Structural Estimation of Price Adjustment Costs in the European Car Market*

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Abstract

This paper characterizes the price adjustment costs that are consistent with observed price dynamics in the European car market. We estimate a dynamic model of international multiproduct firms that set prices in different currencies while facing price adjustment costs. We find that large price adjustment costs are not needed to rationalize the substantial degree of price inertia we observe in the data. Intuitively, since GDP, wages and exchange rates exhibit such a large degree of autocorrelation, small adjustment costs can explain very persistent prices. Also, accounting for country-specific price sensitivity, wages, GDP and exchange rates, the price adjustment costs should differ substantially across producers and markets to match the data.

Keywords: exchange rate pass-through, structural estimation, price adjustment costs.
JEL Classification: F10, F31, L11, L16

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1 Introduction

The source of the widely documented price rigidities observed in the data is a subject of ongoing debate in economics. The implications of rigid prices for resource allocation and the causes of business cycles depend critically on the mechanism generating sluggish price adjustment. There are two competing hypotheses on this issue. The first hypothesis is that price rigidity is caused by a costly adjustment. The second hypothesis is that the persistent economic environment is the cause of sticky prices despite a costless re-pricing. Disentangling these two hypotheses is problematic because it is difficult to jointly identify environmental dynamics and the cost structure of the firms.

In order to shed light on the relative weight of each source of price inertia, we suggest a new approach to characterize price adjustment costs while accounting for the persistent economic environment. In particular, we estimate a dynamic game of the European car manufacturers setting prices under price adjustment costs and persistent state variables such as the exchange rates, GDP and wages.

Although the European car markets impose many difficulties to our structural estimation of price adjustment costs –and certainly we will require simplifications– we think these markets fit nicely into this study for three reasons. First, there is a remarkable price autocorrelation as presented in Table 1. Second, key economic variables as wages, exchange rates and GDP are very persistent over time in each market. Third, several currencies had large and persistent changes in relative terms between 1970 and 1999, ensuring a proper exogenous variation to study pricing dynamics.

We identify price adjustment costs using the methodology developed by Bajari, Benkard, and Levin (2007) (henceforth BBL). In our case, the BBL estimator follows the intuitive idea of finding the cost structure consistent with observed pricing behavior. Namely, we observe pricing behavior for each player in different markets while facing different paths of wages, GDP and exchange rates. We search over the structural cost parameters that support the observed pricing behavior as the optimal equilibrium play. To the best of our knowledge, this is the first paper to propose this approach for price adjustment cost estimation and the main advantage of this approach is that it allows us to estimate the structural costs without solving the complicated dynamic game.

Our structural cost estimates suggest two main findings. First, we find that there is no need for large price adjustment costs to rationalize the substantial degree of price inertia. Intuitively, in an economic environment where wages, GDP and exchange rates are highly autocorrelated, small adjustment costs can rationalize the persistent prices observed in the data. Second, after accounting for country-specific consumer price sensitivity,

Table 1: **Price autocorrelation in the European car market.**

	Markets					
Producers	Belgium	France	Germany	Italy	UK	Average
American	0,979	1,001	0,993	0,999	0,977	0,990
French	1,004	1,003	1,008	1,001	0,995	1,002
German	0,986	0,984	0,993	0,988	0,477	0,885
Italian	0,986	0,989	0,989	0,994	1,003	0,992
British	0,990	0,987	0,972	0,992	0,969	0,982
Japanese	0,992	0,949	0,968	1,004	0,995	0,982
Average	0,989	0,985	0,987	0,996	0,903	0,972

Notes: The figures correspond to the OLS estimates of the lagged price coefficient, $\widehat{\alpha}$, in the linear regression $\ln(p_{it}) = \alpha \ln(p_{it-1}) + d_t + \epsilon_{it}$, where p_{it} is the nominal price of model i at year t in each market-manufacturer combination; d_t is a year fixed effect and ϵ_{it} is a mean zero and homoscedastic random shock. All estimates are significant at the 1 percent level.

pricing behavior of manufacturers, and transition probabilities of GDP, wages and exchange rates, we still require substantial heterogeneity in the price adjustment costs across producers and markets to match the data.

This paper is related to the literature on exchange rate pass-through for differentiated products that supports two stylized facts: i) an incomplete degree of pass-through; and ii) persistent delay in the price response to exchange rate fluctuations.

To study the incomplete degree of pass-through, Goldberg (1995), Verboven (1996) and Goldberg and Verboven (2001) estimate structural models of differentiated products in the automobile market using a static framework. Their findings are consistent with "pricing-to-market" behavior (PTM)[1] and local cost components.[2]

To study the delay in price response requires a dynamic framework and the possibility of price adjustment costs. Goldberg and Hellerstein (2013) and Nakamura and Zerom (2010) estimate price adjustment costs, like our paper, but in different industries and using different approaches. Goldberg and Hellerstein (2013) use a static framework to derive bounds of menu costs in the US beer industry, where prices are adjusted only when the gap between the optimal and current price reaches a certain threshold. The authors assume that the firms use static optimal pricing to update prices as their key variables follow random walks. However, such

[1]PTM allows for price discrimination based on the currency and the segmented market where the transaction takes place (Krugman (1987)).

[2]Burstein, Neves, and Rebelo (2003) argue that the share of costs priced in destination-market currency can be disconnected from exchange rate fluctuations, explaining the observed incomplete pass-through.

an approach would fail to capture the dynamic pricing that takes place when firms perceive shocks as transitory, a feature that describes some exchange rate fluctuations in the European markets before the adoption of the common currency. Nakamura and Zerom (2010) solve a fully dynamic model to estimate menu costs in the US coffee industry. However, given the computational difficulties of this approach, they are able to estimate the model under restrictive assumptions such as a representative market and simple functional form of the marginal cost. In the case of the European car market, this approach would miss important features like the pricing to market behavior and market heterogeneity.

Given the numerous simplifications we need to adopt to keep the estimation tractable, we may overestimate the price adjustment costs. For instance, we assume a static demand for new cars and the absence of entry/exit of new models. However, both simplifications lead to upward biased estimates of price adjustment costs, making our estimates of price adjustment costs conservative. Therefore, our (upward biased) estimates reinforce the main conclusions that price adjustments are relatively unimportant, and that most of the price inertia observed in in the European car market can be explained by persistent exchange rates, GDP and wages.

The remainder of this paper is organized as follows. Section 2 introduces the dynamic game, Section 3 presents the data of the European car market, Section 4 presents the methodology and the results of the estimation and Section 5 concludes.

2 Model

2.1 Dynamic Game

We assume a dynamic game of international manufacturers who set prices in multiple currencies under price adjustment costs.

The players of the game are the car manufacturers grouped in their F nationalities (indexed by f), who trade in M segmented markets (indexed by m). Each multiproduct firm f offers the subset $\mathcal{F}^{fm}$ out of the J^m models available in each market.

The action (or control variable) of each player is to set his or her respective vector of nominal prices. We denote by p_{jt}^{fm} the price model j in market m at time t of player f, where $j \in \mathcal{F}^{fm}$. Thus, full vector of prices in market m is denoted by $\mathbf{p}_t^m = (\{p_{jt}^{1m}\}_{j\in\mathcal{F}^{1m}}, .., \{p_{jt}^{Fm}\}_{j\in\mathcal{F}^{Fm}})$. Players choose their optimal prices simultaneously in all markets at the beginning of each period.

Consistent with Markov perfect equilibrium, players choose their actions based on their relevant economic environment, captured by the state variable vector, $\mathbf{s}_t$. For instance, $\mathbf{s}_t$ may include nominal exchange rates, nominal wages and nominal GDP per capita. Most state variables $\mathbf{s}_t$ are public information; however, in principle, the model also allows for private states or private information, such as productivity or demand shocks.

Conditional on state $\mathbf{s}_t$, the expected future profits of firm f are given by:

$$\mathbb{E}\left[\sum_{\tau=t}^{\infty} \beta^{\tau-t} \pi(\mathbf{p}_\tau, \mathbf{s}_\tau; \nu^f, \Psi^f) | \mathbf{s}_t\right] \tag{1}$$

where firm-specific cost parameters ν^f and Ψ^f are constant over time and observable by competitors. Note that the expectation is taken over actions taken by the firm f's competitors in the current period, as well as future values of the state variables and actions.

The profit function is defined as follows:

$$\pi(\mathbf{p}_t, \mathbf{s}_t; \nu^f, \Psi^f) \equiv R_t^f - C_t^f(\nu^f) - AC_t^f(\Psi^f) \tag{2}$$

where R_t^f are the revenues, C_t^f are the production costs and AC_t^f are the price adjustment costs. We discuss the three terms in detail.

The revenues of manufacturer f, R_t^f, include amounts in domestic and foreign currencies as manufacturers serve both types of markets. The total revenues across markets, expressed in f's currency, are:

$$R_t^f = \sum_m \sum_{j \in \mathcal{F}_{fm}} e_t^{fm} \cdot p_{jt}^{fm} \cdot q_{jt}^{fm}(\mathbf{p}_t^m, \mathbf{s}_t) \tag{3}$$

where e_t^{fm} is the exchange rate between the currency of market m and f's currency ($\$f/\$m$); p_{jt}^{fm} is the nominal price of model $j \in \mathcal{F}_{fm}$ in the currency of market m; and q_{jt}^{fm} is the number of units of model j sold in market m at time t. The demand, q_{jt}^{fm}, depends on the vector of prices $\mathbf{p}_t^m$ and state variables $\mathbf{s}_t$. We provide specifics about the demand in the empirical Subsection 4.4.

The production costs, C_t^f are expressed in the headquarter's currency:

$$C_t^f(\nu^f) = \sum_m \sum_{j \in \mathcal{F}_{fm}} C_{jt}^{fm}(\mathbf{s}_t, q_{jt}^{fm}; \nu^f) \tag{4}$$

Given the complexity of the cost function in this industry, we need to specify a tractable cost function that still accounts for the substantial heterogeneity between European markets. Following the previous literature in the automobile industry, we assume production costs as a function of wages, exchange rates and model-specific characteristics. Thus, we assume a simple quadratic specification based on quantities and their interaction with the state variables (wages and exchange rates). The quadratic specification accounts for economies of scale and ensures an optimal scale of production. Therefore, the cost function C_{jt}^{fm} for each model j in a (f, m) combination is given by:

$$
\begin{aligned}
C_{jt}^{fm}(\mathbf{s}_t, q_{jt}^{fm}; \nu^f) \quad = \quad & \nu_{1,j}^f \cdot q_{jt}^{fm} + \nu_{2,j}^f \cdot \left(q_{jt}^{fm}\right)^2 + \underbrace{\nu_3^f \cdot W_t^f \cdot q_{jt}^{fm} + \nu_4^f \cdot W_t^f \cdot \left(q_{jt}^{fm}\right)^2}_{\text{Labor Cost in Producing Country } f} \\
& + \underbrace{\nu_5^f \cdot e_t^{fm} \cdot W_t^m \cdot q_{jt}^{fm} + \nu_6^f \cdot e_t^{fm} \cdot W_t^m \cdot \left(q_{jt}^{fm}\right)^2}_{\text{Labor Cost in Destination Market } m} + \underbrace{\upsilon_{jt}^{fm}}_{\text{Private shock}} \qquad (5)
\end{aligned}
$$

where W_t^f and W_t^m are the nominal wages in the manufacturing country of firm f and the wages in the destination market m, respectively; and e_t^{fm} is the nominal exchange rate between countries f and m. υ_{jt}^{fm} is a mean zero idiosyncratic private shock that is independent across agents and time.

The first two terms are model-specific costs. The terms $\nu_{1,j}^f$ and $\nu_{2,j}^f$ capture in a reduced form the role of the time-invariant car characteristics (observable and *unobservable*) of model j at time t.

We assume that labor costs are relevant for the marginal costs.[3] We distinguish between labor costs in the manufacturing country and labor costs in the destination market (Burstein, Neves, and Rebelo (2003)). The terms captured by ν_3^f and ν_4^f consider the direct labor costs of production in the manufacturing country, and therefore, they interact with producing-country wage, W_t^f. In addition, in the case of the exported cars, the terms ν_5^f and ν_6^f consider labor costs associated with distribution costs in the destination-market, and therefore, they interact with destination-country wage, W_t^m. We express distribution costs in f's currency using the nominal exchange rate e_t^{fm}.

Costly price adjustment is the only source of dynamics in our model as current prices impact future profits. The well-established fact of persistent prices at the micro level suggests the idea of costly repricing and this persistence is remarkable in differentiated products such as cars. As an example of price rigidity in the auto industry, Gopinath and Rigobon (2008) report an astonishing duration of 14.5 months in at-the-dock prices in the US.

We assume that the price adjustment costs are proportional to the magnitude of the price change and independent of output.[4] Thus, the price adjustment costs of firm f, AC_t^f, are given by:

$$
AC_t^f(\Psi^f) = \sum_m \sum_{j \in \mathcal{F}_{fm}} AC_{jt}^{fm} = \sum_m \sum_{j \in \mathcal{F}_{fm}} \Psi^{fm} \cdot e_t^{fm} \cdot |p_{jt}^{fm} - p_{jt-1}^{fm}| \qquad (6)
$$

[3]The role of firm-specific price of capital on marginal costs can be seen as a nuisance parameter that cannot be recovered separately.

[4]See Rotemberg (1987) for an extensive survey of partial adjustment models.

where the structural parameters of the price adjustment costs of firm f are given by $\Psi^f = \{\Psi^{fm}\}_{m=1}^{M}$.

Price adjustments cost can be due to a broad range of frictions and costs. We remain agnostic regarding the particular nature of these frictions as we are not able to identify a particular source of price stickiness. However, we are able to characterize the size of the price adjustment costs, Ψ^f, that are consistent with the data.

We think our specification in Equation (6) is consistent with *managerial costs* and *strategic costs*. Zbaracki, Ritson, Levy, Dutta, and Bergen (2004) provide direct evidence that managerial costs of price adjustments (for instance time and effort spent by management to determine the new optimal price) increase with the size of the price adjustment. Based on data of a large manufacturing firm, they measure managerial costs of price adjustments such as the costs of gathering information, managerial time of pricing decisions, and the costs of within firm communication. They find that *managerial costs are higher for larger price changes* and even larger for international pricing decisions.[5] In addition, we believe our adjustment cost specification also capture *strategic costs*, which are defined as the amount of money that firms are willing to forego by having persistent prices. Krugman (1987) argues that a firm may not fully adjust their prices to enhance brand reputation. Anderson and Simester (2010) present experimental evidence that firms do not change prices to avoid consumer antagonism. We assume that both types of strategic costs are proportional to the size of the price change and independent of output.

We do not consider the standard menu costs, in which the price adjustment costs are independent of the size of the price change, for mainly two reasons. First, Zbaracki et al (2004) show that the managerial costs are far more important than physical costs of price adjustments which are the literal definition of menu costs. Second, the data shows that the change of prices in the European car markets are continuous and smooth over time. On the contrary, the standard menu cost model would predict constant prices and unfrequent lumpy adjustments that we do not observe in the data.

Note that the adjustment costs specified in Equation (6) do not change marginal costs of production (as they do not depend on quantities q_{jt}^{fm}). Also notice that, in this dynamic game, the lagged price becomes a payoff-relevant variable, and therefore, it should be included as a state variable.

2.2 Equilibrium

We assume the existence of a Markov-perfect Nash equilibrium (MPE), that is the standard equilibrium concept in the literature. Formally, in

[5]Similar arguments are found in Levy, Bergen, Dutta, and Venable (1997).

this setting, a Markov strategy for firm f is a function $\sigma_f : S \times \Upsilon_f \rightarrow P_f$, where S is the set of relevant state variables, Υ_f is the set of private shocks and P_f is the action space of firm f. The decision or control variable of the problem is the current price, $\mathbf{p} \in P_f$.

The future state variable **s'** is drawn from the probability distribution $\mathbb{P}(\mathbf{s'}|\mathbf{s})$, where **s** denotes current state variable (such as the exchange rates, GDP or nominal wages). We assume that current car prices do not affect future state variables. Hence, state variables follow an exogenous first-order Markov process.

A profile of Markov strategies is a vector $\sigma = (\sigma_1, .., \sigma_F)$, where $\sigma : S \times \Upsilon_1 \times ... \times \Upsilon_F \rightarrow P = (P_1, .., P_F)$. If the behavior is given by a Markov strategy profile σ, firm f's expected profit $V_f(\mathbf{s}, \sigma; \theta)$ given a state **s** can be written recursively:[6]

$$V_f(\mathbf{s}, \sigma; \theta) = \mathbb{E}_\upsilon \left[\pi_f(\sigma(\mathbf{s}, \upsilon), \mathbf{s}, \upsilon_f; \theta) + \beta \int V_f(\mathbf{s'}, \sigma; \theta) \mathrm{d}\mathbb{P}(\mathbf{s'}|\mathbf{s}) \Big| \mathbf{s} \right] \quad (7)$$

where π_f is the profit function of firm f and $\theta = (\nu^f, \Psi^f)$ is the vector of unknown parameters.

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

$$V_f(\mathbf{s}, \sigma; \theta) \equiv V_f(\mathbf{s}, \sigma_f, \sigma_{-f}; \theta) \geq V_f(\mathbf{s}, \sigma'_f, \sigma_{-f}; \theta), \quad \forall \sigma'_f \quad (8)$$

This inequality requires that, for each firm f and initial state **s**, σ_f outperform each alternative Markov strategy σ'_f; thus, there are no profitable unilateral deviations.

The standard approach to estimate θ is to solve the MPE using a nested-fixed point algorithm for each potential set of parameters until one finds the estimate $\widehat{\theta}$ that maximizes the log-likelihood function (Rust (1994)). The nested-fixed point algorithm has been successfully implemented in games with a restricted number of players and states.

Unfortunately, to solve the MPE in our dynamic game is unfeasible as the large number of players and state variables makes the use of nested-fixed point estimators impractical (Ackerberg, Benkard, Berry, and Pakes (2007), Aguirregabiria and Nevo (2013)). To circumvent the "curse of dimensionality", several alternative approaches have been suggested. In Subsection 4.1 we present the BBL approach and discuss the identification in our particular setting.

