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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. Using the methodology developed by Bajari, Benkard, and Levin (2007), I estimate a dynamic model of international multiproduct firms that set prices in different currencies while facing price adjustment costs. There are three main results. First, the incomplete degree of exchange rate pass-through can be explained by a sizable destination-currency cost component. Second, large price adjustment costs are not needed to rationalize the large degree of price inertia in a highly autocorrelated economic environment. In fact, small adjustment costs can rationalize the persistent prices observed. Third, the paper identifies an unexplored temporal dimension of "pricing-to-market" behavior, that is the practice of setting prices differently across segmented markets. Estimates of the price adjustment cost suggest that a uniform cost structure is not consistent with the pricing behavior observed.

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

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1 Introduction

The overwhelming evidence that prices are autocorrelated is consistent with two hypotheses. The first is that intrinsic price rigidity is caused by a costly adjustment. The second is that the autocorrelated economic environment is the source of the rigidity 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 firms. The main contribution of this paper is to empirically characterize price adjustment costs while accounting for the heterogeneous and persistent environment that we live in.

This paper focuses on international traders who set prices in multiple currencies and face different environments in each market. These market-specific scenarios are driven by nominal exchange rates and wages, and both series are very persistent over time. How firms set prices in these international environments determines the degree and dynamics of exchange rate pass-through.[1] A vast literature in exchange rate pass-through strongly supports two stylized facts for differentiated goods: 1) there is an incomplete degree of pass-through and 2) there is a persistent delay in the price response.[2]

The first stylized fact of incomplete pass-through rules out models of constant markups and is consistent with the "pricing-to-market" (henceforth PTM) behavior coined by Krugman (1987). PTM allows for price discrimination based on the currency and the segmented market where the transaction takes place. Another explanation for the incomplete degree of exchange rate pass-through is based on the idea of local cost components as in Burstein, Neves, and Rebelo (2003). Local cost components are expressed in destination-market currency, and therefore are not affected by exchange rate fluctuations. This fact implies that prices are not one-to-one related with production costs, explaining incomplete exchange rate pass-through.

The second stylized fact leads us to dynamic pricing because the delays in response may imply deviations of prices from their static optimum. Most empirical work has used time series and panel data reduced forms to shed light on price dynamics.

To gain a deeper understanding of these stylized facts, some empirical literature has moved from reduced forms to structural estimations. Such an econometric approach allows us to estimate the deep parameters of the respective model. Goldberg (1995), Verboven (1996), and Goldberg

[1] Formally, exchange rate pass-through is the percentage change in local currency import prices resulting from a one percent change in the exchange rate between the exporting and importing countries. Zero pass-through refers to the case when prices are insensitive to exchange rate fluctuations, and full pass-through when prices change one to one with exchange rates.

[2] See Goldberg and Knetter (1997).

and Verboven (2001) have estimated structural models of differentiated products in the automobile market. I use the European car dataset of Brenkers and Verboven (2006).[3] The dataset fits nicely into this study for two reasons. First, the car industry is the perfect example of a stable oligopoly of differentiated products in segmented markets. Second, several currencies had large and persistent changes in relative prices, ensuring a proper exogenous source of variation to study exchange rate pass-through.

Goldberg and Hellerstein (2007) and Nakamura and Zerom (2010) also structurally estimate price adjustment costs. Goldberg and Hellerstein (2007) use a static framework to derive bounds of menu costs in the US beer industry. In their model, prices are adjusted only when the gap between the optimal and current price reaches a threshold; otherwise, prices remain unchanged. The authors argue that firms follow the static first order conditions to set new prices because the key variables in their environment follow random walks. However, such an approach would fail to capture the dynamic pricing that takes place when firms perceive shocks as transitory. In fact, during the time period analyzed in this study, there are several fluctuations in European exchange rates that firms may have perceived as transitory shocks. Thus, a dynamic model is required.

Nakamura and Zerom (2010) solve a fully dynamic model to estimate menu costs in the US coffee industry. Given the computational difficulties of this approach, they are able to estimate the model under two main simplifications. First, their marginal cost is just a function of the product-specific constant and the observed commodity price of raw coffee. Second, the model only considers a representative market. Applied to the European car market, this approach would miss important features like market heterogeneity and the complex cost structure of the automobile industry.

