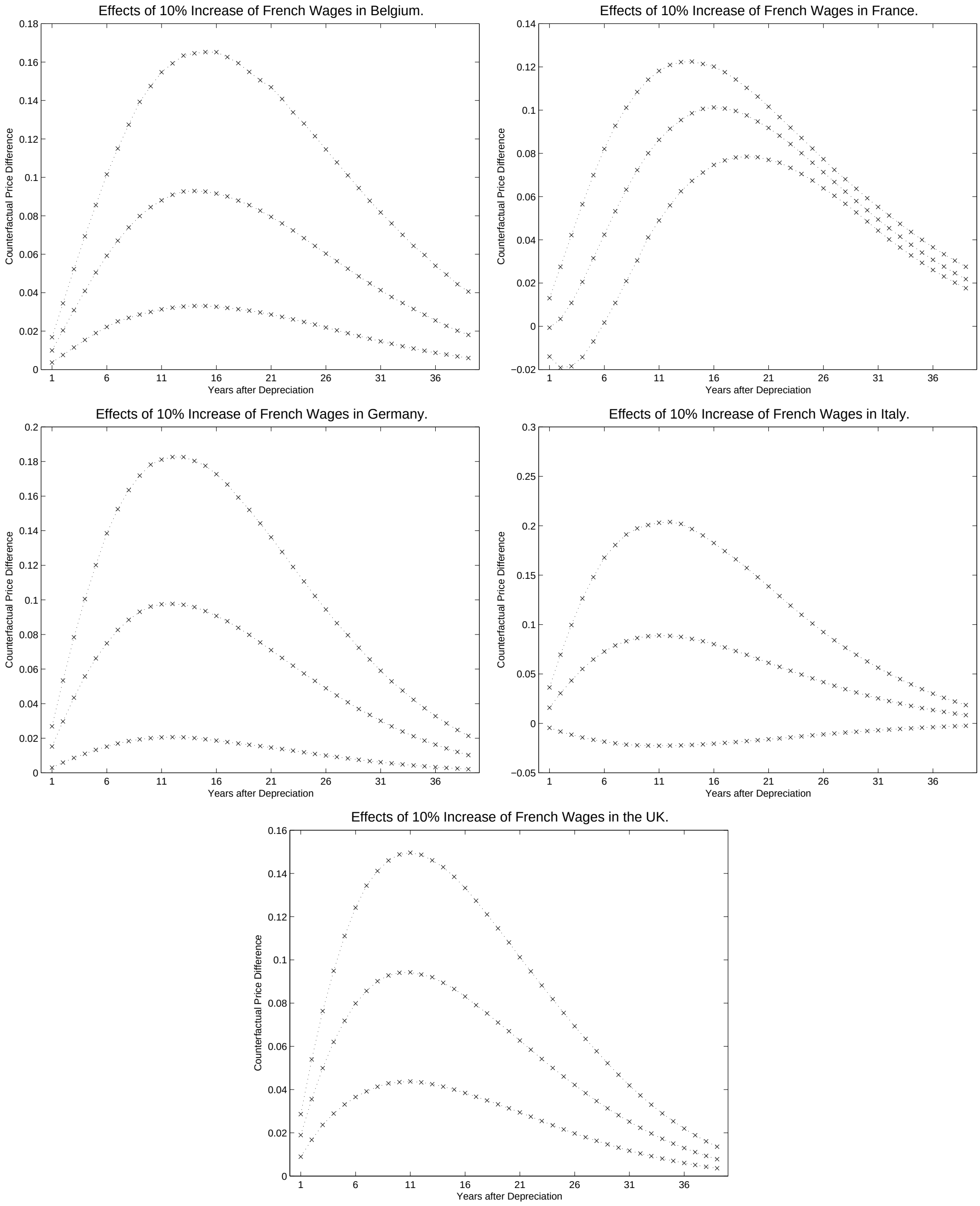


Figure 38: **Reactions across Europe after a 10% increase in German wages.**