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

3 Data

This section describes the dataset collected by Brenkers and Verboven (2006) for the European car market. It is an updated version of the one used by Goldberg and Verboven (2001).[7]

The yearly dataset consists of the prices, sales and physical characteristics of car models sold in Belgium, France, Germany, Italy and the United Kingdom from 1970 until 1999. Prices are post-tax list prices and sales are new car registrations for the model range. The physical characteristics (from consumer catalogues) include dimensions (length, width and height), engine characteristics and performance measures. The data also keep track of the brand, firm, place of production, model and segment.[8]

Since many of the car features are nearly collinear, we construct three variables to summarize these characteristics. The first is size: the product of length, height and width. The second is the inverse of motor power: $IP = [Hp \times Cy \times Sp]^{-1}$, where Hp is horsepower, Cy is the number of cylinders and Sp is the maximum speed. The third is fuel efficiency: the arithmetic average of the fuel efficiency at different speeds, measured as liters per kilometer.

The nationality associated with each car model is crucial for two reasons. First, we need to account for the demand side favoring "domestic" producers (home bias). Second, we must define the relevant currency to measure the total profits for each of the producers.

On the demand side, we consider the nationality historically associated with each brand by consumers. For example, BMW produces its own brand and since 1994 has also produced the brand Rover-Triumph. We assume that consumers would consider the brand Rover-Triumph as British, regardless of the German ownership.

On the supply side, we assume that the location of the firm's headquarters defines the relevant currency to aggregate profits. In the same example, BMW's revenues in different currencies are aggregated in German Marks. Appendix A shows the nationalities associated with each brand (relevant to the demand side) and the nationalities associated with each firm (relevant to the supply side).

For further details regarding the dataset, we refer the reader to Brenkers and Verboven (2006).

[7] The updated data is generously available from the authors' webpages.

[8] The car segments are compact, subcompact, standard, intermediate and luxury.

4 Methodology and Results

4.1 Empirical Strategy and Identification

As of today, finding the MPE in dynamic games is feasible only in a limited number of games with a small number of players and states. In particular, to estimate the MPE in the dynamic game outlined in Section 2 cannot be done using a nested-fixed point algorithm due to the large number of players and state variables. To circumvent this "curse of dimensionality", some recent papers have developed a two stage approach based on the insights of Hotz, Miller, Sanders, and Smith (1994) that does not require to solve the equilibrium of the game.

We use the methodology developed by Bajari, Benkard, and Levin (2007) that does not require the find the MPE of the game to estimate the unknown parameters that, in our particular case, are the production costs (ν) and price adjustment costs (Ψ). This approach has been successfully applied to estimate the cost structure in several other industries (Ryan (2012), Suzuki (2013), Jeziorski (2014)). To the best of our knowledge, this is the first paper to use this methodology to estimate price adjustment costs.

BBL approach comprises a two stage estimator. In the first stage, the researcher estimates the transition probabilities of the state variables and a flexible model of the players' decisions as a function of those state variables. In the second stage, the researcher imposes equilibrium restrictions from a structural model to rationalize the first stage estimates. The structural estimates are going to be those that minimize profitable deviations of using different decision rules from the one observed in the data.

The transition probabilities of the state variables are the stochastic processes that govern the evolution of the relevant economic environment. The transition probabilities allow us to simulate a path (or sequence of correlated draws over time) of the state variables. In our particular case, we assume that the nominal exchange rates, GDP per capita and nominal wages follow a first-order Markov process.[9] Intuitively, a stronger inertia in the state variables makes environmental persistence relatively more important for pricing behavior than the presence of price adjustment costs. By the same token, if state variables were uncorrelated over time, the only reason to observe price inertia would be the price adjustment costs.

In our case, the estimated policy functions capture the observed pricing behavior in each possible state. The policy function allow us to evaluate the predicted price in a given state of the world, using the pricing rule found in the data. It is important to stress that this reduced form estimation does not ensure equilibrium outcomes, as no equilibrium conditions are

[9]Notice that the BBL methodology does not require the environment to be stationary.

imposed. Hence, it differs from the theoretical policy function, denoted by $\sigma(\mathbf{s})$, and cannot be used to perform counterfactuals or to determine equilibrium markup rules. Nevertheless, the estimated policy function is very useful capturing, in a reduced-form fashion, the two sources of price inertia: persistence in the state variables and costly repricing.

In practical terms, the estimated policy function is a flexible regression of prices on state variables and the lagged price. Importantly, the estimated coefficients in this reduced form specification do not have a structural interpretation, although they might have intuitive implications for the second stage estimation. In fact, estimates of the coefficients associated with car characteristics, exchange-rates and wages shed light on the magnitude of production cost coefficients ν that are estimated in the second stage. For instance, if changes in destination wages have large effects on prices, it must be the case that distribution costs are relatively important, although the structural coefficients (ν_5^f and ν_6^f) will be found in the second stage.

A key estimate is the the lagged price coefficient that captures the observed (optimal) degree of price stickiness. As the price is a function of the state variables, highly autocorrelated state variables can generate autocorrelated prices. Similarly, the price adjustment costs penalized large price changes, making price inertia optimal. Our reduced-form estimates capture both sources of inertia. Only through the second stage we separately identify the structural parameters Ψ that establish the relative importance of the two competing sources of persistence. In the second stage, we search for the structural parameters ν and Ψ that, controlling for the dynamics of the state variables, rationalize the players' behavior as captured in the reduced form policy functions.

The first step in the second stage is to forward simulate various sequences of the state variables using the estimated transition probabilities. For each different path, we use the *estimated policy function* to compute the respective predicted price in each scenario. Conditional on an initial value of parameters $\theta_0 = (\nu_0, \Psi_0)$, we are able to evaluate the profits of every player by replacing the sequence of state variables and their respective prices at each time period. Thus, the sum of the discounted profits over time yield the estimator of the value function, $V(\theta_0)$, for each player under θ_0.

Bajari, Benkard and Levin exploit the fact that under the true cost parameters, using any deviation of the policy function should yield a suboptimal value function. Hence, BBL suggest to compute the value function for an alternative policy function, keeping constant the transition matrix and θ_0. If the alternative value function $\widetilde{V}(\theta_0)$ is larger than $V(\theta_0)$, then we have found a unilateral profitable deviation. Therefore, the BBL estimate is the parameter vector that minimizes the existence of unilateral profitable deviations, supporting the estimated policy function as the equilibrium play of the game.[10]

Example of the BBL approach in a static game: To compare the identification strategy of BBL with the typical static approach, we present a very simple example to illustrate the parallel between the two methods.

Without loss of generality, assume a single agent producing a single product with unobservable marginal costs given by $c_t = \nu s_t + \epsilon_t$, where s_t is a scalar state variable, say wages, and ϵ_t is the standard white noise. Suppose the researcher seeks to estimate the cost parameter ν and, for simplicity, assume that the demand function $q_t = q(p_t, \Omega)$ is known.

In static framework, the first order condition typically yields a tractable equation system in which the unobservable marginal costs c_t (treated as latent variables) can be written as a function of observable prices p_t, demand q_t and demand parameters Ω.

$$c_t \equiv p_t - f(\Omega)q_t \tag{9}$$

The usual next step is to obtain the estimate $\widehat{\nu}_{static}$ running the following type of regression:

$$p_t - f(\Omega)q_t = \nu s_t + \varepsilon_t \tag{10}$$

where ε_t is the usual white noise.

Replacing the demand function $q_t = q(p_t, \Omega)$, we solve the game. In other words, we find the equilibrium prices that satisfy the first order conditions, and therefore, to find the structural policy function σ:

$$p_t^{sta} = \sigma(\nu, \Omega, s_t) \tag{11}$$

Notice that σ allows us to compute counterfactual prices and markups under different parameters ν and Ω because equilibrium conditions are imposed.

To understand the similarities and differences between solving the game and the BBL approach, we describe the application of BBL to this static game. The BBL implementation requires the following steps: i) estimate transition probabilities for state variables: $\mathbb{P}(s_t|s_{t-1}) = \mathbb{P}(s_t)$; ii) estimate the policy function $\widehat{p}(s_t)$, running the following type of regression:

$$p_t = \lambda s_t + \varepsilon_t \tag{12}$$

The second stage of BBL is as follows: i) In order to simulate path of the state variables, we draw simulations from the estimated distribution probabilities $\mathbb{P}(s_t)$; ii) We compute predicted prices evaluating the estimated policy function at the simulated state variables, $\widehat{p}_t = \widehat{\lambda} s_t$ and evaluate the demand function at those predicted prices $\widehat{q}_t = q(\widehat{p}_t, \Omega)$; and

[10] Appendix B provides more details of the implementation of BBL methodology in our setting.

iii) We compute the expected sum of discount profits (or value function) under some initial structural parameter ν_0:

$$V(\nu_0) = \sum_t \left(\widehat{p}_t - \nu_0 s_t\right) \widehat{q}_t \tag{13}$$

We compute an alternative value function by redoing the same procedure for a given alternative policy function $\widetilde{p}_t = \widetilde{\lambda} s_t$:

$$\widetilde{V}(\nu_0) = \sum_t \left(\widetilde{p}_t - \nu_0 s_t\right) \widetilde{q}_t \tag{14}$$

We replicate this procedure for a large number, B, of alternative paths of the state variables. Thus, the second stage estimator $\widehat{\nu}_{BBL}$ that minimize profitable deviations is given by:

$$\widehat{\nu}_{BBL} = \arg\min_{\nu} \sum_{b=1}^{B} (\min\{V^b(\nu) - \widetilde{V}^b(\nu), 0\})^2 \tag{15}$$

where the sum is over different draws of state variables indexed by b.

Suppose the static game is well specified, and therefore, the data on prices is consistent with Equation (10). If the estimated policy function in Equation (12) is an accurate description of the observed pricing behavior, the estimates $\widehat{\nu}_{static}$ and $\widehat{\nu}_{BBL}$ should be close (up to simulation noise) as both estimates maximize the value function of the firm.

Although cost estimates can be close, the policy function σ in Equation (11) might be very different from estimated policy function in Equation (12) as the latter does not necessarily meet equilibrium constraints. Consequently, the lack of equilibrium conditions makes the estimated policy function $\widehat{p}_t$ not suitable for counterfactual exercises, for example of changes in ν or Ω.

In the case of a dynamic game, the first order conditions do not yield a tractable equation system and, in general, it is not possible to solve the game and find the policy function. However, BBL approach does still provide an estimate of cost parameters as the methodology does not require to solve the game or find the theoretical policy function σ.

The remainder of the Section is organized as follows. Subsection 4.2 introduces the transition probabilities, Subsection 4.3 presents the estimated policy functions, Subsection 4.4 presents the structural demand. Finally, the results of the structural estimates are presented Subsection 4.5.

4.2 Transition Probabilities

To estimate the transition probabilities, we assume that the payoff relevant state variables follow a first order Markov process as it is standard in this literature. We estimate a single equation for exchange rates, and a VAR system for wages and GDP per capita.

Exchange Rates: We assume that nominal exchange rates follow a first order autocorrelated process with contemporary shocks correlated across countries. Hence, the equation for the currency of country $f = \{\text{Belgium, France, Germany, Italy, UK, Japan}\}$ at time t is given as follows:[11]

$$\log(e_t^f) = \rho_0^f + \rho_1^f \log(e_{t-1}^f) + u_t^f \tag{16}$$

where the shocks u_t^f are correlated between markets but not across time. The process towards a common currency in Europe took place in the second half of the sample as scheduled by the Maastricht treaty (1992). Since the Euro was introduced in 1999, there is no relative variation in most of the currencies after 1998. Using quarterly data between 1971 and 1998, the estimates of the exchange rate model (including correlation matrix of residuals) are presented in Tables 15 and 16 in the appendix Section D. Not surprisingly, the exchange rate models show strong autocorrelation and large heterogeneity between countries.

Nominal Wages and Nominal GDP per capita: We estimate a vector autoregressive model of order one as the transition probabilities of nominal wages in the manufacturing sector (or automobile sector if available) and the nominal GDP per capita. Consistent with segmented labor markets, the wages, W^f, and the GDP per capita, Y^f, are correlated within a country but not between countries.

The estimated model for each country f is as follows:

$$\begin{bmatrix} \log(W_t^f) \\ \log(Y_t^f) \end{bmatrix} = \begin{bmatrix} \lambda_W^f \\ \lambda_Y^f \end{bmatrix} + \begin{bmatrix} \lambda_{WW}^f & \lambda_{WY}^f \\ \lambda_{YW}^f & \lambda_{YY}^f \end{bmatrix} \begin{bmatrix} \log(W_{t-1}^f) \\ \log(Y_{t-1}^f) \end{bmatrix} + \begin{bmatrix} v_{1,t}^f \\ v_{2,t}^f \end{bmatrix} \tag{17}$$

As expected, all the processes are extremely autocorrelated, implying a very slow adjustment. Also, shocks to nominal wages are correlated with shocks to nominal GDP and captured by the country-specific correlation parameter. Table 17 in the appendix section D presents the estimates using yearly data between 1971 and 1999.

Observable and Unobservable Car Characteristics: Recent literature has explored the determinants of innovations in the automobile industry mainly focusing on the effects of different regulations (Klier and Linn (2012), Blonigen, Knittel, and Soderbery (2013), Knittel (2011), Hashmi and Biesebroeck (2016)).

[11] The exchange rate series are expressed relative to the US Dollar. However, we use the ratio of the producer's currency to the destination's currency when computing revenues and costs, and therefore, using the US Dollar as a denominator is irrelevant.

We do not consider the dynamics in the car characteristics (observable and unobservable) and their implications in pricing behavior. We are not aware of research supporting the hypothesis that the introduction of car characteristics or models is linked to the pricing policies of the manufacturers. However, we state upfront our assumptions and their consequences on this regard. If manufacturers use the car characteristics to smooth price changes, and since we have not accounted for this link, then our price adjustment costs would be upward biased as our estimates capture the price adjustment costs and the price inertia caused by car characteristics.

The main reason to abstract from the dynamics in characteristics is tractability. A dynamic framework dealing with entry and exit of firms and models is quite complex, especially if needed to perform forward simulations of market configurations. We would need a theoretical model able to forecast the new characteristics of the new models, the identity of the surviving incumbent models and the identity of the exiting models at each moment in time. We are not aware of empirical research on pricing behavior tackling all these issues simultaneously.

In order to minimize the potential biases in our estimates, we hold the car characteristics constant during our forward simulations in the second stage of the BBL estimation as described in Subsection 4.5. Hence, the dynamics of car characteristics do not play any role in the dynamics of prices.

4.3 Policy Functions

The policy functions are estimated separately for each manufacturer-market combination, allowing the equilibria to vary across markets and producers. This flexibility allow us to account for the market features that are time-invariant such as taxation, degree of competition, pricing to market behavior, and any other market and manufacturing-country specifics.

Hence, the policy function for models sold in market m by manufacturers of country f are given by:

$$\begin{aligned}\log(p_{jt}^{fm}) &= \beta_0\log(p_{j,t-1}^{fm}) + \beta_1\log(e_t^m/e_t^f) + \beta_2\log\left(e_t^m/e_t^f\right)^2 + \beta_3\log(X_{jt}^{fm}) \\ &\quad +\beta_4'\log(e_t^m/e_t^f)\cdot\log(X_{jt}^{fm}) + \beta_5\log(W_t^f) + \beta_6'\log(X_{jt}^{fm})\cdot\log(W_t^f) \\ &\quad +\beta_7\log(Y_t^m) + \beta_8' D_{jt}^{fm} + \varepsilon_{jt}^{fm} \qquad (18)\end{aligned}$$

where p_{jt}^{fm} is the nominal price of model j expressed in the currency of destination-market m at time t. e_t^m/e_t^f is the ratio of nominal exchange rates that enters in a linear and quadratic form and also interacts with car characteristics X_{jt}^{fm}, same as wages W_t^f. The set of dummies D_{jt}^{fm} controls for firm, brand and segment fixed effects. The nominal GDP per capita, Y_t^m, plays the role of deflator since the demand uses $\widetilde{p}_{jt}^{fm} = p_{jt}^{fm}/Y_{jt}^m$.

We consider the consecutive models as defined in Brenkers and Verboven (2006), even though some models could change some characteristics over time. Another approach would be to consider quality-adjusted prices. We prefer to keep the price persistence as given by the models for the sake of transparency and simplicity.

The error term in the policy function, ε_{jt}^{fm}, includes car's unobservable characteristics denoted by ξ_{jt}^{fm}:

$$\varepsilon_{jt}^{fm} \equiv \xi_{jt}^{fm} + \omega_{jt}^{fm} \tag{19}$$

where ω_{jt}^{fm} is an *iid* shock with mean zero and constant variance. We assume that the unobservable characteristics, ξ_{jt}^{fm}, are uncorrelated over time. Thus, we rule out the presence of autocorrelation in the random term, ε_{jt}^{fm}, that would cause endogeneity issues as the lagged dependent variable is also a regressor.

Note that the coefficients, β, in the estimated policy function *do not* have any structural interpretation as no equilibrium constraints are imposed.[12] Nevertheless, lagged price, p_{jt-1}^{fm}, captures environmental inertia and price stickiness in a reduced form. The characteristics vector, X_{jt}^{fm} and the producer-country nominal wage, W_t^f, are explained by the nominal costs of production.

Recall that consistent with the definition of MPE, only contemporaneous state variables are allowed as regressors in the policy function, ruling out including lagged state variables.[13]

The fit of the policy functions is good showing R-squared above .95, although the statistical significance of some estimates can be quite low.[14] This is expected given the collinearity of some explanatory variables and the high degree of autocorrelation of the series.

To evaluate the economic content of the estimated policy functions, we compute impulse-response exercises. We compare the prices under the long-run value of the state variables and the alternative path of prices after an initial shock of a 10 percent increase in exchange rates (or wages).[15] Using the transition probabilities, we simulate for 40 periods ahead and compare the two trajectories of prices.[16]

Exchange Rate Depreciation: As an example, Figure 1 presents the

[12]We drop the (f, m) superscripts in the parameters for presentation purposes.

[13]In general, the policy function should depend also on the competitors' state variables but these turned out to be not statistically significant.

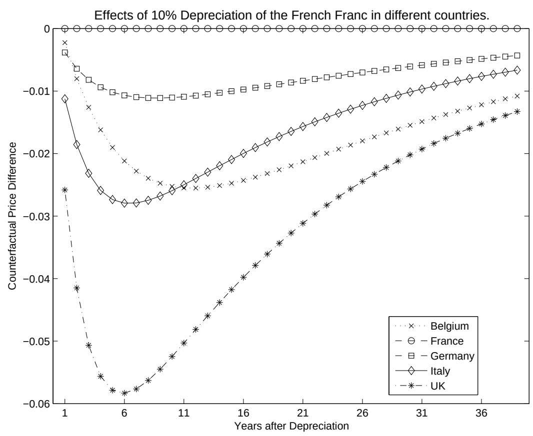
[14]The entire set of 13 estimates for each of the 30 market-producer combinations is available upon request.