This paper aims to overcome some of the limitations of the previous literature by using a methodology that allows for a model of price adjustment costs in a dynamic framework. I use the methodology developed by Bajari, Benkard, and Levin (2007) (henceforth BBL). Applied to price adjustment cost estimation, BBL follow the intuitive idea of finding a cost structure consistent with observed pricing behavior.

The main advantage is that BBL allow us to estimate the structural cost function without solving the game. In the first stage we estimate the transition probabilities of the state variables and the policy functions. The second stage identifies the structural parameters that rationalize the first stage estimates. Thus, BBL structural estimates minimize profitable deviations; equivalently, BBL estimates support observed pricing behavior as optimal. Using this technique I am able to characterize the price adjustment costs consistent with the actual inter-temporal profile of prices.

[3]The dataset includes Belgium, France, Germany, Italy, and the United Kingdom. The dataset includes 47 international multiproduct firms for the period 1970-1999.

Taking into account all the heterogeneity found in the first stage, there are three main results of the structural cost estimates. First, I rationalize the incomplete degree of pass-through by a destination-currency cost that corresponds to a third of the total costs. This result is consistent with the hypothesis of Burstein, Neves, and Rebelo (2003) also found by Goldberg and Verboven (2001). Second, I find that there is no need for large price adjustment costs to rationalize the large degree of inertia in prices. 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. My estimates show that less than 10 percent of total costs can generate the actual autocorrelation of car prices. Third, I find that estimates of the price adjustment cost seem to be producer-destination market specific. A uniform cost structure is not consistent with the observed timing of pricing behavior captured through the estimated policy functions and transition probabilities, even after controlling for their outstanding heterogeneity. Thus, I find heterogeneity in the temporal dimension of pricing-to-market, which has not been explored before.

Section 2 presents the dynamic game considered in the European car market, section 3 presents the data, section 4 presents the results of the estimation and section 5 concludes and present potential extensions.

2 Model

This section presents the dynamic game of international manufacturers who set prices in multiple currencies while facing price adjustment costs. Subsection 2.1 introduces the dynamic game, defining the players, payoff functions, information sets, and control and state variables. To close the model, Subsection 2.2 presents the static demand system for differentiated products.

2.1 A Dynamic Game of Multi-currency Pricing under Price Adjustment Costs.

The players of the game are car manufacturers aggregated in F nationalities indexed by $f \in \{1, .., F\}$. I assume that firms from a given country follow the same pricing behavior. This aggregation is not an assumption on the degree of competition.

All the players sell in M segmented markets indexed by $m \in \{1, .., M\}$. Each multiproduct firm f offers a subset $\mathcal{F}_{fm}$ of the J_m car models available in each destination market $m \in \{1, .., M\}$.

The control variable (or action) of player f is the vector of nominal prices. Denote prices of player f in market m at time t by $\{p_{jt}^{fm}\}, \forall j \in \mathcal{F}_{fm}$.

Thus, prices in market m are 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.

The players choose their actions based on the relevant economic environment, which is summarized in the vector of state variables, $\mathbf{s}_t$. For instance, $\mathbf{s}_t$ includes nominal exchange rates, characteristics of the car models, nominal wages, and nominal GDP per capita. Section 4 discusses the economic rationale of each state variable.

Most state variables $\mathbf{s}_t$ are public information; however, in principle, the model allows for private states or private information, such as productivity or demand shocks.

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

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

where firm-specific parameters ν_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:

$$\pi(\mathbf{p}_t, \mathbf{s}_t; \nu_f) \equiv R_{ft} - C_{ft} - AC_{ft} \tag{2}$$

where R_{ft} are the revenues, and C_{ft} are the production costs. A key ingredient is the cost of price adjustment, AC_{ft}, which is a penalty associated with price changes. Consequently, agents engage in dynamic pricing because undoing past decisions is costly. I discuss the three terms in detail.

The revenues, R_{ft}, include amounts of domestic and foreign currencies because firm f produces for both domestic and foreign markets. The aggregated revenues across markets, expressed in f's currency, are as follows:

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

where e_{fmt} is the exchange rate required to convert revenues from the currency in market m to firm 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 on state variables $\mathbf{s}_t$.[4]

The second term in the profit function is the production cost, C_{ft}. I assume that production occurs domestically, and that there is no offshoring.[5]

[4] Subsection 2.2 presents the relevant state variables in the demand. The empirical implementation accounts for tax considerations that are not explicit in the model.

[5] There is some data on car models produced outside the country in which a firm's headquarters are located. Unfortunately, there are too few observations for a reliable empirical estimation.