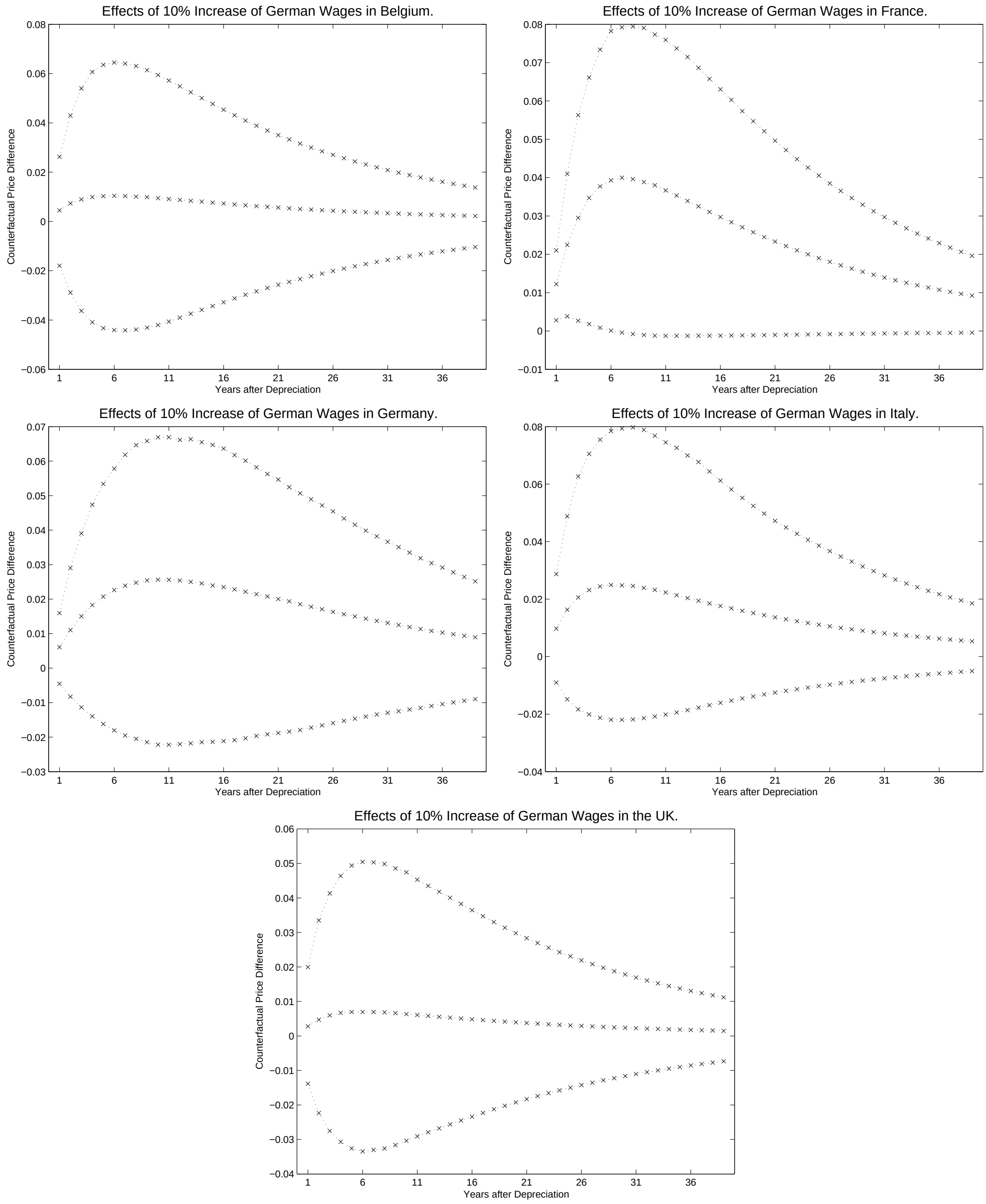


Figure 39: **Reactions across Europe after a 10% increase in Italian wages.