[15]The existence of steady-state is not necessary but simplifies the exercise.

[16]For clarity in the exercise, the shocks are uncorrelated, although during the BBL forward simulation we draw correlated shocks using their respective variance-covariance matrix.

reaction of French producers outside France after a 10 percent depreciation of the French Franc, which allows French producers to reduce their prices abroad. The figure shows the heterogeneity in responses, both in size and temporal profile of the price change. The price decrease ranges between -6 percent in the UK and -1 percent in Germany, ruling out full pass-through. Notice the delay of six periods to reach the peak of reaction.

Figure 1: **French car prices after a 10% depreciation of the French Franc by country**



An interpretation of Figure 1 is that French manufacturers react faster and with larger adjustments in the UK, than in Italy. This can be due to a larger price adjustment costs in Italy relative to the UK, or due to different correlations between the French Franc and their respective currencies. The identification of the relative weight of these two competing explanations is found in the second stage estimates when also accounting for the transition probabilities.

Figure 2 presents the reaction of foreign producers in France after a 10 percent depreciation of the French Franc, which force foreign producers to increase their prices as their revenues are less valuable in their domestic currency, and keeping French producers unaffected. The policy functions show European producers increasing prices in 6 percent. Instead, Japanese manufacturers change their prices by 1 percent and keep an almost flat price trajectory. Intuitively, this difference can be rationalized by larger price adjustment costs of the Japanese in France relative to European countries or by a future path of wages and exchange rates that makes optimal for Japanese to avoid large price changes in France.[17]

[17] See Appendix E for the entire set of impulse response exercises. On-line Appendix includes the same exercise for wage increase and the 90 percent confidence intervals for each response based on a bootstrapping of 1000 draws of each policy estimation.

Figure 2: **Car prices in France after a 10% depreciation of the French Franc**

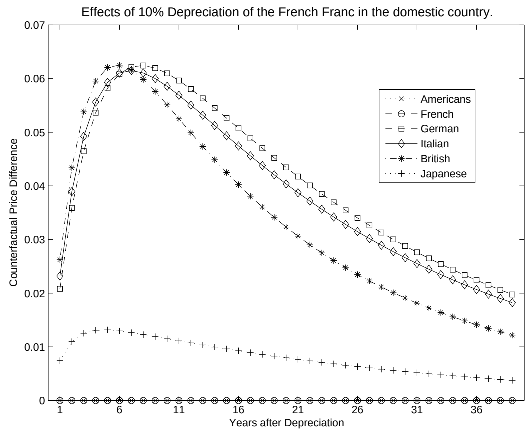


Figure 3 presents the demand under the predicted path of prices, in which the consumers have re-optimized their choices given the new relative prices. The demand for domestic cars in France seems not affected, even though they are relatively cheaper after the depreciation as many consumers choose the outside option rather than switching to a domestic car. The implied losses in demand for foreign producers can be as large as 20 percent. Therefore, a 10 percent depreciation in the French Franc implies a 20 percent reduction in revenues for foreign producers in France as shown in Figure 4.

We think these losses are sizeable, despite our price elasticities being smaller than previous estimates. In fact, larger elasticities would imply even larger predicted losses in revenues (close to 50 percent). We see this result as an advantage of our BLP demand over the previous nested logit estimations. The nested logit model would predict implausibly large losses caused by frequent exchange rate shocks.

Regarding the general features of our policy functions, note that we do not make assumptions regarding the degree of competition in the industry. Our estimated reduced form does not identify the degree of competition in the market as the estimated pricing rules can be consistent with perfect competition (all manufacturers pricing at marginal cost captured by the state variables) or perfect collusion (all manufacturers coordinated to increase prices based on the state variables). Moreover, given the market-producer specific estimations, we do not impose the equilibrium to be the same across markets.

The theoretical model allows for a large list of potential state variables and their interactions. Note the MPE assumption rules out the possibility of "state path dependence" as the equilibrium depends only on the cur-

Figure 3: **Demand in France after a 10% depreciation of the French Franc by producer**

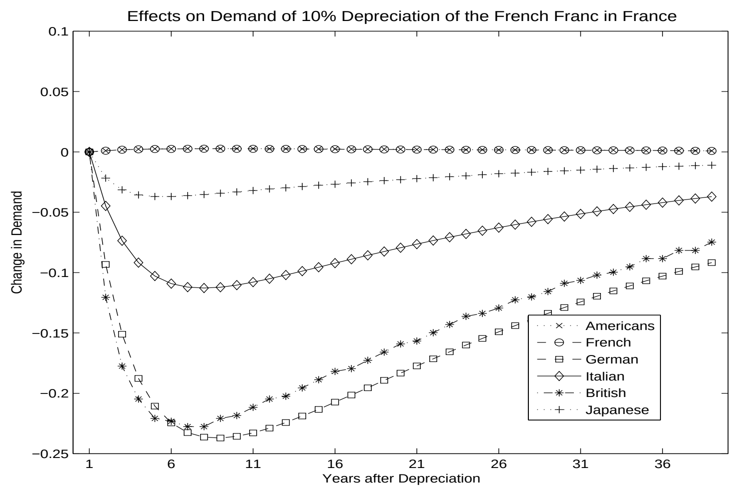
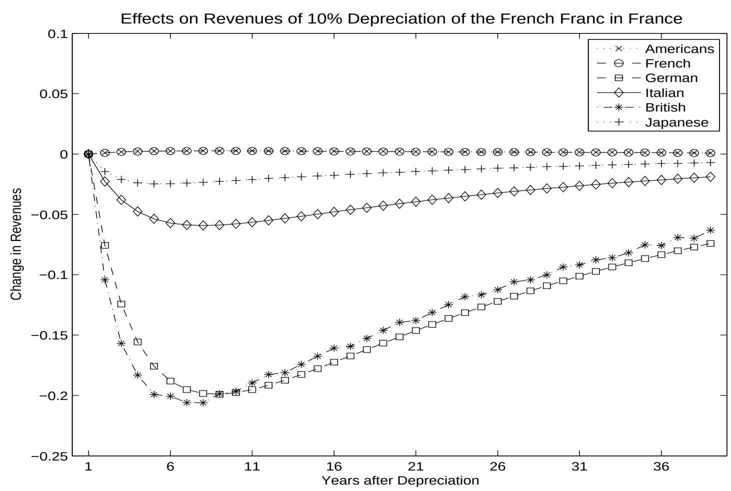


Figure 4: **Revenues in France after a 10% depreciation of the French Franc by producer**



rent state. Therefore, the lags of the state variables cannot be considered explanatory variables in the policy function.

We take several decisions in terms of the variables that were excluded, mostly based on statistical properties, as the estimated policy function needed to be an accurate description of the observed pricing behavior. For instance, consumer's income Y_{jt}^m is almost collinear with domestic wages W_{mt}, so the latter was not included as regressor. Also, theoretically, it could be possible to include a exchange rates for domestic producers selling at home, arguing some strategic reaction. However, the empirical results did not support this possibility either, and therefore, we impose a zero effect.

We estimate alternative specifications including several state variables of competitors, such as the average of competitor's past prices (at the market and segment level), the competitor's characteristics, the competitor's wages and exchange rates. Unfortunately, none of these specifications were statistically significant. Instead, the best estimated policy functions only considered the state variables related to their own production costs. This suggests that the potential strategic interactions could be coordinated through the exchange rates, wages and GDP. We are not able to identify the exact mechanisms, but it is certainly the case that common shocks in wages or exchange rates can help to coordinate certain expected actions such as price increases or decreases.

Given our limited sample size of consecutive models, we assume a second-degree polynomial in Equation (18). From the initial 11,549 observations, we have to reduce the sample for various reasons. First, we only use producers from the main six producer countries.[18] Second, price adjustment cost terms require at least two consecutive periods for a given car model. Third, we focus on cars produced domestically discarding those few models produced outside the country of the headquarter.[19]

4.4 Demand System

To close the model we need to specify the demand function. We assume a demand system for differentiated products as in Berry, Levinsohn, and Pakes (1995) (henceforth BLP). We depart from nested logit demands used in the previous literature to allow for heterogeneous consumers in each country and to impose less structure on the decision nest.[20]

[18]Due to the small number of observations, we leave out car models from the Netherlands, Czechoslovakia, Sweden, Spain, Korea, Russia and Yugoslavia. We keep American cars made in the UK and Germany.

[19]See Table 11 in Appendix Section A for details on the sample used for the policy function estimation.

[20]See Wojcik (2000) and Berry and Pakes (2001) for a discussion regarding the convenience of nested logits (NL) versus random coefficient models (RC). Grigolon and Verboven (2014)

Assuming that consumer preferences are stable over time, the utility of individual i from model $j = \{1, .., J^m\}$ is given by:[21]

$$U_{ij} \quad = \quad \alpha_1' X_j - \alpha_{2i}\widetilde{p}_j + \alpha_3 h_j + \xi_j + \epsilon_{ij} \qquad (20)$$

where X_j is a vector of observable characteristics, $\widetilde{p}_j = \frac{p_j}{Y}$ is the real price of the car model (ratio price-GDP per capita), h_j is a home bias dummy that is equal to 1 if car j is sold in the same country as its brand's nationality, ξ_j is an unobservable product characteristic, and ϵ_{ij} is an i.i.d. stochastic shock with a type I extreme value distribution.

The vector of characteristics, X_j, includes size, inverse of motor power, fuel efficiency and various fixed effects. As in Goldberg and Verboven (2001), the price $\widetilde{p}_j$ accounts for the income and inflation differences between countries during our time period.

The European car market features a noticeable "home bias", which is consumers' strong preference for domestic cars. To capture this bias, our demand includes the domestic/foreign distinction, h_j.

The scalar product characteristic, ξ_{jt}, is unobserved by the econometrician but observed by the agents. BLP (1995) assume that ξ_{jt} is uncorrelated with the car characteristics X_{jt} in the American automobile market and we keep the same set of assumptions. Since the development or redesign of car models take several years (Blonigen, Knittel, and Soderbery (2013)), we assume that car characteristics are fixed or predetermined for any realization of shocks ξ_{jt}. As in BLP (1995), we also assume that ξ_{jt} is uncorrelated over time. Recall that we include model fixed effects in our estimation limiting the possibilities of autocorrelation. Besides the obvious gains in terms of simplicity, this assumption is also useful to overcome issues on endogeneity and initial conditions when estimating the policy function.

Regarding the demand parameters, we have α_1, a common vector of taste coefficients, α_{2i}, a consumer-specific price-sensitivity coefficient and α_3, a country-specific home-bias parameter. Consumer i's marginal utility of income is given by $\alpha_{2i} = \alpha_2 + \sigma_p v_i$, with standard normal shocks v_i capturing the unobservable consumer heterogeneity and parameter α_2 capturing the country-specific mean of price sensitivity.

Given that ϵ_{ij} is i.i.d. with a type I extreme value distribution, we have a closed form solution for the individual probability s_{ij}. Moreover, integrating over the mass of consumers who prefer product j, denoted by A_j, we derive the predicted market share, s_j:

$$s_j(\mathbf{X}, \mathbf{p}, Y, \xi; \theta) = \int_{A_j} \frac{\exp(\alpha_1' X_j - \alpha_2 \widetilde{p}_j + \alpha_3 h_j + \xi_j - \widetilde{p}_j \sigma_p v_i)}{1 + \sum_k \exp(\alpha_1' X_k - \alpha_2 \widetilde{p}_k + \alpha_3 h_k + \xi_k - \widetilde{p}_k \sigma_p v_i)} \mathrm{d}\Phi(v_i) \qquad (21)$$

found that the RC model provides a better approximation of the own-price elasticities than the NL model, while both models tend to underestimate the cross-price elasticities within a group. Grigolon and Verboven suggest the more general random coefficients nested logit model.

[21]For simplicity, we suppress the subscripts for time t, market m and producing country f.

where $\theta = (\alpha_1, \alpha_2, \alpha_3, \sigma_p)$ is the vector of demand parameters to be estimated, where the terms α_2 and α_3 are *country-specific* allowing for heterogenous preferences between countries.

Since ξ_j might be known by the manufacturer when setting prices, we have a potential endogeneity problem. To overcome the endogeneity issue, we choose to remain close to BLP (1995) using their suggested instruments. The so-called BLP instruments are functions of the contemporaneous characteristics of competitors' models or within a firm models. In a differentiated product setting, the exogenous characteristics are correlated with prices but not with ξ_j. We estimate the model using the generalized method of moments presented in BLP (1995).

The demand estimates are summarized in appendix section C. We estimate alternative specifications to include more random coefficients that were not significant. See Noton (2015) for details regarding the estimation and alternative specifications.

Despite the literature in dynamic demands (Schiraldi (2011)), we abstract from the dynamics coming from the demand side, mainly for simplicity and the lack of data on the second hand markets of cars. An undesirable consequence of abstracting from demand dynamics is that the estimates of price adjustments are likely to be upward biased as they capture the effects of demand dynamics and the price adjustment costs. As we discussed in the conclusion, this feature implies that our estimates are conservative and reinforce the main conclusions that price adjustments are relatively unimportant.

4.5 Structural Cost Parameters

This section presents the structural cost estimates that rationalize the behavior of the players as captured by the first stage estimates. Using these estimates, we are able to identify the magnitude of the price adjustment cost consistent with the observed price inertia.

As outlined in Subsection 4.1, we simulate 1,000 different sequences of the state variables and each path involves 40 periods of time for all models traded in the European markets in 1985. Using the estimated policy functions and an alternative policy function, we compute the predicted prices in each scenario and thus, the expected discount sum of profits for each player under the two policy functions. We search for the cost parameters that minimize profitable deviations from the estimated policy function. See Appendix Section B for details regarding the implementation of the forward simulations.

For simplicity, we keep the same market configuration of firms and models traded in 1985 when performing the forward simulation stage.[22] Thus,

[22]Different years yield qualitatively similar results.

we abstract from the entry and exit of models with different characteristics as mentioned in Subsection 4.2.

Importantly, by holding constant the market configuration through the forward simulations, we shut down the potential endogeneity of the market configuration caused by large shocks in the exchange rates or wages.[23] Note that our estimated policy functions do capture the fixed effects of characteristics on prices but not their dynamics.

Cost Share by Components: For simplicity, instead of reporting the large number of estimates (ν and Ψ), we present the share of each relevant component over total costs. This is a simple way to provide estimates of a comparable order of magnitude for each player in each destination market. The shares of each component are presented in the following decomposition:

$$\text{Production Cost Share} = \frac{\nu_{1,j}^{f} q_{jt}^{fm} + \nu_{2,j}^{f} \left(q_{jt}^{fm}\right)^2 + \nu_3^f W_t^f \cdot q_{jt}^{fm} + \nu_4^f W_t^f \cdot \left(q_{jt}^{fm}\right)^2}{C_{jt}^{fm} + AC_{jt}^{fm}} \tag{22}$$

$$\text{Distribution Cost Share} = \frac{\nu_5^f \cdot e_t^{fm} \cdot W_t^m \cdot q_{jt}^{fm} + \nu_6^f \cdot e_t^{fm} \cdot W_t^m \cdot \left(q_{jt}^{fm}\right)^2}{C_{jt}^{fm} + AC_{jt}^{fm}} \tag{23}$$

$$\text{Price Adj. Cost Share} = \frac{\Psi^{fm} \cdot e_t^{fm} \cdot |p_{jt}^{fm} - p_{jt-1}^{fm}|}{C_{jt}^{fm} + AC_{jt}^{fm}} \tag{24}$$

where the cost terms are those described in Equations (5) and (6).

Table 2 presents the share of each component by the nationality of the producer.[24] Intuitively, the production costs (in column 1) of American models are about 83 percent of total costs. In addition, the distribution cost (in column 2) suggests that American cars have 17 percent of their total costs in destination-currency. Finally, the price adjustment costs (in column 3) suggest that to rationalize the price persistence of American cars, the price adjustment cost should be about 0.15 percent of total costs.[25]

The main insight from Table 2 is that the price adjustment costs are small and sometimes economically insignificant. In fact, the small shares of price adjustment costs required to justify the observed price persistence suggest that price autocorrelation is mostly due to the autocorrelation in the economic environment manufacturers face. However, accounting for country-specific price sensitivity in demand and the persistence of exchange rates and wages, a sizable price adjustment cost is required to rationalize the observed price persistence of Japanese and Italian manufacturers.

[23] See Rodríguez-López (2011) for a theoretical model.

[24] Due to the small number of British models, we have no reliable cost estimates for them.

[25] Appendix F presents an alternative adjustment cost specification that assume log-difference penalties for price changes ($\Psi^{fm} \cdot |\log(p_{jt}^{fm}) - \log(p_{jt-1}^{fm})|$). Both specifications yield qualitatively similar results.

Table 2: **Cost Components over Total Costs**

Exports	Production Costs (1)	Distribution Costs (2)	Price Adj. Costs (3)
Americans	83.17	16.68	0.15
French	77.91	20.11	1.98
Germans	62.10	37.58	0.31
Italians	35.33	59.17	5.50
Japanese	60.12	28.91	10.97
Domestic			
Americans	99.99	-	6e-04
French	97.42	-	2.58
Germans	99.99	-	3e-05
Italians	88.59	-	11.41

Notes: The table presents the different cost components over total costs as in Equations (22), (23) and (24) for the models available in the European markets in 1985. Destination market component is for exported cars only. Due to small sample issues, we have no cost estimates for British models.

Estimates in Table 2 suggest that even controlling for a wide range of country-specific factors (demand sensitivity, exchange rates, wages, GDP and market-specific pricing behavior), the price adjustment costs must vary substantially between countries to match the data.

To compare these estimates with the related literature, our price adjustment cost represents at most three percent of total revenues. These results are similar to those reported by Zbaracki et al.(2004), who provide direct evidence of price adjustment costs for a manufacturing firm. Consistent with their findings, the adjustment cost component seems more important in exports. Nakamura and Zerom (2010) find menu-costs representing 0.23 percent of total revenues in the US coffee industry solving a dynamic model. Using a static framework, Goldberg and Hellerstein (2013) find that menu-costs are less than 1 percent of total revenues in the US beer industry.