Thus, production costs are expressed in domestic currency only.

$$C_{ft} = \sum_{m} \sum_{j \in \mathcal{F}_{fm}} C_{jt}^{fm}(\mathbf{s}_t, q_{jt}^{fm}; \nu_f) \tag{4}$$

The production costs depend on model-specific quantities and on state variables such as wages. These static marginal costs will consider fixed car characteristics (model fixed effect) and quadratic terms of domestic and destination-market wages. Section 4 discusses in detail the state variables and the functional form of the production costs.

Finally, let us turn to the price adjustment cost term. Persistent prices are a well-established fact at the micro level, especially for differentiated products like cars. As evidence 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.

In this paper, price adjustment costs are the monetary penalties that rationalize the persistent pricing by producers. This definition includes not only the actual costs but also the cost of strategic decisions of the firms. An example of actual costs is the time and effort spent by management to determine the new optimal price. An example of the cost of strategic decisions is the money that firms are willing to forego by having persistent prices that enhance brand reputation (Krugman (1987)).

Clearly, a firm's price adjustment policy is a strategic decision based on a broad range of frictions and costs. This paper cannot identify the particular source or nature of measured frictions on the supply side. However, its main contribution is to empirically characterize the price adjustment costs that are consistent with pricing behavior in the face of ongoing uncertainty, and in heterogeneous and persistent economic environments.

Supporting the modeling in this paper, Zbaracki, Ritson, Levy, Dutta, and Bergen (2004) provide direct evidence of managerial costs of price adjustment for a large manufacturing firm, including costs of gathering information, costs of managerial decision on the price, and the cost of communicating to different members of the firm. Quantitatively, they show that the managerial costs are more than six times the physical costs associated with changing prices.

Price adjustment costs are modeled as partial adjustment terms that are proportional to the magnitude of the price change.[6] Zbaracki, Ritson, Levy, Dutta, and Bergen (2004) provide evidence that managerial costs of price adjustment increase with the size of the adjustment because the decision and internal communication costs are higher for larger price changes.[7] Moreover, they show that managerial costs are larger in the context of international pricing. This feature is at the heart of our specification since

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

[7] Similar arguments can be found in Levy, Bergen, Dutta, and Venable (1997).

larger price adjustments require more resources. Notice that none of the considered adjustment costs affect marginal costs of production.

In line with empirical patterns of European car prices, the partial adjustment specification predicts smooth changes over time. Instead, menu-cost model, however, implies a step function pattern: lumpy adjustments followed by a constant level for some periods. The prices in the data do not show this pattern. Thus, this paper does not consider standard menu costs.

The first specification of price adjustment costs, AC_{ft}, considers a penalty proportional to the price difference in levels:

$$AC_{ft} = \sum_{m} \sum_{j \in \mathcal{F}_{fm}} \Psi_{fm} \cdot e_{fmt} \cdot |p_{jt}^{fm} - p_{jt-1}^{fm}| \tag{5}$$

where the structural parameters are given by $\Psi_{fm} \subset \nu_f$.

The second specification, $\widetilde{AC}_{ft}$, considers a penalty based on the price difference in percentage terms (or log-difference):[8]

$$\widetilde{AC}_{ft} = \sum_{m} \sum_{j \in \mathcal{F}_{fm}} \Psi_{fm} \cdot |\log(p_{jt}^{fm}) - \log(p_{jt-1}^{fm})| \tag{6}$$

The price difference is computed at the model level, considering the same or consecutive car models. Consecutive models may vary slightly in characteristics over time. Hence, one approach would be to consider quality-adjusted prices. The price persistence for consecutive car models is massive; for simplicity and tractability, I only consider the nominal price change even if other characteristics change. This approach could overestimate price adjustment costs if the change in characteristics plays an important role in the adjustment.

Introducing the price adjustment cost, which links two consecutive periods, makes the model dynamic. Without price adjustment costs, the model is reduced to a repeated static game in which producers do not face future consequences of current actions; this is because undoing an action is absolutely costless. Consequently, in this setting, the lagged price is a payoff-relevant state variable.[9]

Dynamic considerations does not provide a closed formula for markups as found in static models. Optimality conditions to set model j's price is given by:

$$\frac{\partial \pi(\mathbf{p}_t, \mathbf{s}_t; \nu_f)}{\partial p_{jt}} + \frac{\partial}{\partial p_{jt}} \mathbb{E}\left[\sum_{\tau=t+1}^{\infty} \beta_f^{\tau-t} \pi(\mathbf{p}_\tau, \mathbf{s}_\tau; \nu_f) | \mathbf{s}_t\right] = 0 \tag{7}$$

In static models, optimal pricing behavior yields closed solutions since the second term of equation 7 is zero. In fact, standard static approach

[8] Estimations of quadratic price differences yielded poor empirical results.