**

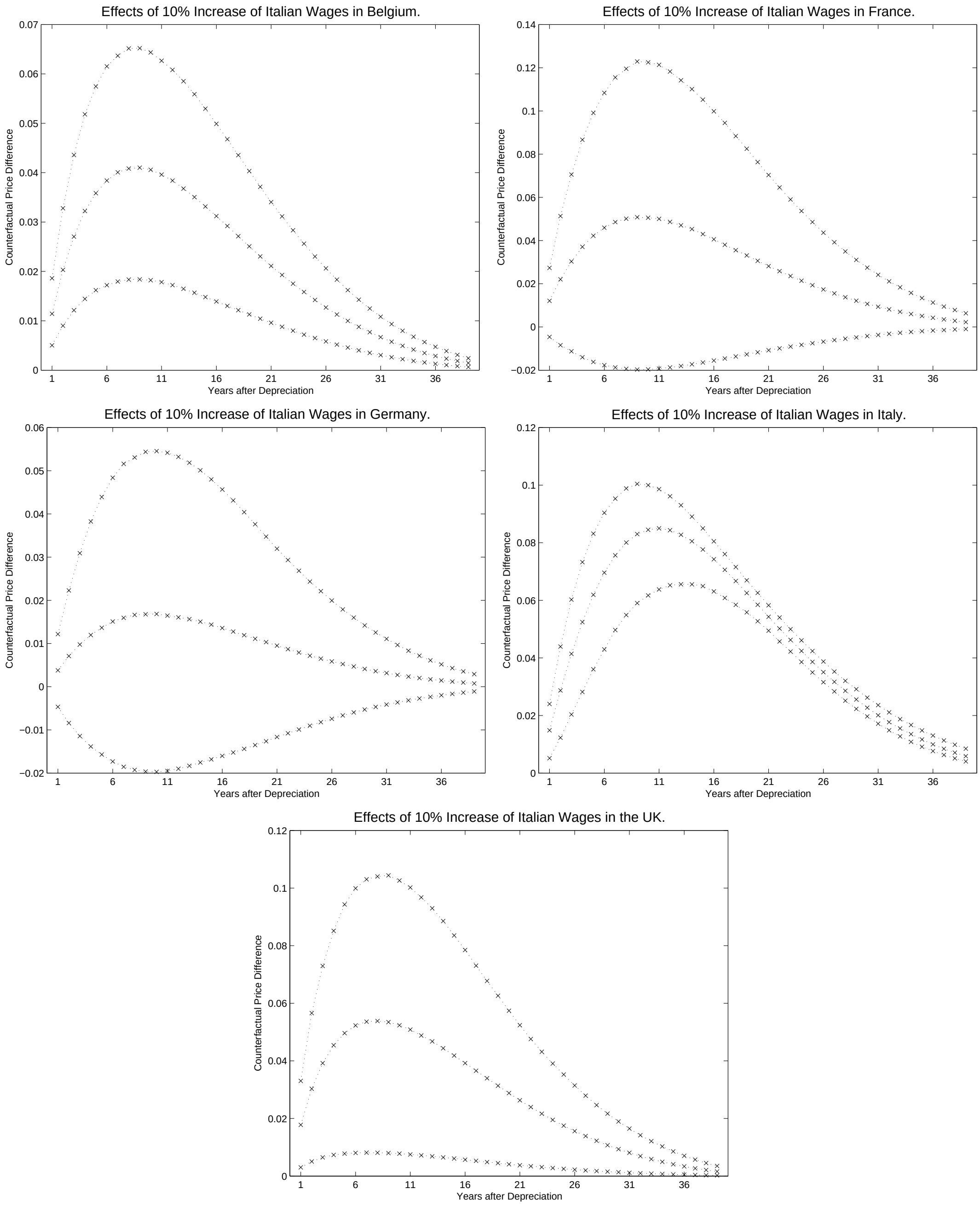


Figure 40: **Reactions across Europe after a 