We also find that the distribution costs (also known as "local costs") need to be about one-third of total costs. Local costs are defined as the costs expressed in the destination-market currency, usually associated to the distribution costs (Burstein, Neves, and Rebelo (2003)). These costs can explain the stylized fact of incomplete pass-through. For instance, suppose a French model sold in Italy, so the revenues are in Italian Lire. Suppose production cost (in French Francs) are 70 percent of the total costs and the local costs are the remaining 30 percent (in Italian Lire). The exchange rate fluctuations between the Franc and the Lire do not affect the relative value of revenues and distribution costs. Therefore, this phenomenon can explain the stylized fact of incomplete degree of exchange rate pass-through. Consistent with our results, Goldberg and Verboven (2001) find local costs to be around 40 percent in the European car market. Nevertheless, our estimates of the local cost for Italian producers seem too high to be plausible. Substitution of intermediate inputs may play a role, but the lack of model-level input information preclude us to explore this or other input related hypotheses.

Finally, we also explore heterogeneity across producer and destination-market combinations. We compare our estimates of the price adjustment coefficients between markets for a given manufacturer in Table 3 and we present the relative magnitude of the price adjustment costs for each producer-destination pair in Table 4.

Table 3: **Ratio of Price Adjustment Cost Parameters (Ψ^{fm}/Ψ^{ff})**

	Belgium	France	Germany	Italy	UK
Americans	0.01	8.46	0.09	0.02	1.00
French	1e-04	1.00	1e-04	1.78	0.08
Germans	3.57	1e-04	1.00	1.31	1.49
Italians	0.37	0.02	0.02	1.00	0.23
Japanese	1e-04	0.25	1.00	-	14.28

Notes: Each cost adjustment coefficient, Ψ^{fm}, is normalized by the home-country price adjustment coefficient, Ψ^{ff}. We express the coefficient of American models relative to the coefficient in the UK, and those of the Japanese models relative to coefficient in Germany. No Japanese model sold in Italy is included in our sample.

Table 4: **Cost Share of Price Adjustment Costs by Destination Market**

	Belgium	France	Germany	Italy	UK
Americans	3e-03	0.43	1e-04	4e-04	1e-04
French	4e-04	2.21	1e-04	7.43	0.06
Germans	0.06	1e-07	1e-04	0.82	0.08
Italians	12.87	1.94	0.05	10.21	2.07
Japanese	0.05	1.44	3.82	-	37.22

Notes: We compute the share of price adjustment cost as in Equation (24) for each market separately. No Japanese model sold in Italy is included in our sample.

We find a clear heterogeneity in the price adjustment cost by destination markets within a manufacturer. Notice that our structural estimates account for the country-specific price sensitivity in demand, the different transition probabilities of GDP, wages and exchange rates and the different policy functions of each manufacturer in each destination market. Still, the adjustment costs need to vary substantially across markets to match the data. A uniform cost structure would allow for profitable deviations to manufacturers and would not rationalize the pricing behavior observed in the European car market as an equilibrium play. Since our price adjustment costs capture managerial and strategic costs (amount of resources that firms are willing to forego to follow a persistent pricing strategy), our evidence points out to different market-specific strategies of the firms. The literature has not, so far, explored this timing decisions, so this paper introduces a new dimension of pricing heterogeneity that complements the previous static literature on the different degree of exchange rate pass-through across destinations.

5 Conclusions

Using a structural model, this paper identifies the price adjustment costs that can rationalize the pricing behavior in the European automobile industry. The large autocorrelation in prices could be consistent with large and homogenous price adjustment costs. However, accounting for the heterogeneity in demand factors, and the wage and exchange rate dynamics, we find that large adjustment costs are not needed to rationalize the large price inertia observed in the data. Intuitively, in an economic environment where wages, GDP and exchange rates are highly autocorrelated, small adjustment costs can rationalize the persistent prices. Furthermore, price adjustment costs seem to be specific to each producer-destination combination. This finding suggests a novel time dimension to the established pricing-to-market behavior.

There are several and important simplifications that we needed to assume in order to keep the estimation tractable. In particular, not including a dynamic demand and the absence of entry/exit of new models are the most relevant. However, both simplifications lead to upward biased estimates of price adjustment costs, making our estimates of price adjustment costs conservative, and therefore, reenforcing our main conclusion that puts more weight on the autocorrelation of the exchange rates and wages as the main source of price stickiness in the European car market.

To the best of our knowledge, this paper is the first attempt of estimating a dynamic game of multi-currency pricing with price adjustment costs using Bajari, Benkard, and Levin (2007), and therefore, able to overcome important limitations of the existing literature. In general, the methodology of BBL seems quite suitable for studying price adjustment costs in a wide range of markets.

Finally, we think there are at least two natural extensions for future research that can take place with more updated and larger datasets. First, we could estimate price adjustment costs consistent with a broader variety of pricing functions, such as a (S, s) rule. Second, a larger dataset could test changes in the cost structure of the firms due to some important changes in the environment such as the adoption of the Euro or the eventual exit of the UK from the European Union.

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APPENDIX SECTIONS

A Data Details

This appendix presents the two criteria for classifying the nationalities of car models.

Demand Side Nationalities: We use model brands to define the relevant nationality from the consumer's point of view. This assignment follows Goldberg and Verboven (2001) and it is invariant to changes in ownership of the manufacturer. Table 5 presents the nationality considered for each brand name.

Table 5: **Brands and Nationalities (Demand Side)**

Country	Brand Name	Country	Brand Name
Czech Republic	Škoda	Japan	Daihatsu
France	Citroën		Honda
	Peugeot		Mazda
	Renault		Mitsubishi
	Talbot		Nissan-Datsun
	Talbot-Hillman-Chrysler		Subaru
	Talbot-Matra		Suzuki
	Talbot-Simca		Toyota
The 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

Tables 6 and 7 present the market shares and the share of total models available under the demand side criterion. One observation is a model, year, market combination.

Table 6: **Sample Size by Nationality and Brands**

Nationality \ Market	Belgium	France	Germany	Italy	UK	Total
Americans	130	126	126	123	126	631
French	566	561	509	509	502	2647
Germans	338	325	347	317	293	1620
Italians	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 7: **Market Shares by Brands and Nationalities**

	% 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
The Netherlands	0.20	0.24
Czech Republic	0.16	0.42

Supply Side Nationalities: To express firm's revenues in a single currency, we use the location of the firm's headquarters to define the relevant currency. This nationality does not necessarily match the nationality perceived by consumers. Table 8 presents firms and the historical location of each firm's headquarters. Tables 9 and 10 present the market shares and the share of total models available in each market by nationality and destination market.

Table 8: **Nationalities using Headquarters (Supply Side)**

Nationality	Firm	Nationality	Firm
France	Peugeot	Italy	AlfaRomeo
	Renault		DeTomaso
	Talbot-Matra		Fiat
	Simca-Hillman-Sunbe		Lancia
Germany	BMW	Korea	Daewoo
	Daimler		Hyundai
	Mercedes		Kia
	VW	The Netherlands	DAF
Japan	FujiHI (Subaru)	Spain	Seat
	Honda	Sweden	Saab
	Mazda		Volvo
	Mitsubishi	UK	Rover
	Nissan	US	Ford
	Suzuki		General Motors
	Toyota	Yugoslavia	Yugo

Table 9: **Sample Size by Headquarter's Nationality**

HQ's Nationality	Belgium	France	Germany	Italy	UK	Total
Americans	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 10: **Market Shares by Headquarter's Nationality**

Nationality	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
The Netherlands	0.20	0.24

Sample for Policy Function: A subsample of the original dataset is suitable for the estimation of the policy functions as defined in Equation (18). Table 11 shows the sample details.

Table 11: **Final Sample for Policy Function Estimations**

	Belgium	France	Germany	Italy	UK	Total
Americans	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

Notes: We only consider the consecutive car models of the six largest producing countries, and produced domestically in the headquarters' country.

B BBL Details

This Appendix Section provides details of our application of the two stage estimator developed by Bajari, Benkard, and Levin (2007), following the nomenclature introduced in Subsection 2.2.

Without loss of generality, assume the profit function, π, is indexed by a finite cost parameter vector ν^f. As in BBL, we assume the data is generated by a unique MPE in each market, the goal is to estimate the true value of $\nu = (\nu^1, .., \nu^F)$, denoted by ν^0.

FIRST STAGE: The first stage of BBL is to estimate the policy function $\sigma_f : S \times \Upsilon_f \to P_f$, for each firm $f = \{1, .., F\}$ and the common state transition probabilities $\mathbb{P} : S \to \Delta(S)$. The purpose of estimating the equilibrium policy functions is that they allow us to construct estimates of the equilibrium value functions; these, in turn, can be used to estimate the structural parameters of the model. BBL suggest to use flexible functional forms.

SECOND STAGE: The second stage of BBL uses first stage estimates to compute the equilibrium value functions through forward simulations. Given an estimated policy function $\widehat{\sigma}$ and transition probabilities $\mathbb{P}$, an estimate of the expected value of payoff for player f under pricing rule $\widehat{\sigma}$, $\widehat{EV}(\nu^f, \widehat{\sigma})$, can be obtained as follows:

1.- Set an initial cost parameters $\nu = \{\nu^1, .., \nu^F\}$ and initial state $\mathbf{s} = \mathbf{s}_0$.

2.- Draw a sequence of states over T periods using the estimated transition probabilities $\mathbb{P}(\mathbf{s}_{t+1}|\mathbf{s}_t)$, hence generating 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, $p_t = \widehat{\sigma}(\mathbf{s}_t)$. Hence, we generate the respective sequence $\{\mathbf{p}_1, \mathbf{p}_2, .., \mathbf{p}_T\}$ for every player. The random shocks in the policy function are set to zero (their expected value) and do not play any role in our application.

4.- Given the known functional form of the profit function π_t compute the resulting profits $\widehat{\pi}_t$, for every player $f \in \{1, .., F\}$ at every simulated time period t.

5.- Compute the present discounted value for each player using discount factor β:

$$\widehat{V}(\nu^f, \widehat{\sigma}, \mathbb{P}) = \sum_{\tau=0}^{T} \beta^\tau \widehat{\pi}_\tau(\nu^f, \widehat{\sigma}, \mathbb{P}) \tag{25}$$

We use a player-specific discount factor based on the average inflation between 1971-1999 to account for country-specific inflation.

6.- Repeat steps 1-5 for an arbitrary large number $\mathbf{B}$ of alternative paths. Denote the discounted value for each alternative path $b = (1, .., B)$ by

$\widehat{V}^b(\nu^f, \widehat{\sigma}, \mathbb{P})$. Averaging firm f's discounted sum of profits over the **B** simulated paths yields an estimate of the expected payoff value for player f:

$$\widehat{EV}(\nu^f, \widehat{\sigma}) = \frac{1}{B}\sum_{b=1}^{B} \widehat{V}^b(\nu^f, \widehat{\sigma}, \mathbb{P}) \tag{26}$$

Now, consider an alternative rule for the agent:

$$\widetilde{\sigma}(\mathbf{s}) = \sigma(\mathbf{s}) + \widetilde{u} \tag{27}$$

where $\widetilde{u}$ is a white noise random term. By construction, the rule $\widetilde{\sigma}$ should be suboptimal under the true cost parameters because it differs from the observed behavior $\widehat{\sigma}$. Therefore, using the same draws of the state variables but using the prices predicted by the alternative rule $\widetilde{\sigma}$, we compute the alternative expected payoff $\widetilde{EV}(\nu^f, \widetilde{\sigma})$.

$$\widetilde{EV}(\nu^f, \widetilde{\sigma}) = \frac{1}{B}\sum_{b=1}^{B} \widehat{V}^b(\nu^f, \widetilde{\sigma}, \mathbb{P}) \tag{28}$$

Consequently, the structural parameter estimates, $\widehat{\nu}$, are those that rationalize the observed rule $\widehat{\sigma}$ or, equivalently, those that minimize the profitable deviations of using alternative rule $\widetilde{\sigma}$. Under the MPE assumption, the structural estimates, $\widehat{\nu}$, should maximize the likelihood of the optimality condition stated in Equation (8).

Estimated policy function $\widehat{\sigma}$ and transition probabilities $\mathbb{P}$ are fixed during the second stage. Let $x \in X$ index the equilibrium conditions, so that each x denotes a particular $(f, \mathbf{s})$ combination. Define

$$g(x, \nu^f) = \widehat{EV}(\nu^f, \widehat{\sigma}) - \widetilde{EV}(\nu^f, \widetilde{\sigma}) \tag{29}$$

The MPE assumption of Equation (8) is satisfied at ν^f if $g(x, \nu^f) \geq 0$. Otherwise, if $\widetilde{g}$ is negative, then it means that $\widetilde{\sigma}_f$ was a profitable deviation for firm f. Define the function

$$Q(\nu^f) \equiv \int (\min\{g(x, \nu^f), 0\})^2 dH(x) \tag{30}$$

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

$$Q(\nu_0) = 0 = \min_{\nu \in \Theta} Q(\nu) \tag{31}$$

Finally the second stage estimator is

$$\widehat{\nu} = \arg\min_{\nu \in \Theta} \frac{1}{C}\sum_{c=1}^{C} (\min\{g(x_c, \nu), 0\})^2. \tag{32}$$

where C is the number of different draws of inequalities x_c, indexed by c.

Implementation: We simulate 1,000 different sequences of the state variables; each path involves 40 time periods for the models presented in all markets in 1985. Table 12 presents the car models we consider in the forward simulations. We did not obtain reliable cost estimates for the British producers given the few British cars in the sample. Also notice no Japanese models in Italy was traded in 1985.

Table 12: **Final Sample used in Forward Simulations**

	Belgium	France	Germany	Italy	UK	Total
Americans	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

Notes: We use the market configuration of firms and models traded in 1985 in the European markets when performing the forward simulation stage.

C Demand Estimates

This appendix section presents the main demand estimates that are described in detail in Noton (2015). Table 13 presents the demand estimates used in this paper.

The considered BLP instruments are the sum of competitors' characteristics, the sum of characteristics of other products of the same producer, the number of competitors, the number of a producer's own products.

Although all the coefficients could have an individual-specific random component, the unobserved heterogeneity is only significant in the price coefficient when considering country-specific price and home bias coefficients. The results of different specifications, elasticities and other robustness checks are reported and discussed in Noton (2015).

Table 14 presents the average price elasticity by destination markets using our the BLP estimates.

Table 13: **Demand Estimates**

Linear BLP Parameters	**Coeff.**	SD	t-test
	(1)	(2)	(3)
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-Germany	**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 Motor 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 Parameter σ_p			
Std Dev on Price Coeff.	**0.68**	(0.35)	1.93
GMM Obj. function	**286.46**		

Notes: Column 1 presents the demand parameters in Equation (21). Column 2 presents the standard deviation of the coefficient estimates and column 3 their respective t-test statistics.

Table 14: **Own price elasticities by market and origin.**
(Standard deviations in parenthesis)

	Belgium	France	Germany	Italy	UK
All	-1.09	-2.79	-1.92	-1.53	-0.83
	(0.36)	(1.06)	(0.69)	(0.49)	(0.15)
Domestic	-	-2.58	-2.29	-1.51	-0.84
	-	(0.84)	(0.83)	(0.53)	(0.13)
Foreign	-1.09	-2.85	-1.86	-1.53	-0.83
	(0.36)	(1.11)	(0.64)	(0.48)	(0.15)

Notes: Elasticities computed as in BLP (1995) that is a weighted average of logit elasticities when considering heterogenous consumers. No domestic car manufacturers in Belgium.

D Transition Probabilities

This section presents the estimates of transition probabilities of the state variables used in the paper. Table 15 shows the AR1 estimates for the exchange rates, while Table 16 presents the respective variance-covariance matrix of the shocks. We compute the yearly coefficients based on a transformation of the quarterly coefficients.

Table 17 presents the VAR estimates for GDP and wages. The correlation between the shocks in wages and GDP is allowed within a country in the same period ($\Gamma = \mathbb{E}(v_{1,ft}v_{2,rp}) \neq 0$ if and only if $f = r$ and $t = p$).

Table 15: **Transition Probability Estimates for Nominal Exchange Rates**

		Quarterly Estimates	Yearly Estimates
Belgian	ρ_1	0.98^{**}	0.93
Franc	ρ_0	0.06^{*}	0.23
French	ρ_1	0.99^{**}	0.96
Franc	ρ_0	0.02	0.07
German	ρ_1	0.98^{**}	0.91
Mark	ρ_0	0.01	0.04
Italian	ρ_1	0.98^{**}	0.92
Lira	ρ_0	0.15^{**}	0.60
British	ρ_1	0.97^{**}	0.89
Pound	ρ_0	-0.01	-0.05
Japanese	ρ_1	0.98^{**}	0.91
Yen	ρ_0	0.12^{*}	0.44

Notes: The estimated coefficients are described in Equation (16). * denotes an estimate significant at 5% and ** significant at 1%.

Table 16: **Correlation Matrix of Exchange Rate Shocks**

Yearly	Belgium	France	Germany	Italy	UK	Japan
Belgium	1.00					
France	0.93	1.00				
Germany	0.97	0.91	1.00			
Italy	0.81	0.84	0.79	1.00		
UK	0.66	0.65	0.65	0.70	1.00	
Japan	0.62	0.60	0.62	0.45	0.46	1.00

Table 17: **Estimates for Nominal Wages and GDP per capita**

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

Notes: The estimated coefficients are described in Equation (17). * denotes an estimate significant at 5% and ** significant at 1%. Non-significant coefficients are labeled **ns** and replaced by zero in the forward simulation stage. Note that the GDP equation is required for the destination markets only, thus it is not estimated for Japan.

E Impulse-Response exercises of Policy Functions

E.1 International Effects of Exchange Rate Depreciation

This appendix presents impulse response exercises for a 10 percent depreciation in all the European currencies considered, as explained in section 4.3. Each figure presents the percentage difference between the altered and steady state paths for predicted prices. These prices are computed with the estimated policy functions, which use the exchange rates with an initial 10 percent increase and 39 subsequent periods predicted by their respective estimated transition probabilities.

This section presents the effect of domestic depreciation on every foreign European market. A domestic depreciation allows domestic producers to sell cheaper abroad.[26] Note that there are no domestic producers in Belgium, hence all cars are more expensive in Belgian Francs after a domestic depreciation. Also, a depreciation of the Japanese Yen implies lower prices of Japanese cars all across Europe.

[26]Recall that in 1985 there were no British cars in Germany and Italy and no Japanese cars in Italy.