[9] I assume there is no penalty for setting prices in the first period.

can provide a straight markup rule based on marginal costs and demand parameters. Because the second term of equation 7 is untractable in our dynamic game, we have no closed form policy function which implies that this paper cannot provide a closed formula to compute equilibrium markups.[10] To circumvent this problem, this paper will use an econometric technique that does not require the structural pricing rule to uncover marginal cost of production and price adjustment costs.

A dynamic structural model seems the natural framework to estimate the parameters of the price adjustment cost, Ψ_{fm}. On one hand, the usual dynamic reduced-form estimations cannot identify whether it is the autocorrelated economic environment or the cost structure of the firm that is the source of price rigidity. Reduced forms only capture the net effect of these two forces. On the other hand, static structural models cannot address the intrinsic dynamic nature of these parameters. In fact, existing structural estimations are unable to tackle this dynamic issue because they rely on the static first order conditions of multiproduct firms.

Since this paper considers a static demand function, the root of the price dynamics lies on the supply side. The estimates in this paper can therefore be considered an upper bound for price adjustment costs if the demand side plays a role in the price persistence.[11]

Since this paper focuses on pricing behavior, the theoretical model does not consider entry/exit of firms or car models. An entry/exit analysis requires a framework that can identify incumbent players who exit; it must also identify the entry and location of new firms. Furthermore, the theoretical framework should be able to specify the characteristics of entering and exiting car models. I abstract from these issues and discuss the empirical support for this assumption in appendix C.3.

2.2 Demand Model

This subsection presents the demand for differentiated products that will be used to close the model. The demand system is based on the random coefficient model introduced by BLP (1995). I depart from the nested-logits used previously in this literature to match important features of the European car market. For example, the random coefficient model allows for heterogeneous consumers, and imposes less structure on the decision nest.[12]

For simplicity, this section drops the producer index f that is implicit in the model subscript $j \in \mathcal{F}_{fm}$. Similarly, the time t and market m subscripts are also suppressed.

[10] Under zero adjustment costs we recover static setting since $\frac{\partial \pi_\tau}{\partial p_{jt}} = 0, \forall \tau > t$

[11] For example, Heidhues and Kőszegi (2008) generate persistent prices based on non-classical preferences.

[12] See Wojcik (2000) and Berry and Pakes (2001).

The utility of individual $i = \{1, .., R\}$ from product $j = \{1, .., J_m\}$ is given by:

$$U_{ij} \quad = \quad X_j \alpha_1 - \alpha_{2i} \frac{p_j}{Y} + \gamma h_j + \xi_j + \varepsilon_{ij} \tag{8}$$

where X_j is a k-dimensional row vector of observable characteristics; $\frac{p_j}{Y}$ is the real price of the car model given by the ratio price-GDP per capita; and h_j is a home bias dummy that is equal to one if car j is sold in the same country as its brand's nationality. ξ_j is a scalar product characteristic that is unobserved by the econometrician, and ε_{ij} is a mean-zero stochastic term.

The vector of characteristics includes size, inverse of motor power, fuel efficiency, besides firm, market-segment, brand, and model dummies. As in Goldberg and Verboven (2001), the price-GDP ratio aims to account for the income and inflation differences between countries.

The European car market features a remarkable "home bias", which is consumers' strong preference for domestic cars. To capture this bias, the demand specifications consider the domestic/foreign distinction as a "utility shifter."[13]

While GDP and the set of car characteristics are common knowledge, the unobservable characteristic, ξ_j, is only known by model j's manufacturer at the moment of pricing. Hence, manufacturers set prices based on public information (like GDP, exchange rates and observable characteristics) and their own ξ_j. [14]

Regarding demand parameters, α_1 is a vector of taste coefficients, and α_{2i} is consumer i's marginal utility of income. The distribution of the idiosyncratic parameter is given by $\alpha_{2i} = \alpha_2 + \sigma_p v_i$, where shock v_i has a standard normal distribution, and captures unobservable consumer heterogeneity. The parameters α_2 and σ_p captures the mean and standard deviation of the marginal utility of income among the population. Note that the marginal utility parameter varies across consumers but not across products for a given individual.[15]

Under the standard assumption that ε_{ij} is i.i.d. with a Type I extreme value distribution, we have a closed form for the individual probability s_{ij}. Integrating over the mass of consumers who prefer product j, say A_j, we

[13]This paper account for home bias but cannot trace the sources of such behavior. γ can capture a variety of causes like "nationalism," network quality (cheaper spare parts or repair service), brand loyalty (as in Train and Winston (2007)), or any combination of the above.