10% increase in British wages.**

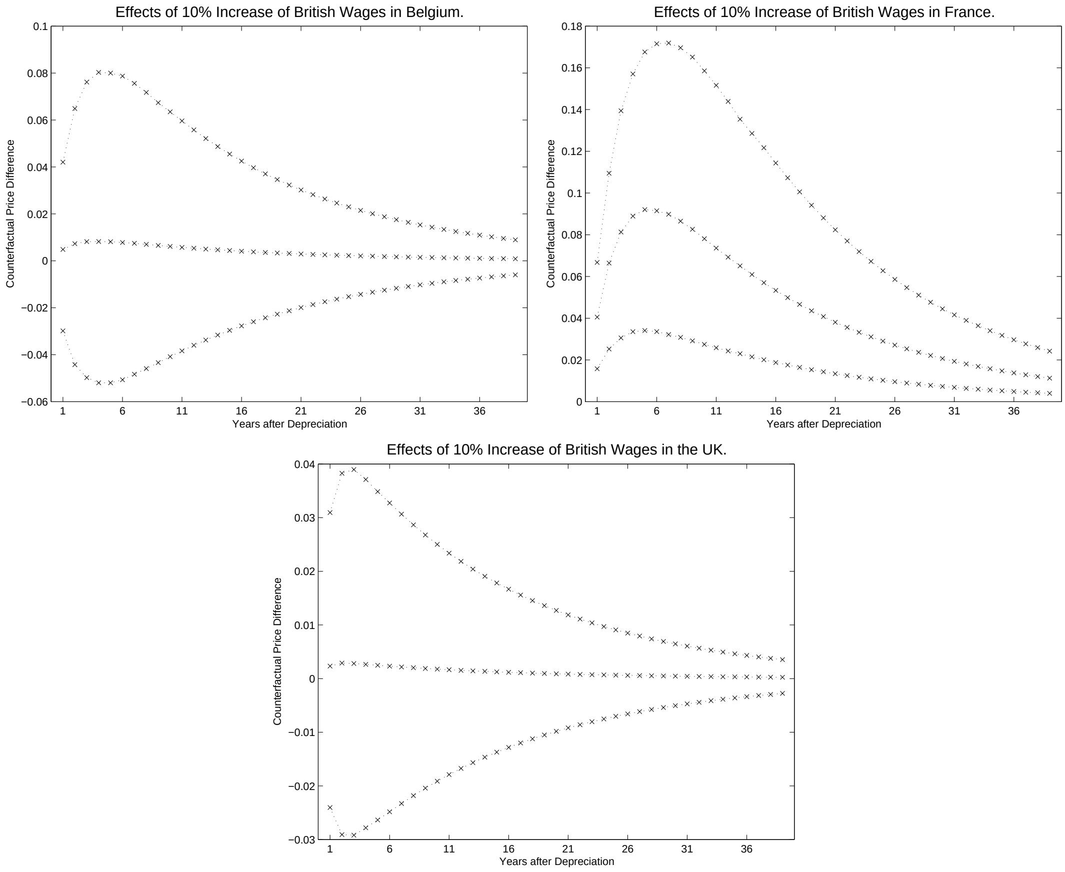
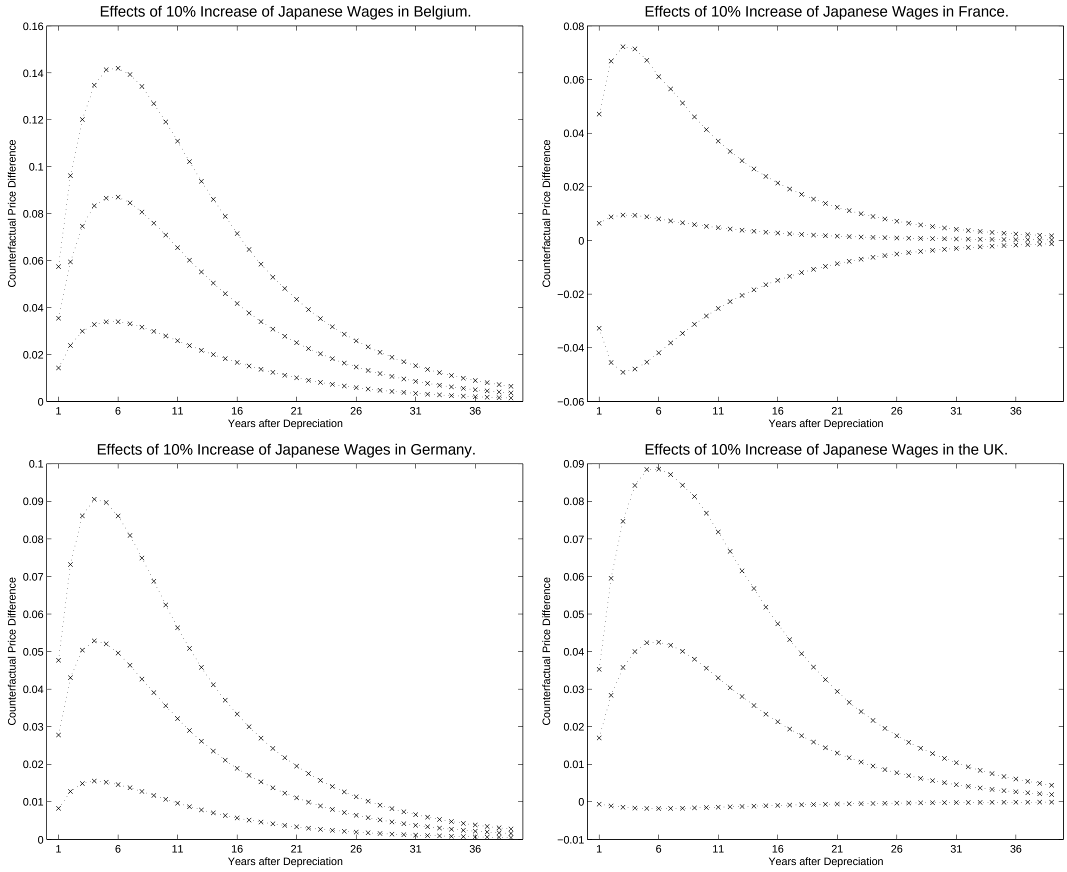