Figure 5: **Price Reactions in Europe after a 10% depreciation of the Belgian Franc**

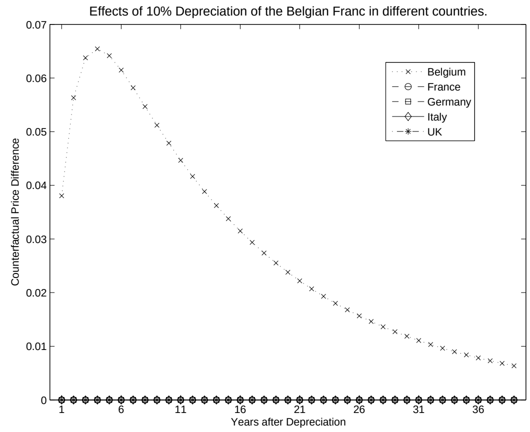


Figure 6: **Price Reactions in Europe after a 10% depreciation of the French Franc**

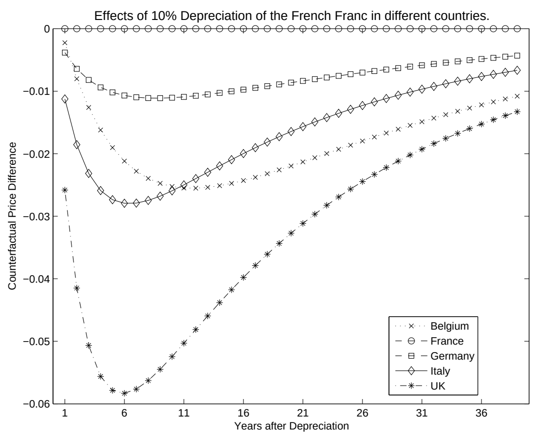


Figure 7: **Price Reactions in Europe after a 10% depreciation of the German Mark**

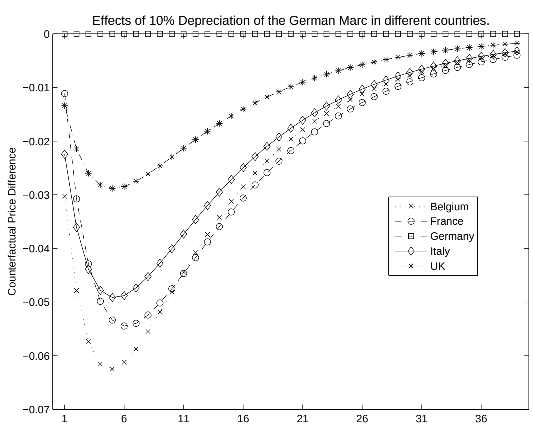


Figure 8: **Price Reactions in Europe after a 10% depreciation of the Italian Lire**

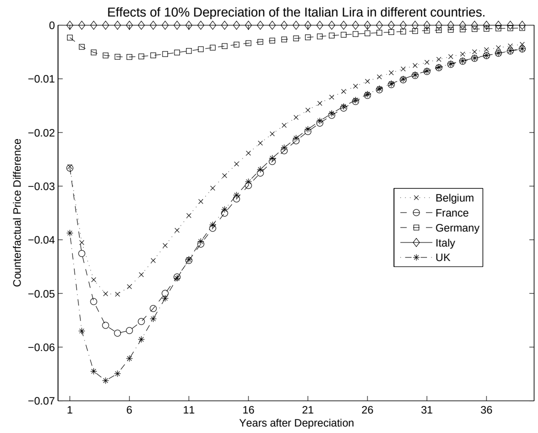


Figure 9: **Price Reactions in Europe after a 10% depreciation of the British Pound**

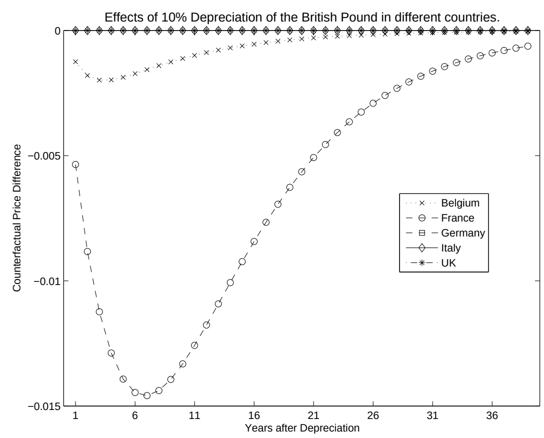
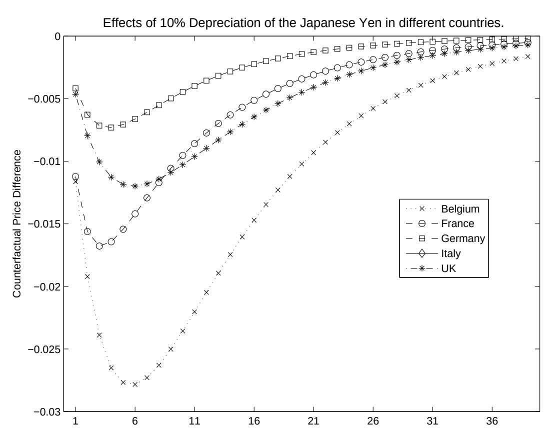


Figure 10: **Price Reactions in Europe after a 10% depreciation of the Japanese Yen**



E.2 Domestic Effects of Exchange Rate Depreciation

This appendix presents the impulse response exercises of a 10 percent depreciation in each of the considered European currencies as explained in section 4.3. The Figures below shows the effects on quantity, prices and revenues of a domestic depreciation. As mentioned before, a domestic depreciation does not affect domestic producers through domestic costs. However, a domestic depreciation may force all foreign car producers to set higher prices because revenues are lower in their headquarter currency. The demand summarizes consumers' substitution under this new set of relative prices. These exercises are extended to compute the path of demand and the revenues for each producer in the market.[27]

[27] Recall that in the year 1985, there were American or British cars made in Germany and Japanese or British cars were made in Italy.

Figure 11: **Price, Demand and Revenues in Belgium after a 10% depreciation of the Belgian Franc**

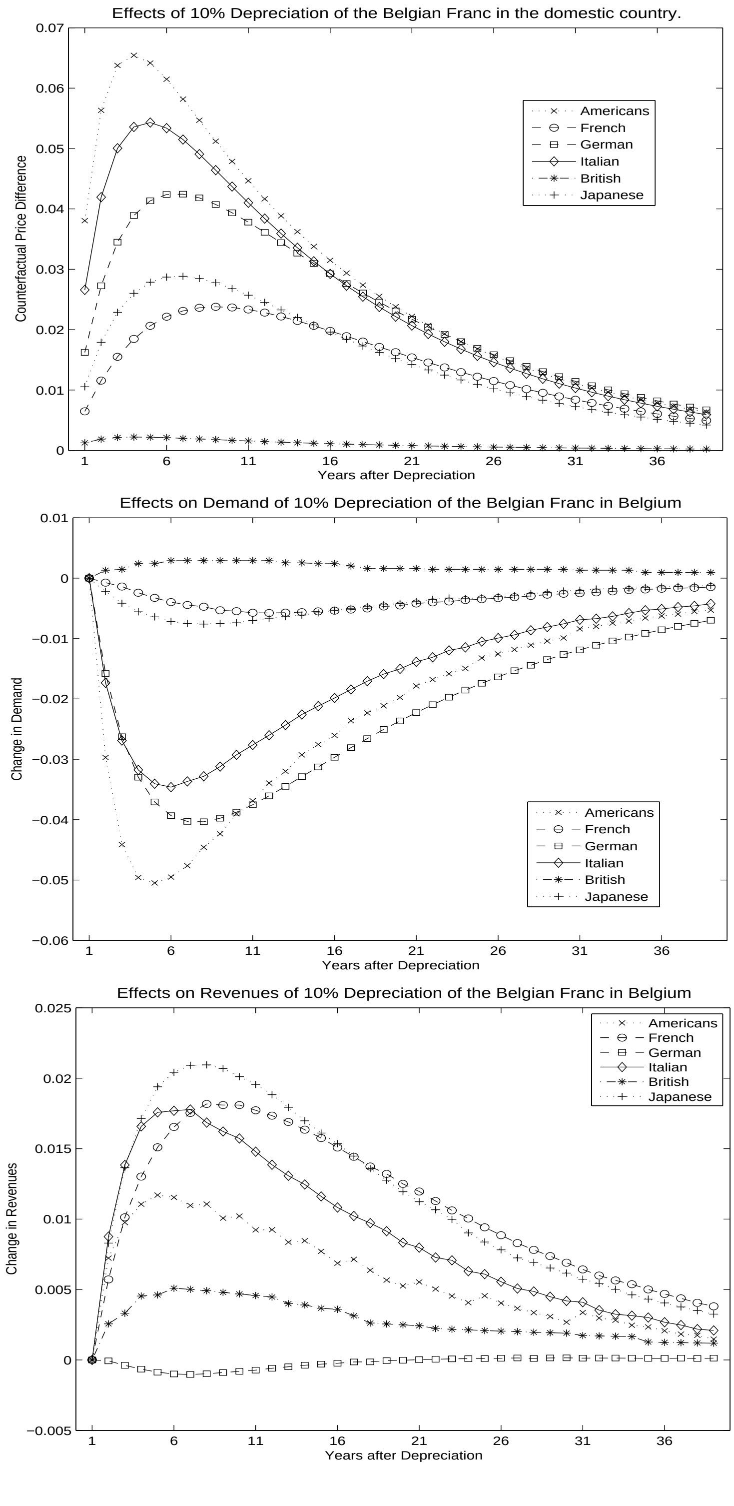


Figure 12: **Price, Demand and Revenues in France after a 10% depreciation of the French Franc**

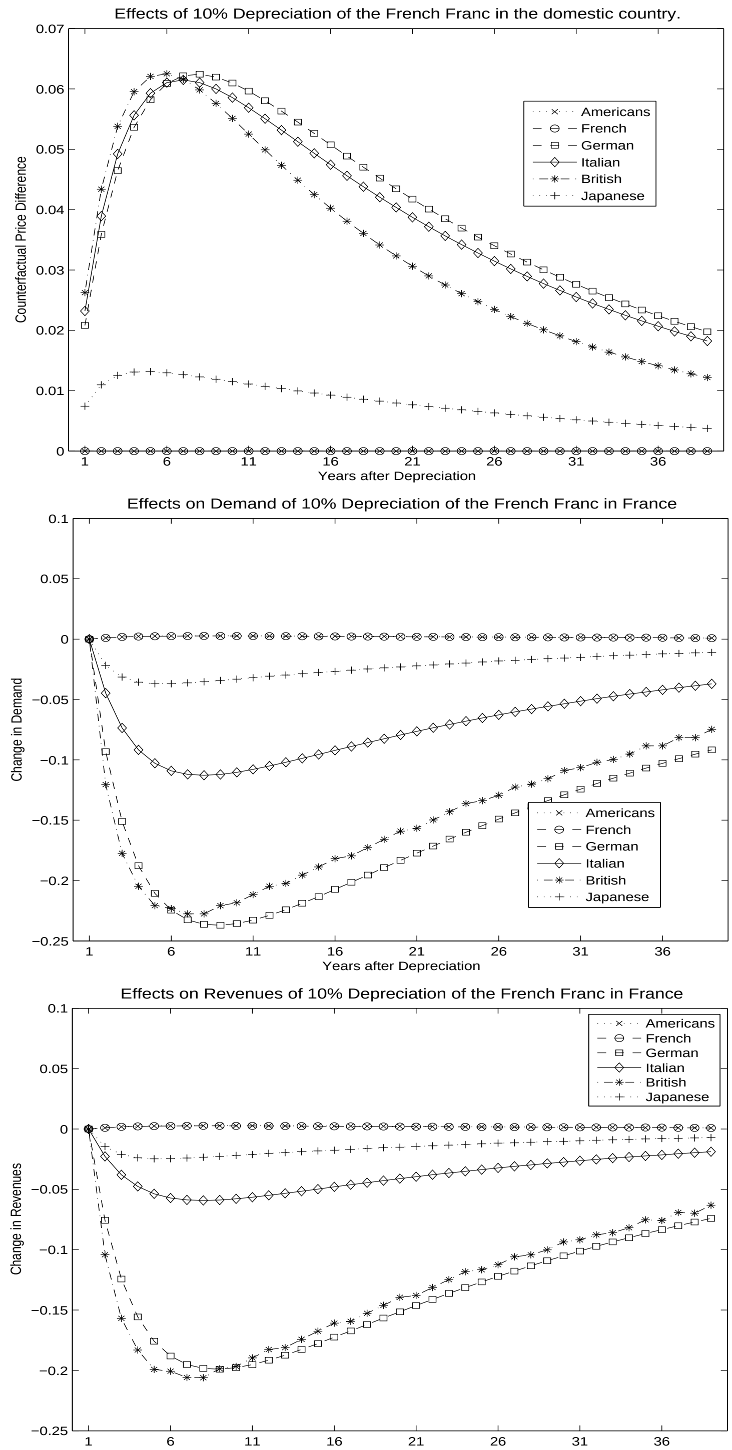


Figure 13: **Price, Demand and Revenues in Germany after a 10% depreciation of the German Mark**

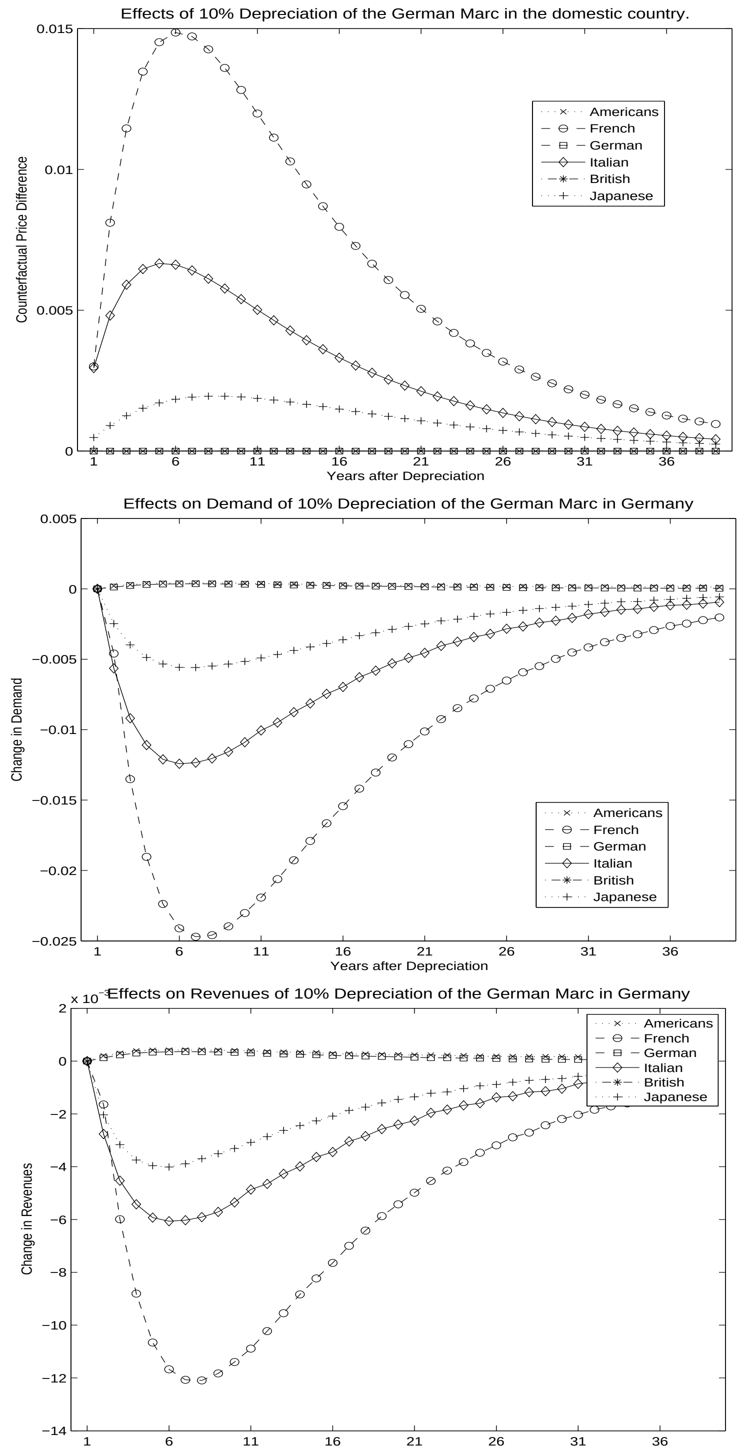


Figure 14: **Price, Demand and Revenues in Italy after a 10% depreciation of the Italian Lire**