[14]The car model characteristics, X_j, include fixed effects per producer, brand, and model (when possible); therefore the unobservable characteristic, ξ_j, is not correlated with those features.

[15]Linearity is usually assumed to reduce the complexity of the computational optimization routine. Although alternative specifications (such as $\alpha_{2i} = \alpha_2(1 + \sigma_p v_i)$) could provide richer insights, they create non-linearities in the optimization that are difficult to overcome.

derive the predicted market share, s_j:

$$s_j(\mathbf{X}, \mathbf{p}, Y, \xi; \theta) = \int_{A_j} \frac{\exp(X_j\alpha_1 - \alpha_2 \frac{p_j}{Y} + \xi_j - \frac{p_j}{Y}\sigma_p v_i)}{1 + \sum_h \exp(X_h\alpha_1 - \alpha_2 \frac{p_h}{Y} + \xi_h - \frac{p_j}{Y}\sigma_p v_i)} d\Phi(v_i) \quad (9)$$

where $\theta = (\alpha_1, \alpha_2, \sigma_p)$ is the vector of demand parameters to be estimated. As standard in the literature, the non-analytical integral over the individual shocks v_i will be computed through simulations.

Naturally, the estimator will minimize the difference between actual and predicted market shares, where ξ acts as the unobservable residual. Additionally, there is an endogeneity issue because ξ_j is correlated with p_j. Thus, I use the set of instruments suggested by BLP (1995). See the companion paper Noton (2010) for details on the method of moments (GMM) used in this demand estimation.

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).[16]

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: the final prices suggested by manufacturers to retailers. 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 dataset also tracks the brand, firm, place of production, model, and segment.[17]

Since many of the car features are nearly collinear, I 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 trends of these three characteristics in the five destination markets are in appendix C.1, in figures 5, 6, and 7, respectively. Size and Motor power have some linear trend while fuel efficiency seems to be less systematic.

[16] The updated data is generously available on the authors' webpages.

[17] The car segments are compact, subcompact, standard, intermediate, and luxury. These characteristics are included as dummies in the demand estimation; hence, the estimation allows for segment differences.

The nationality associated with each car model is fundamental for two reasons. First, to account for home bias on the demand side, I have to identify “domestic” producers. Second, to express all the revenues in a single currency, I must define the relevant currency for each producer. On the demand side, I consider historic brand association for the consumer’s decision. For example, BMW produces its own brand, and since 1994 has also produced the brand Rover-Triumph. I assume that consumers would consider the brand Rover-Triumph a British one, regardless the ownership of the manufacturers. On the supply side, I assume that the location of the firm’s headquarters defines the relevant currency to aggregate profits. In the same example, all BMW revenues are expressed and aggregated in German Marks. Appendix C.2 shows the nationalities associated with each brand (relevant to the demand side) and the nationalities associated with each firm (relevant to the supply side).

4 Methodology and Results

This section presents the methodology and estimates for the European car market. To estimate the dynamic game outlined in section 2, I use the approach developed by Bajari, Benkard, and Levin (2007) (BBL).

Mainly, BBL suggest a two stage procedure. In this particular game, the BBL first stage estimates are: 1) The transition probabilities of state variable, which are the exogenous stochastic processes that predict the distribution of the future economic environment; and 2) The policy functions, which compute optimal prices (up to a white noise) in a given state of the world for each player.