Figure 41: **Reactions across Europe after a 10% increase in Japanese wages.**



H From quarterly estimates to yearly estimates.

This appendix section describes the procedure under which the quarterly estimates of exchange rates forecast the yearly series for the six currencies used in the paper.

The quarterly process is given by:

$$e_t = \alpha + \rho e_{t-1} + u_t \tag{35}$$

where e_t is the vector of N currencies. $\rho_{N\times N}$ and $\alpha_{N\times 1}$ are parameters that generate this AR(1) process. Each currency only depends on its lagged value, thus:

$$\rho_{N\times N} = \begin{bmatrix} \rho_1 & 0 & \dots & 0 \\ 0 & \ddots & 0 & 0 \\ \vdots & \dots & \rho_{N-1} & 0 \\ 0 & \dots & 0 & \rho_N \end{bmatrix}$$

The u_t is the random term that allows for correlation among contemporaneous shocks only. Formally, I have:

$$E(u_t) = 0_{N\times 1} \quad \text{and} \quad E(u_j u_k') = 0_{N\times N} \forall j \neq k$$

The symmetric variance-covariance matrix is given by:

$$E(u_t u_t') = \Omega_{N\times N}$$

Based on the stationarity conditions, I compute the long run or steady-state value for the i^{th} currency e_t^i

$$E(e_t^i) = \frac{\alpha_i}{1-\rho_i}$$

Also I express the P correlation as follows:

$$E[e_t^i e_{t-P}^i] = E[\alpha_i + \rho_i e_{t-1}^i + u_t)e_{t-P}^i] = ... = \rho_i^P$$

I want to use these estimates of $\widehat{\rho}$ and $\widehat{\alpha}$ to do forward simulations over the yearly process $\widetilde{e}_t$. Hence, I need to write yearly parameters $\widetilde{\rho}$ and $\widetilde{\alpha}$ in terms of the quarterly parameters ρ and α.

$$\widetilde{e}_t = \widetilde{\alpha} + \widetilde{\rho}\widetilde{e}_{t-1} + \widetilde{u}_t \tag{36}$$

The yearly process is defined as the average of the last four quarters.