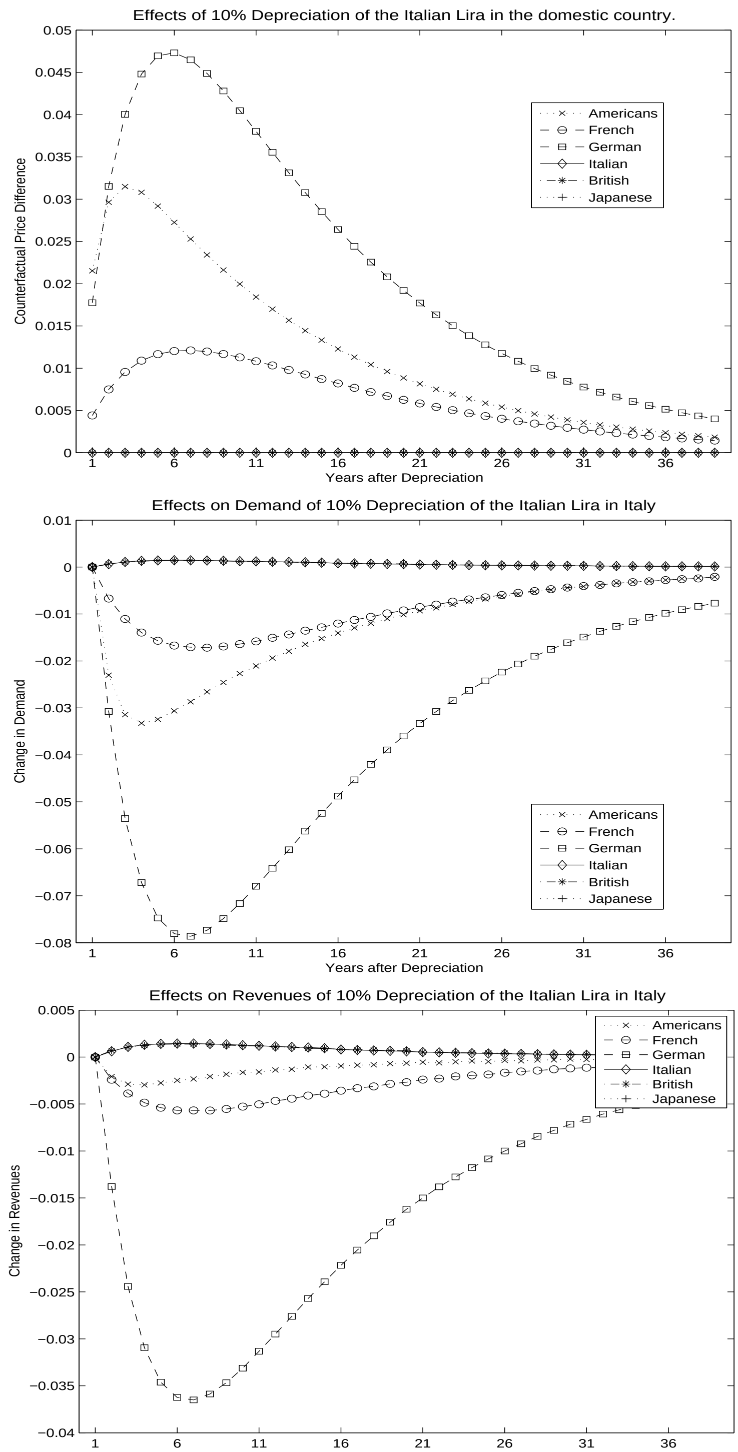
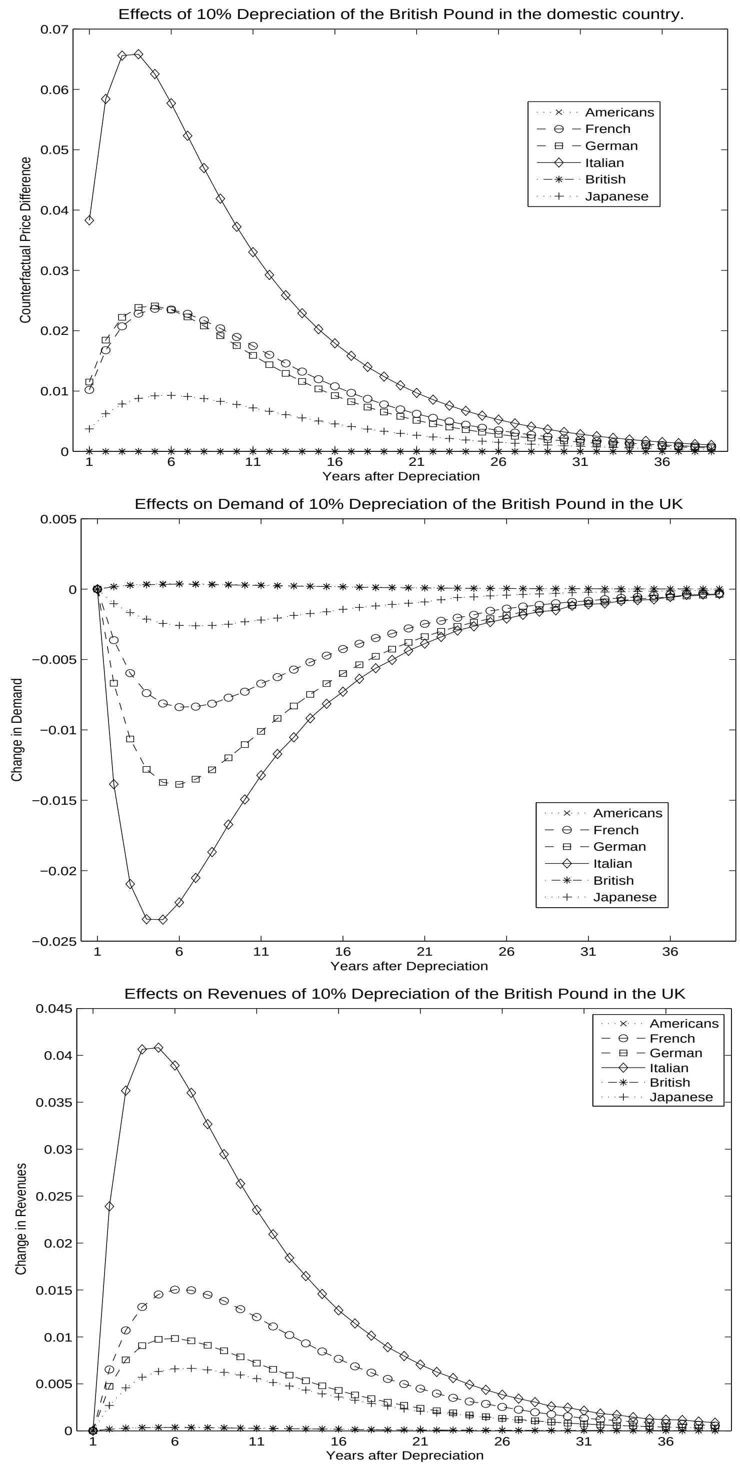


Figure 15: **Price, Demand and Revenues in the UK after a 10% depreciation of the British Pound**



F Alternative Price Adjustment Cost Function

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

$$\widetilde{AC}_t^f = \sum_m \sum_{j \in \mathcal{F}_{fm}} \Psi^{fm} \cdot |\log(p_{jt}^{fm}) - \log(p_{jt-1}^{fm})|$$

The following tables replicate the results of Tables 2, 4 and 3 using the alternative specification for the price adjustment cost function. The main results still hold, although the rankings or estimates may change.

Table 18: **Cost Components over Total Costs using alternative adjustment cost function**

Exports	Production Costs (1)	Distribution Costs (2)	Price Adj. Costs (3)
Americans	79.81	14.28	5.91
French	75.51	23.31	1.17
Germans	78.75	21.18	0.06
Italians	20.69	66.38	12.93
Japanese	59.75	26.99	13.26
Sold Domestically			
Americans	99.97	-	0.03
French	97.19	-	2.81
Germans	100.00	-	1e-9
Italians	90.37	-	9.63

Notes: The table presents the different cost components over total costs as in Equations (22), (23) and (24) for the models available in the European markets in 1985. Destination market component is for exported cars only. Due to small sample issues, we have no cost estimates for British models.

Table 19: **Cost Share of Price Adjustment Costs by Destination Market using alternative adjustment cost function**

	Belgium	France	Germany	Italy	UK
Americans	7.2	0.1	1e-04	9.3	1e-04
French	3.4	2.1	1e-04	0.4	0.5
Germans	1e-04	1e-04	1e-04	0.1	1e-04
Italians	18.8	10.6	8.6	9.6	3.5
Japanese	19.3	1e-04	4.1	-	20.2

Notes: We compute the share of price adjustment cost as in Equation (24) for each market separately. No Japanese model sold in Italy is included in our simulations.

Table 20: **Ratio of Adjustment Cost Parameters, Ψ^{fm}/Ψ^{ff}, using alternative adjustment cost function**

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

Notes: Each cost adjustment coefficient, Ψ^{fm}, is normalized by the home-country price adjustment coefficient, Ψ^{ff}. We express the coefficient of American models relative to the coefficient in Germany, and those of the Japanese models relative to coefficient in Germany. No Japanese model sold in Italy is included in our simulations.

ONLINE APPENDIX (not for publication)

A Car characteristics and entry/exit in the European auto industry

This Appendix section presents the dynamics of car characteristics and the entry and exit of models in the European auto industry. We abstract from the dynamics of the car characteristics based on the lack of evidence that model or characteristics are chosen in this industry to smooth prices. For instance, we could face an endogenous market configuration if, for instance, large fluctuations in exchange rates cause entry or exits of certain models or firms (Rodríguez-López (2011)).

Any attempt to include this endogeneity in the forward simulations would require a theoretical model able to forecast market configurations at each time period, ie, the new characteristics of the new models, the identity of the surviving incumbent models, and the identity of the exiting models at each time period. We prefer tractability over such a complex empirical model for the several characteristics and models in the auto industry.

We have no evidence suggesting that manufacturers choose car characteristics or models to smooth prices. Instead, recent literature has suggested that the determinants of innovations in the automobile industry is mainly driven by regulations or other long-run strategies (Klier and Linn (2012), Blonigen, Knittel, and Soderbery (2013), Knittel (2011), Hashmi and Van Biesebroeck (2016)). Figures 16, 17, and 18 presents the evolution of the size, inverse of motor power and fuel efficiency of the car models in Europe. Some characteristics like fuel efficiency seems to follow certain regulations, while others (like size and motor power) seemed increasing over time.

Furthermore, although none of previous empirical papers in the car industry have found evidence on this potential endogeneity, we argue that new firms and the new models are a relative small share of the market. The average percentage of the new firms is relatively low, with small firms being absorbed by bigger players. The percentage of the new firms across the 30 years is less than 7% and the average percentage of the new models close to 5%. Weighted by market shares, the relevance of the new firms is even lower. Figure 19 presents the evolution of the percentage of the new firms while Figure 20 shows the percentage of the new models across the 30 years.

Figure 16: **Car size by country**

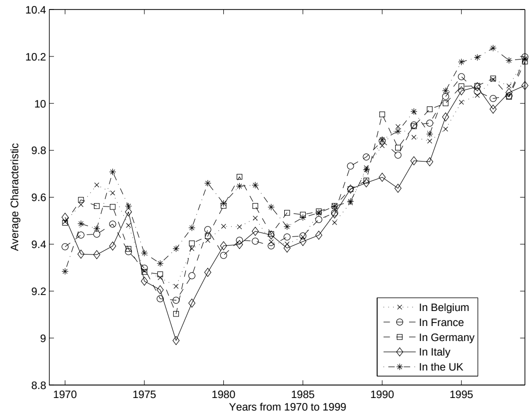


Figure 17: **Inverse of Motor Power by country**

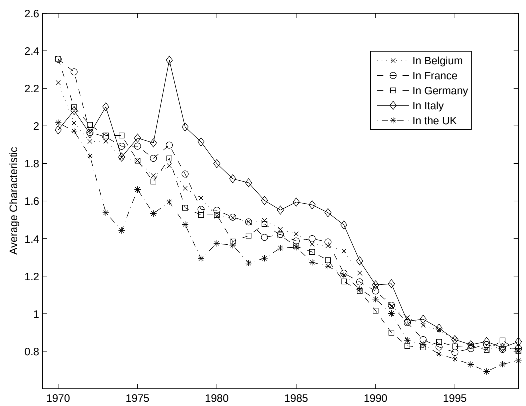


Figure 18: **Fuel Efficiency by country**

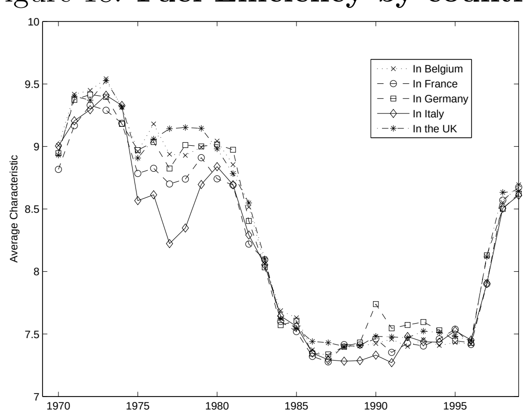


Figure 19: **Percentage of new firms by country**

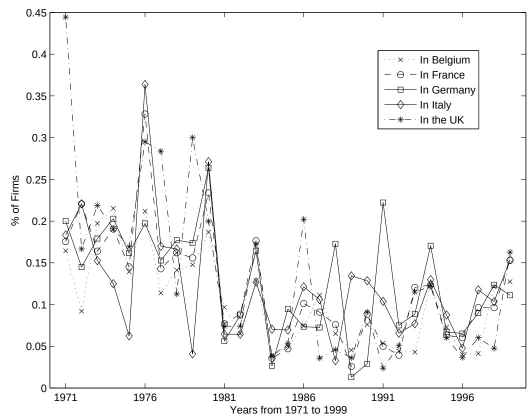
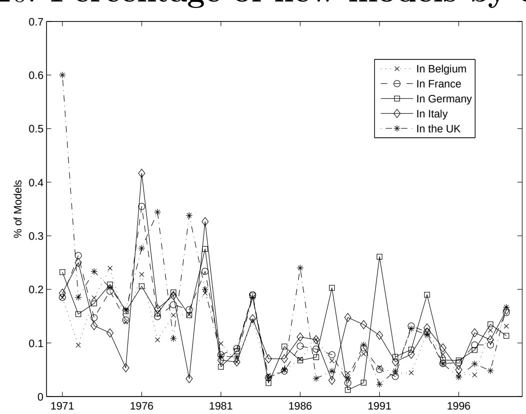


Figure 20: **Percentage of new models by country**



B Impulse Response Exercise for Domestic Wage Increase

This appendix presents the impulse response exercises of a 10 percent increase in each of the considered European wages as explained in section 4.3.

Figure 21: **Price Reactions across Europe after a 10% increase in French wages**

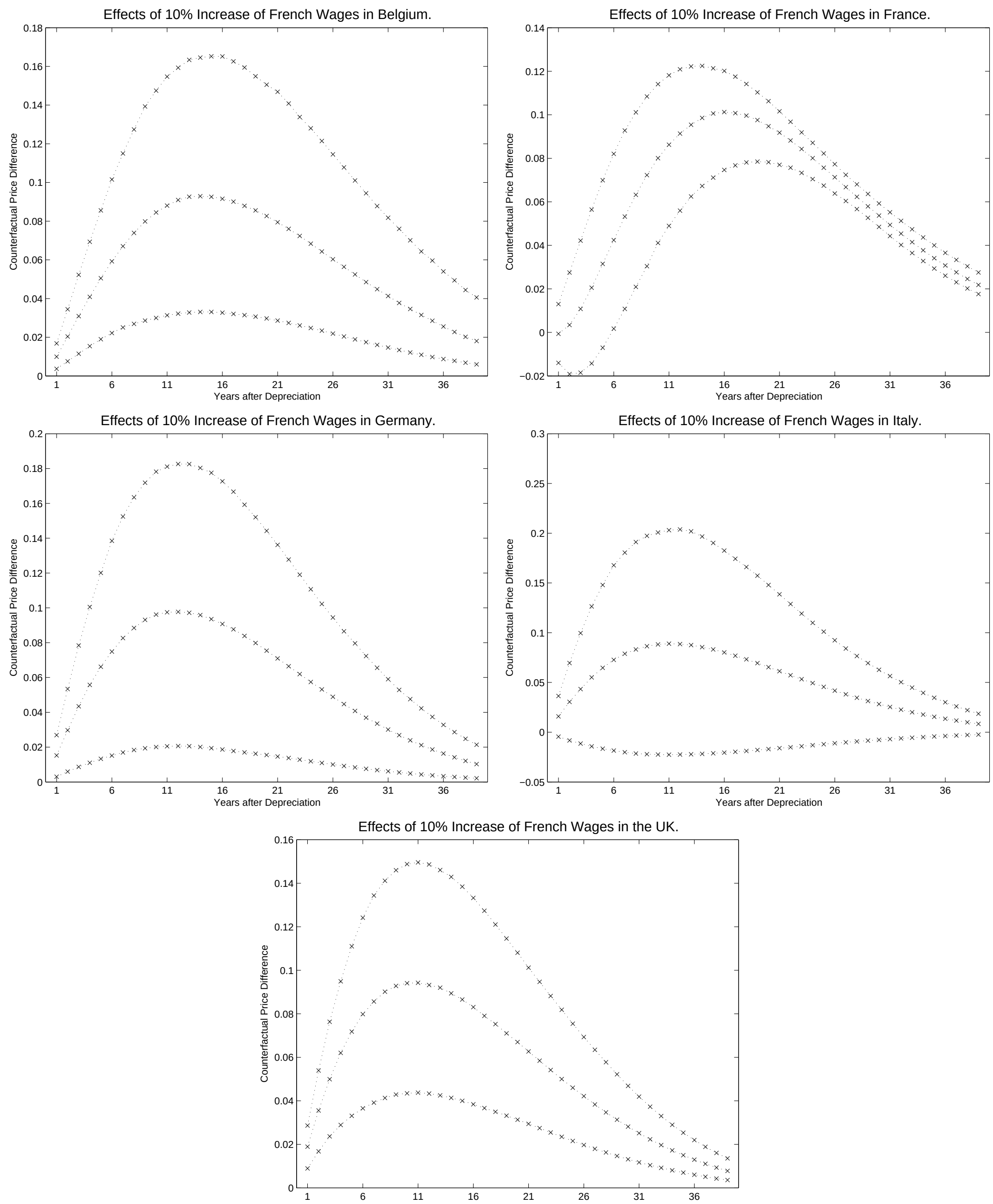


Figure 22: **Price Reactions across Europe after a 10% increase in German wages**