The BBL second stage finds the structural parameters that rationalize the first stage estimates. In short, the second stage is as follows: using the transition probabilities I perform forward simulations for a large number of alternative scenarios and using the policy function I compute their respective prices. For each simulated path, BBL compute each player’s discounted sum of profits using the estimated policy functions. BBL exploit the fact that under the true cost parameters, the same procedure should yield sub-optimal payoffs if using an altered policy function. Consequently, the structural estimates are the cost parameters that minimize profitable deviations, making the observed pricing rule optimal. Using those structural parameters I can characterize production costs, as well as the price adjustment cost that explains the inter-temporal profile we observe.[18]

There are several state variables in this dynamic game. First, the way that revenues are defined in equation 3 implies that nominal exchange rates must be included as state variable of the game. Second, the nominal wages are considered state variables due to their effects on production costs. I

[18]Appendix A provides details on the general framework and estimation of BBL.

assume that the evolution of nominal wages is observable and homogenous within a country.[19]

The BLP demand system provides the endogenous quantity of manufactured cars. I will not cover the dynamics of the car characteristics that are driven by some exogenous technological processes. Instead, the vector of car characteristics is held constant during the forward simulations using model fixed effects. I do include the dynamics of the GDP per capita, which is used as deflator in the demand.

Subsection 4.1 presents the BLP demand estimates. Subsections 4.2 and 4.3 present the estimates of transition probabilities and policy functions, respectively. Finally, subsection 4.4 presents the structural estimates.

4.1 Demand System

This subsection outlines the results that are fully reported in Noton (2010). Table 1 presents the demand estimates that are used in the following sections.

To address the potential endogeneity of prices, I use the instruments suggested by BLP: 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. These instruments have a strong predictive power over prices.

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.[20]

Supporting the idea of using BLP instead of the previous nested logit, the estimates suggest no particular differences in terms of own-price elasticities between domestic and foreign producers. Unlike nested logits, BLP's methodology does not impose the home-foreign nest that necessarily alters price elasticities.

4.2 Transition Probabilities

This subsection presents the transition probabilities that will capture the dynamics of exchange rates, nominal wages of the manufacturing sector

[19] I assume the capital price is firm specific. Capital price is important for investment decisions, such as the decision to build a manufacturing plant; it is not important for pricing decisions since those decisions are mainly based on marginal costs, which I assume are driven by the labor cost. I cannot identify the sunk costs of production, such as investment or research and development of new cars. Capital can be seen as a nuisance parameter that cannot be recovered separately.

[20] See Noton (2010) for more details.

Table 1: **Demand Estimates**

Linear BLP Parameters	**Coef**	s.d.	t-test
Price-Belgium	**-1.86**	(0.55)	-3.40
Price-France	**-4.09**	(0.97)	-4.22
Price-Germany	**-3.25**	(0.85)	-3.82
Price-Italy	**-2.03**	(0.62)	-3.26
Price-UK	**-1.28**	(0.63)	-2.05
Home-Bias-France	**1.75**	(0.09)	19.07
Home-Bias-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 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	**Coef**	s.d.	t-test
Std Dev on Price Coeff.	**0.68**	(0.35)	1.93
GMM Obj. function	**286.46**		

(or automobile sector, if available), and nominal GDP per capita in all the destination markets.[21]

I assume that the state variables follow a first order Markov process as it is standard in this literature. This is a reasonable assumption for yearly data.

The existence of a unit root in the state variables is crucial for justifying the static framework considered in Goldberg and Hellerstein (2007). Mean reversion in the state variables might imply optimal pricing different from the one based on static first order conditions. Instead, BBL estimate a cost structure consistent with dynamic pricing, regardless the presence of unitary roots in the state variables. This is because BBL uses just these specifications to forecast without structural interpretations.

The actual pricing behavior in this market is consistent with shocks perceived as transitory by the agents, especially regarding nominal exchange rates. This is at odds with permanent shocks as in a non-stationary environment.

I estimate a single equation for exchange rates, and a VAR system for wages and GDP. I do so to take advantage of the higher frequency of exchange rate data. Thus, for the countries and time span considered, I use the quarterly data available for exchange rates, and the yearly data available for country-specific wages and GDP. Although the transition proba-

[21] The car characteristics remain fixed in the simulation stage.

bilities have been previously estimated, I estimate them again to have the entire variance-covariance matrix that is key for the simulation stage and is usually not reported.[22]

Exchange Rates: I assume that the log of the nominal exchange rate follows a first order autocorrelated process with contemporary shocks correlated across countries. The exchange rate series are expressed relative to the American dollar.[23] Hence, the equation for the currency of country $f = \{$Belgium, France, Germany, Italy, UK, Japan$\}$ at time t is given as follows:

$$e_{ft} = \alpha_f + \rho_f e_{ft-1} + u_{ft} \tag{10}$$

where the shocks u_{ft} are correlated between markets but not across time. The estimates of the exchange rate process are in Table 6 in the appendix section. I find a large autocorrelation and heterogeneity.[24] The correlation matrix of residuals plays an important role in accounting for the covariance pattern of shocks in the simulation stage. Table 7 in appendix section presents the full matrix.