$$\widetilde{e}_t = \left[\frac{e_t + e_{t-1} + e_{t-2} + e_{t-3}}{4}\right]$$

The first order correlation can be written in terms of the quarterly process:

$$\begin{aligned}
\widetilde{\rho}_i &= E(\widetilde{e}_t\widetilde{e}_{t-1}) = E\left(\left[\frac{e_t + e_{t-1} + e_{t-2} + e_{t-3}}{4}\right]\left[\frac{e_{t-4} + e_{t-5} + e_{t-6} + e_{t-7}}{4}\right]\right) = ... \\
\widetilde{\rho}_i &= \frac{1}{16}(\rho_i + 2\rho_i^2 + 3\rho_i^3 + 4\rho_i^4 + 3\rho_i^5 + 2\rho_i^6 + \rho_i^7) \qquad (37)
\end{aligned}$$

The steady-state value for the i^{th} currency e_t^i of this average can be written as:

$$E(e_t^i) = E(\widetilde{e}_t^i) \Leftrightarrow \frac{\alpha_i}{1-\rho_i} = \frac{\widetilde{\alpha}_i}{1-\widetilde{\rho}_i}$$

and they should match the quarterly steady state, I have the relationship between the constants:

$$\widetilde{\alpha}_i = \frac{\alpha(1-\widetilde{\rho}_i)}{1-\rho_i} \qquad (38)$$

Finally I also need to describe the error parameter for

$$\widetilde{u}_t = \left[\frac{u_t + u_{t-1} + u_{t-2} + u_{t-3}}{4}\right]$$

It is straightforward to show that $E(\widetilde{u}_t) = 0$ and the covariance matrix is given by:

$$\widetilde{\Omega} = E\left(\left[\frac{u_t + u_{t-1} + u_{t-2} + u_{t-3}}{4}\right]\left[\frac{u_t + u_{t-1} + u_{t-2} + u_{t-3}}{4}\right]'\right) = \frac{1}{4}\Omega$$

I Alternative Adjustment Cost Function.

This appendix section presents the results under the alternative specification for the price adjustment cost function given by:

$$AC_{f,t,2} = \sum_{m} \sum_{j \in \mathcal{F}_{fm}} \Psi_{fm} \cdot |\log(p_{jt}^{m}) - \log(p_{jt-1}^{m})|$$

The following tables replicate the results of tables 13 to 16 using the alternative specification for the adjustment cost function. The main findings still hold, although some rankings or estimates may change about an acceptable neighborhood.

Table 23: **Different Components (%) over Total Cost in 1985 using alternative adjustment cost function.**

Exports	Local Cost	Destination Cost	Adjustment Cost
American	79.81	14.28	5.91
French	75.51	23.31	1.17
German	78.75	21.18	0.06
Italian	20.69	66.38	12.93
Japanese	59.75	26.99	13.26
Sold Domestically	**Local Cost**	**-**	**Adjustment Cost**
American	99.97	-	0.03
French	97.19	-	2.81
German	100.00	-	-
Italian	90.37	-	9.63

Table 24: **Adjustment Cost Share by Destination Market using alternative adjustment cost function.**

	Belgium	France	Germany	Italy	UK
American	7.2	0.1	0.0	9.3	0.0
French	3.4	2.1	0.0	0.4	0.5
German	0.0	0.0	0.0	0.1	0.0
Italian	18.8	10.6	8.6	9.6	3.5
Japanese	19.3	0.0	4.1	-	20.2

Table 25: **Ratio of Adjustment Cost Parameters using alternative adjustment cost function: Ψ_{fm}/Ψ_{ff}.**

	Belgium	France	Germany	Italy	UK
American	44.21	4.98	1.00	75.47	0.05
French	1.08	1.00	0.04	0.12	0.19
German	0.26	0.60	1.00	0.93	1.00
Italian	0.18	0.43	4.27	1.00	0.05
Japanese	0.44	0.03	1.00	-	0.18

Table 26: **Implied Markups in 1985 using alternative adjustment cost function.**

	Mean	Std Dev
American	71%	40%
French	81%	36%
German	51%	46%
Italian	78%	33%
Japanese	86%	33%