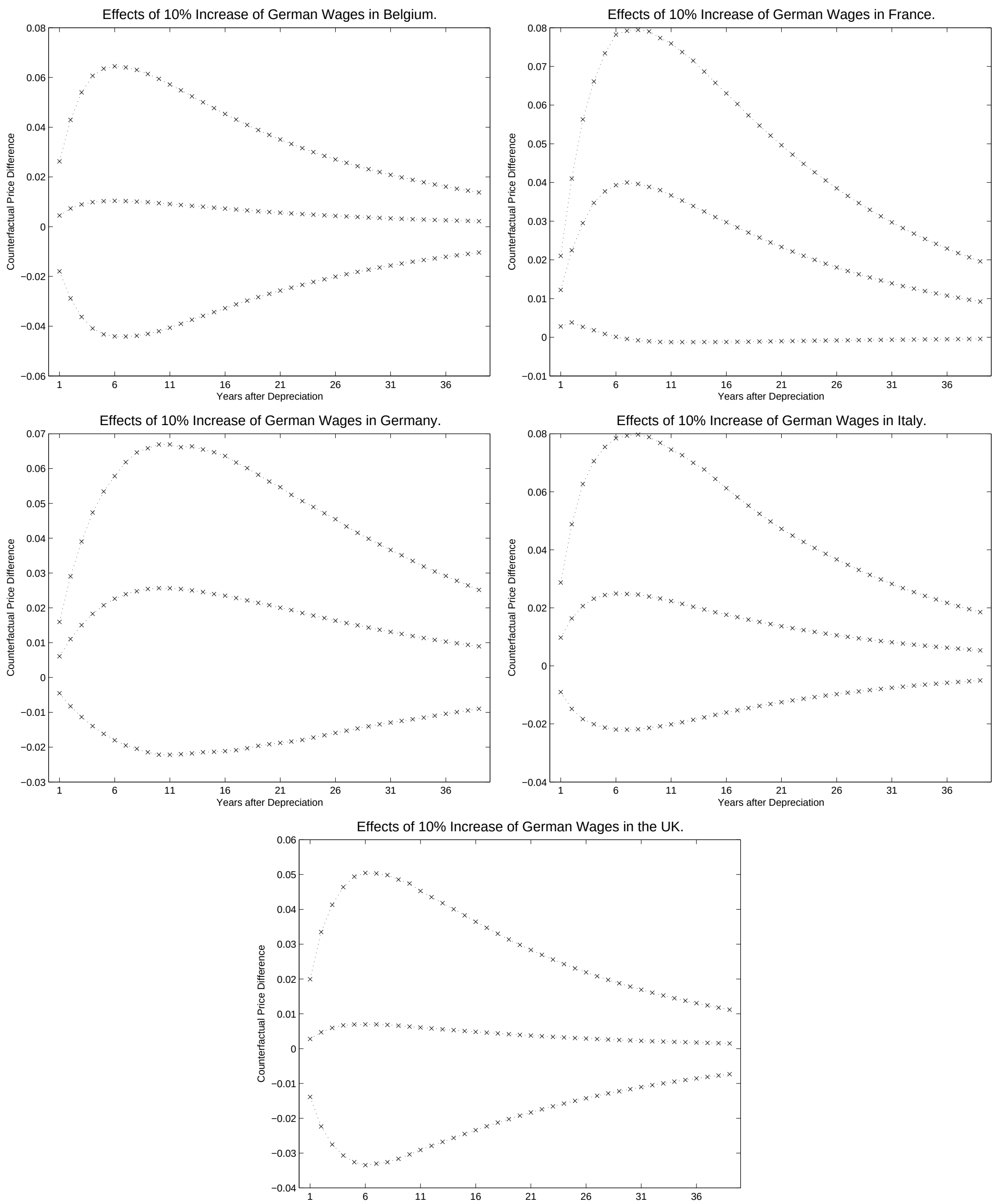


Figure 23: **Price Reactions across Europe after a 10% increase in Italian wages**

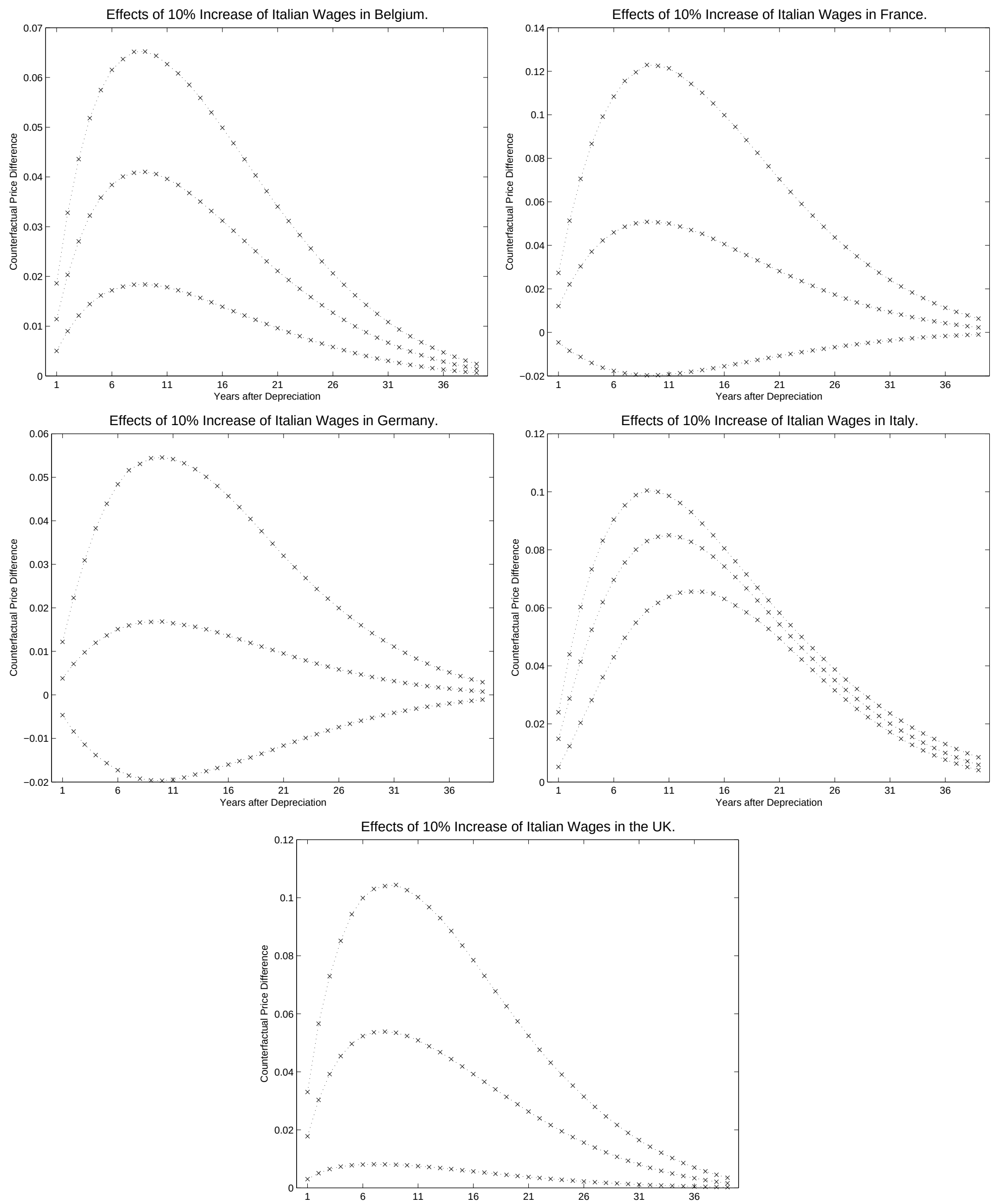


Figure 24: **Price Reactions across Europe after a 10% increase in British wages**

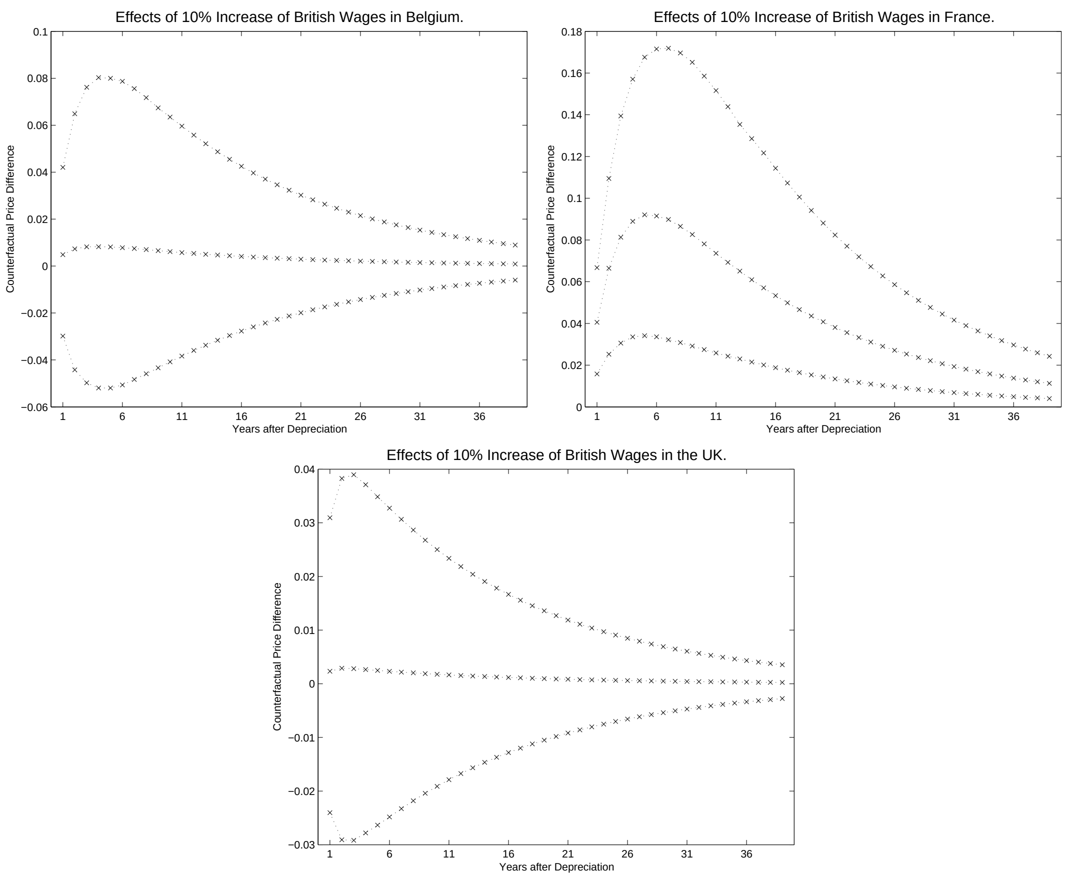
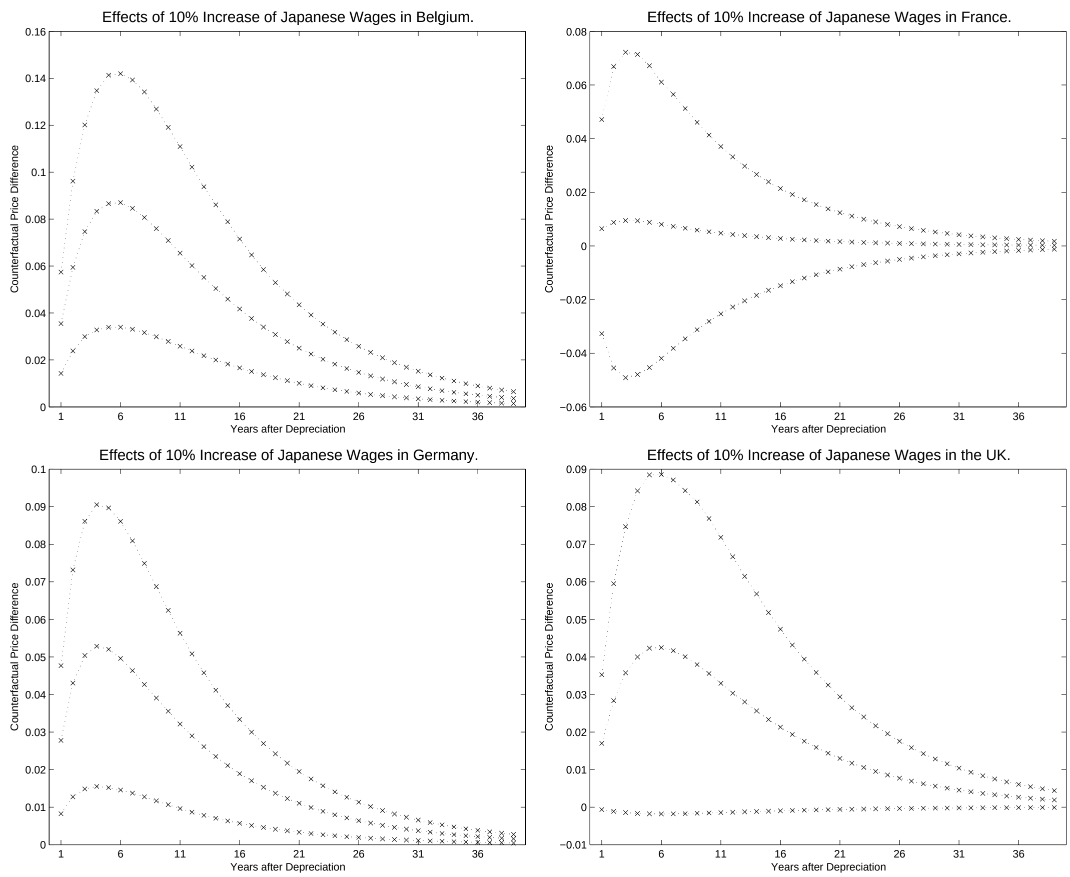


Figure 25: **Price Reactions across Europe after a 10% increase in Japanese wages**

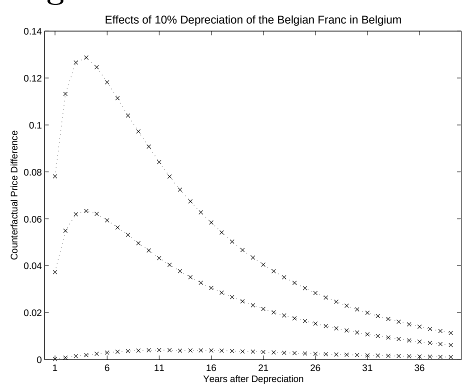


C Confidence Intervals for Policy Functions

This appendix presents the confidence intervals for the impulse-response exercises. The figures present bootstrapping exercises for each price panel and show both international effects of domestic depreciation on domestic producers and the domestic effects of domestic depreciation on foreign producers.[28]

C.1 Confidence Interval for the International Effect of Domestic Depreciation

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



[28]Recall that there were no British cars in Germany and that American cars were made in Germany. Neither British nor Japanese cars were sold in Italy and American cars were made in the UK.

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

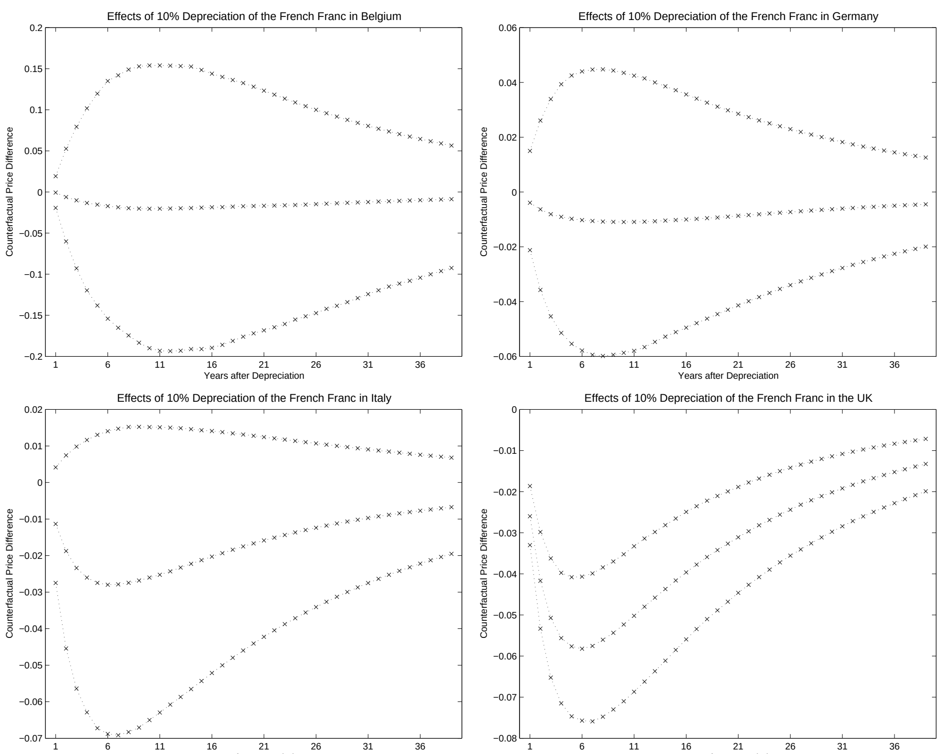


Figure 28: **Confidence Interval for Price reactions in Europe after a 10% depreciation of the German Mark**

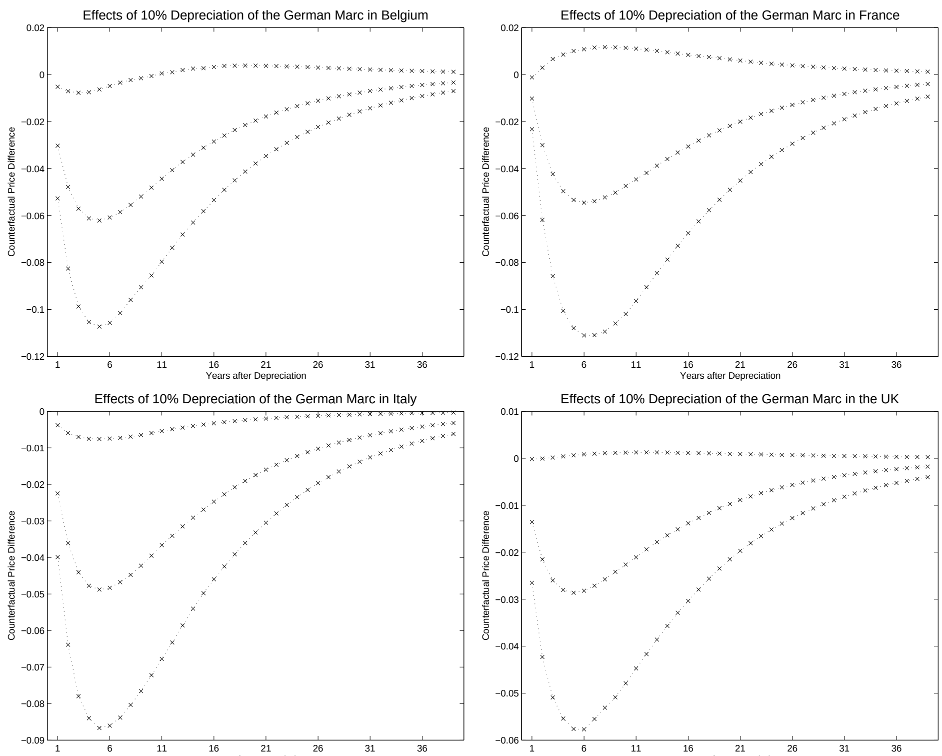


Figure 29: **Confidence Interval for Price reactions in Europe after a 10% depreciation of the Italian Lire**