Nominal Wages and Nominal GDP per capita: Let us turn to the transition probabilities of nominal wages in the manufacturing sector (or automobile sector if available), denoted by W, and the nominal GDP per capita, denoted by Y. Consistent with segmented labor markets, wages and GDP are correlated within a country but not between countries.

Using logs, the estimated model for each country f is the following VAR(1) system:

$$\begin{bmatrix} W_t \\ Y_t \end{bmatrix} = \lambda_0 + \lambda_f' \begin{bmatrix} W_{t-1} \\ Y_{t-1} \end{bmatrix} + \begin{bmatrix} v_{1,t} \\ v_{2,t} \end{bmatrix} \tag{11}$$

Table 8 in the appendix section presents the estimates using yearly data between 1971 and 1999. Not surprisingly, all the processes are extremely autocorrelated, implying a slow adjustment. Similarly, for most of the countries, shocks to nominal wages are correlated with shocks to nominal GDP, and are captured by the country-specific correlation parameter. Germany is the only country where there was no significant wage-GDP correlation.

[22] Details are reported in appendix B.

[23] To compute revenues and costs, I use the ratio of the producer's currency to the destination market currency, so the dollar as denominator is irrelevant.

[24] The process of integration toward 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. I use the sample between 1971 and 1998.

4.3 Policy Functions

This section presents the estimated policy functions. First I discuss the explanatory variables and the functional form considered, and afterwards I present the results. The goal is to capture optimal pricing through a reduced form estimation that will be used to simulate prices in the second stage of BBL.

To specify the explanatory variables, I decide to include those state variables that yield significant and sensitive economic implications. After detailed analysis I conclude that pricing behavior is well predicted by the state variables associated with own-production costs for each manufacturer. I also tried several other specifications including competitors' variables: the average of a competitor's past prices by market or by segment; the competitor's characteristics; the competitor's wages; and the competitor's exchange rates. None of these specifications were statistically significant. Note that including lags of the state variables is not consistent with the Markov perfect equilibrium assumption, since current state variables are sufficient for pricing.

To define the number of players and functional form to be considered the sample size places an important constraint. In order to be consistent with pricing to market behavior, a given agent will have a different policy function in each destination market. Among the flexible functional forms that can be used the sample size of consecutive models put a strong restriction.[25] Hence, I consider a second-degree polynomial.

The policy functions are estimated separately for each combination of producer country f and destination market m. Hence, the coefficients are (f, m)-specific although I drop these superscripts for presentation purposes. The estimated policy functions are given as follows:

$$\begin{aligned}\log(p_{jt}^{fm}) &= \alpha \log(p_{j,t-1}^{fm}) + \beta_1 \log(e_{mt}/e_{ft}) + \beta_2 \log(e_{mt}/e_{ft})^2 \\ &\quad + \beta_3' \log(e_{mt}/e_{ft}) \cdot \log(X_{jt}^{fm}) + \gamma_0 \log(X_{jt}^{fm}) + \gamma_1 \log(W_{ft}) \\ &\quad + \gamma_2' \log(X_{jt}^{fm}) \cdot \log(W_{ft}) + \lambda_1 \log(Y_t^m) + \lambda_2' D_{jt}^{fm} + \varepsilon_{jt}^{fm}\end{aligned} \tag{12}$$

where p_{jt}^{fm} is the nominal price of model j produced in nation f and sold in the currency of destination market m at time t. e_{mt}/e_{ft} is the ratio of nominal exchange rates; it enters in a linear and quadratic form and also interacts with the model-specific characteristic vector X_{jt}^m. The characteristics, X_{jt}^{fm}, and the producer-country nominal wage, W_{ft}, represent terms associated with the nominal costs of production.[26]

[25] See appendix C.4 for details.

[26] Consumer's income Y_{jt}^m is almost collinear with nominal domestic wages in the destination market, so W_{mt} is not included.

The nominal GDP per capita, Y_t^m, plays the role of a deflator since the real price in the demand is the ratio p_{jt}^{fm} to Y_{jt}^m. The set of dummies D_{jt}^{fm} controls for firm, brand, and segment fixed effects.