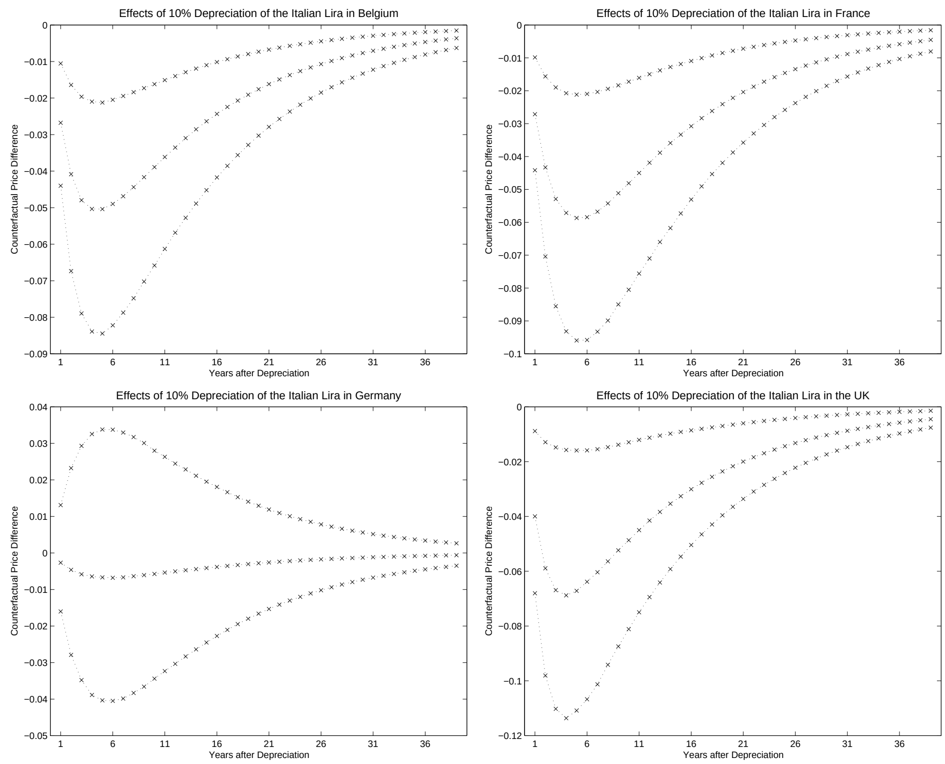


Figure 30: **Confidence Interval for Price reactions in Europe after a 10% depreciation of the British Pound**

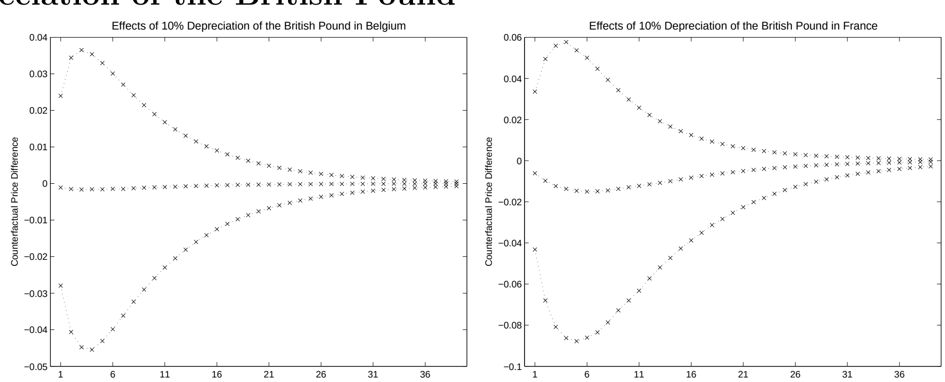
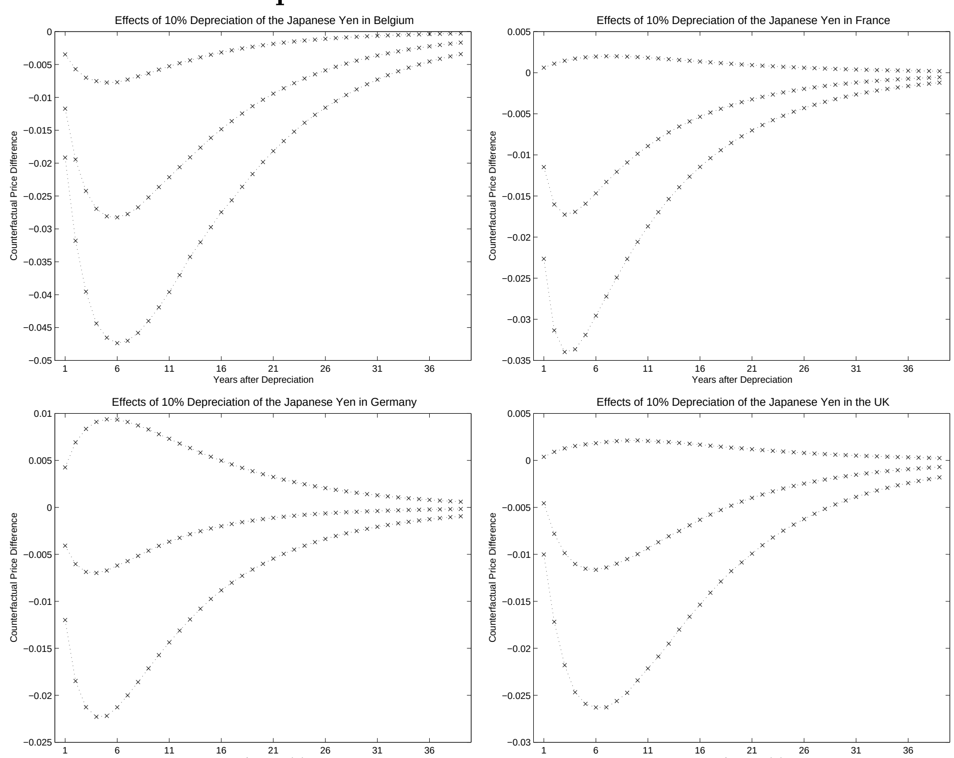


Figure 31: **Confidence Interval for Price reactions in Europe after a 10% depreciation of the Japanese Yen**



C.2 Confidence Interval for the Domestic Effect of Domestic Depreciation

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

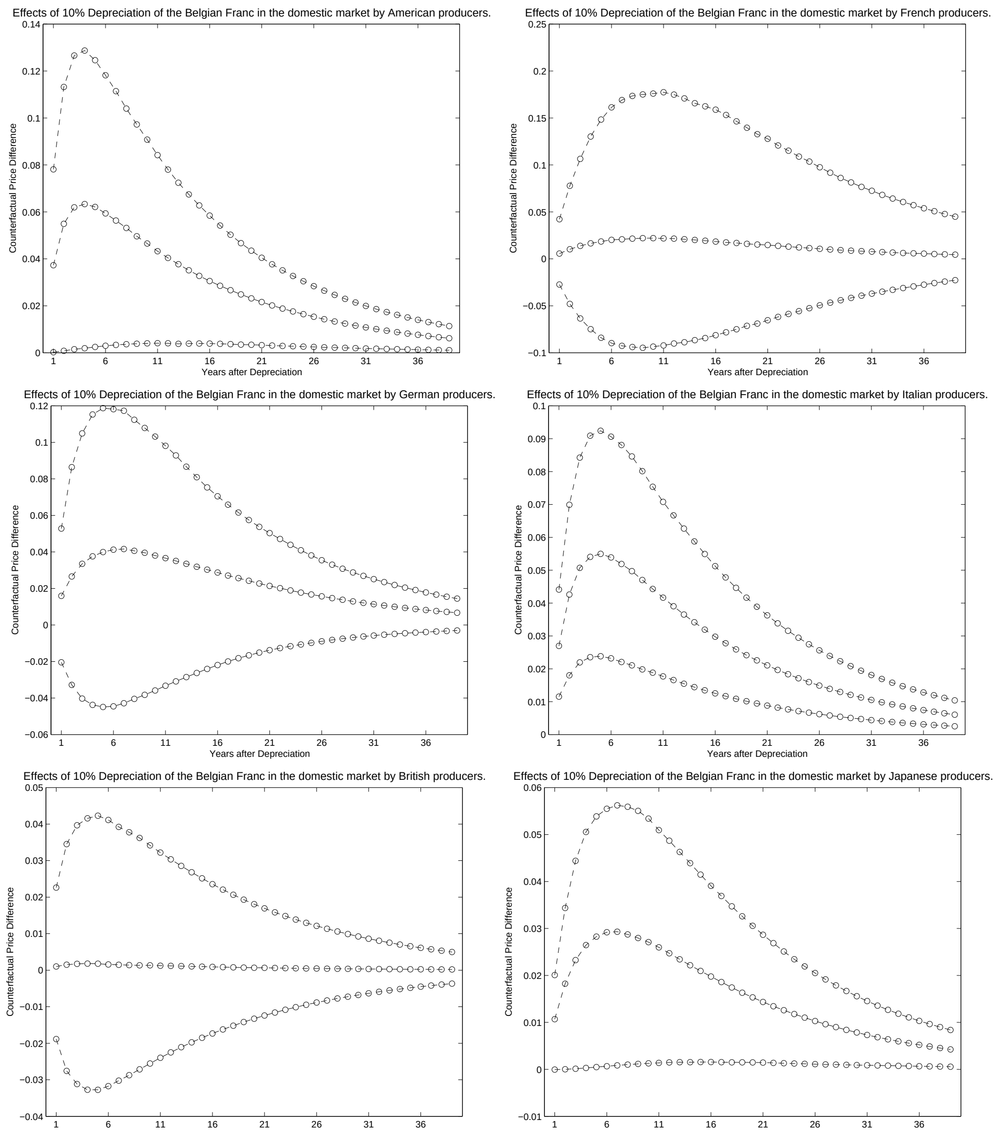


Figure 33: **Confidence Interval for Price Reactions in France after a 10% depreciation of the French Franc**

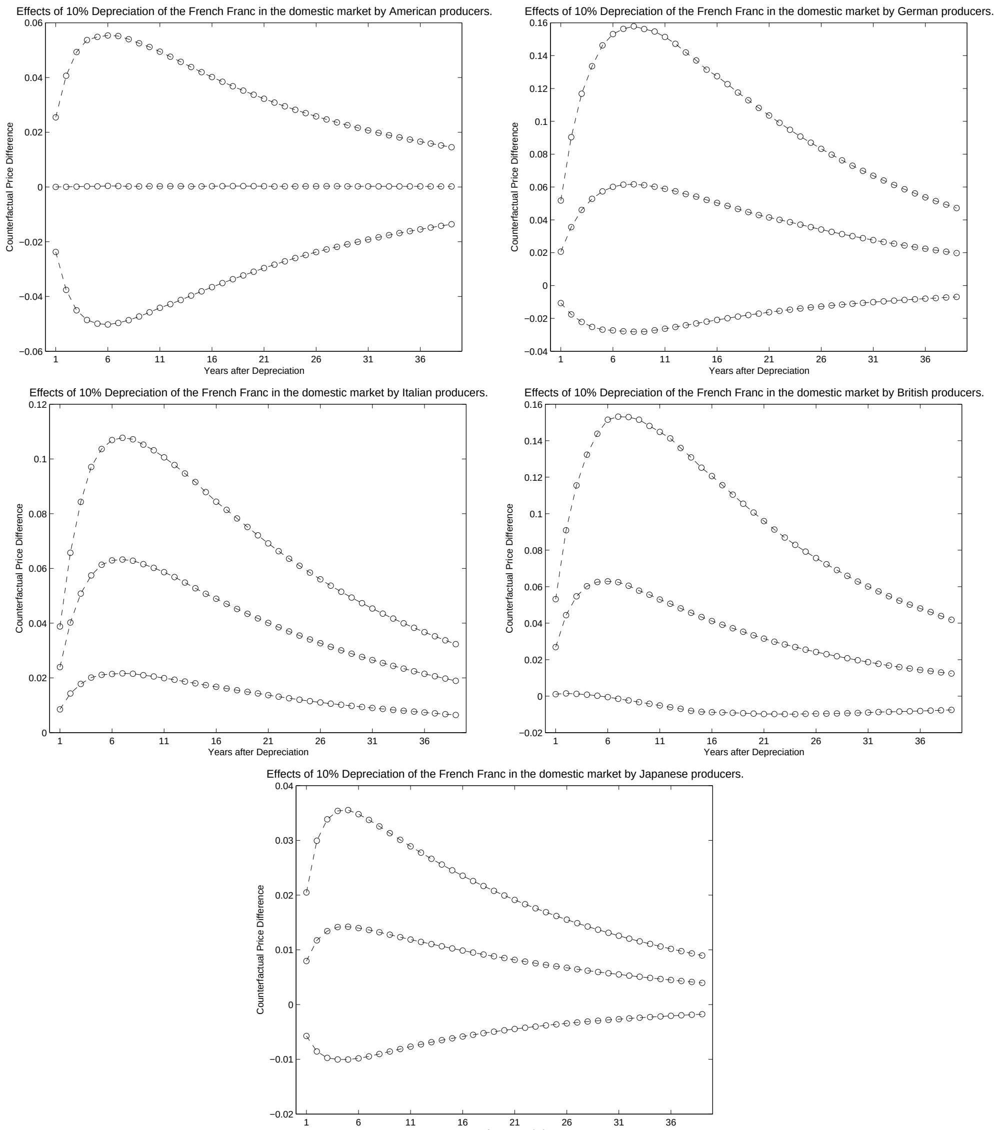


Figure 34: **Confidence Interval for Price Reactions in Germany after a 10% depreciation of the German Mark**

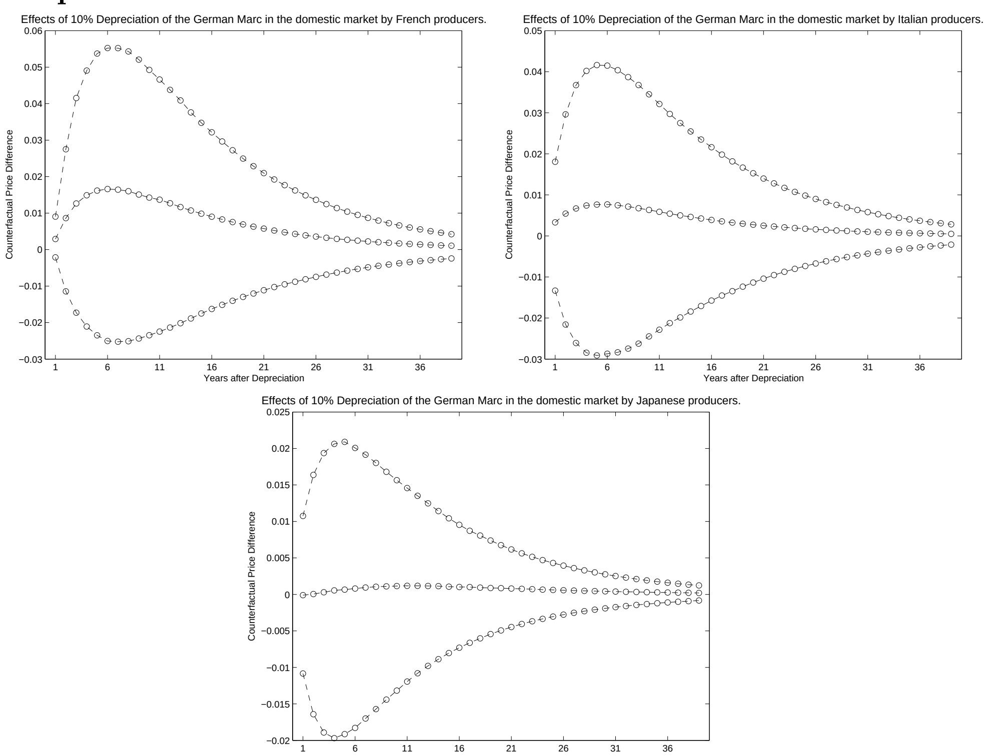


Figure 35: **Confidence Interval for Price Reactions in Italy after a 10% depreciation of the Italian Lire**

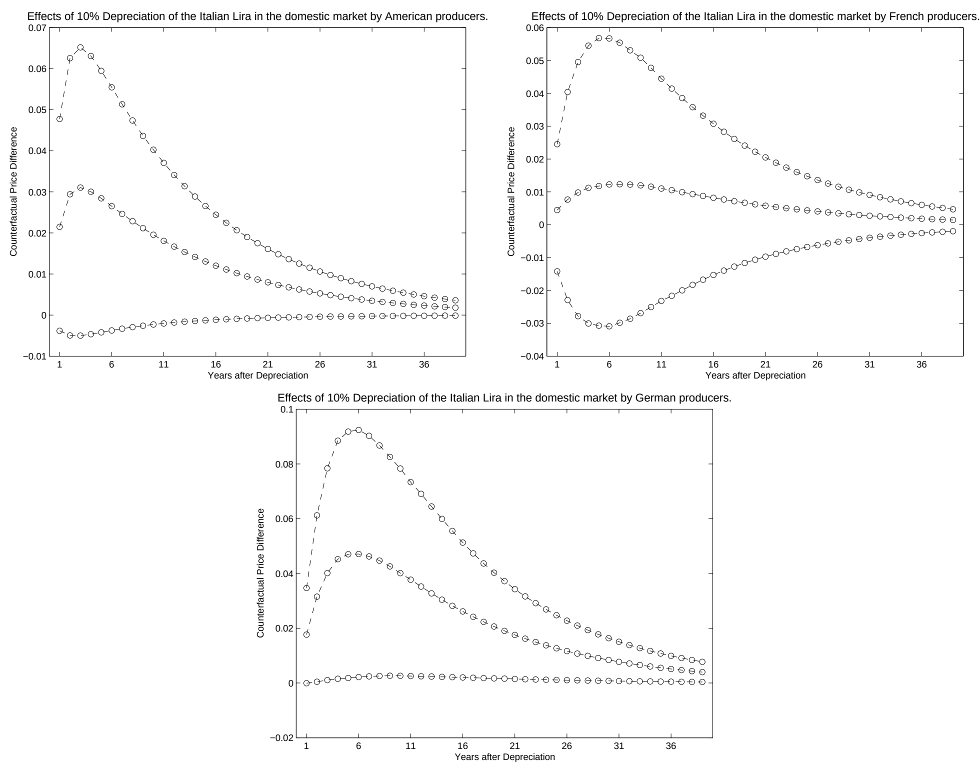


Figure 36: **Confidence Interval for Price Reactions in the UK after a 10% depreciation of the British Pound**