The error terms, ε_{jt}^{fm}, can be rationalized by the unobservable characteristics, ξ_{jt}^{fm}, plus a usual idiosyncratic noise u_{jt}^{fm} (i.e., $\varepsilon_{jt}^{fm} = \xi_{jt}^{fm} + u_{jt}^{fm}$). In the simulation stage, these residuals play no role and are set to zero.

Including the lagged price, p_{jt-1}^{fm}, captures environmental inertia and price stickiness in a reduced form. This coefficient *does not* have a structural interpretation. Still, the price autocorrelation shows a large heterogeneity across producer-destination pairs.

The degree of fit of the policy functions is quite good with an R-squared above .95 although the statistical significance of some estimates is quite low.[27] This is expected given the high collinearity of many of these variables and the high degree of autocorrelation of the series. Since reasonable predictions are at the heart of the structural second stage estimation, one way to evaluate the policy functions is through the implications of the forecasts. Consequently, I rule out estimates that either predict overshooting or negative pass-through for exchange rates and wages.[28] To ensure that the policy function estimates imply sensible economic results, I stress the importance of the impulse-response exercises. This is because forward simulation is the key ingredient to identify the deep parameters that rationalize the behavior captured in the first stage estimates.

A key prediction for the BBL second stage is to obtain a reasonable ratio of price to GDP for each car model. Recall that nominal GDP per capita follows its own process; therefore, any miss-specification might lead to the price ratio going to infinity or zero. I have selected the specifications that yield a sensible forecast of real prices.

The predicted response of nominal state variables to shocks has important implications for the empirical results. Hence, I evaluate the policy functions using different paths of the state variables. I do so to assess the changes in price, demand, and revenue for each player. Using the policy function estimates, I simulate two different paths under two different scenarios. The baseline case keeps all the state variables at their long-run value.[29] A second path has an initial shock of a 10 percent increase in exchange rates or wages. After the initial shock, the state variable follows its own process.[30] I simulate the exercise for 40 forward periods and refer to these exercises as impulse-response experiments.

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

[28] This fact implies zero pass-through in very few particular cases.

[29] The existence of steady-state is not necessary for an estimation using the BBL technique. However, it simplifies this exercise by avoiding dependence on the initial conditions.

[30] For clarity in the presentation, the shocks are uncorrelated, although during the forward simulation I draw the shocks using the estimated covariances.

Note that these predictions do not impose assumptions of a specific game, the degree of competition, or any optimality condition. They are the best forecast given a set of explanatory variables. To present and validate these policy function estimations I will present some impulse-response examples.

Exchange Rate Depreciation: This subsection presents predicted prices using the estimated policy functions for a 10 percent nominal depreciation in each of the nominal currencies. This exercises graphically shows some of the standard analysis of exchange rate pass-through in the reduced form literature. The same type of exercise is performed for a ten percent wage increases, which is contained in Appendix G.

Domestic and foreign producers are affected differently by shocks. For example, a depreciation of the French Franc may allow French producers to reduce the prices of all French cars abroad. Simultaneously, only foreign producers are affected in France. The depreciation might force foreign producers to increase their prices since their revenues are less valuable in their own currency. Since French producers have costs and revenues in this depreciated currency, they do not change their prices domestically. I denote the effects of domestic depreciation as *international effects* when domestic producers can sell cheaply abroad and *domestic effects* when foreign competitors have to increase their prices in a depreciated market.

In general, it is possible to include a domestic effect of domestic depreciation in a strategic way. However, the empirical attempts with this dataset did not support this possibility; hence, I impose a zero effect of the domestic currency on the domestic policy function.[31]

As an example, figure 1 presents the reaction of French producers outside France after a 10 percent depreciation of the French Franc. 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 2 presents the reaction of foreign producers in France after a 10 percent depreciation of the French Franc. Foreign producers increase their prices because their revenues are less valuable in their domestic currency. Instead, French prices are unaffected in the French market because the costs and revenues of French producers have been not hit by the depreciation.[32]

[31] Belgium is a special case: since there are no domestic producers, all cars are more expensive in Belgian Francs after a domestic depreciation. Also, depreciation of the Japanese Yen implies lower prices for Japanese cars across Europe. Appendix D contains the set of figures of international effects for all responses after a 10 percent depreciation of each currency in each market; similarly appendix E contains the set of figures of domestic effects. Appendix F presents the 90 percent confidence intervals for each response based on a bootstrapping of 1000 draws of each policy estimation.

[32] Recall that strategic effects were not significant and ruled out from the policy functions.

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

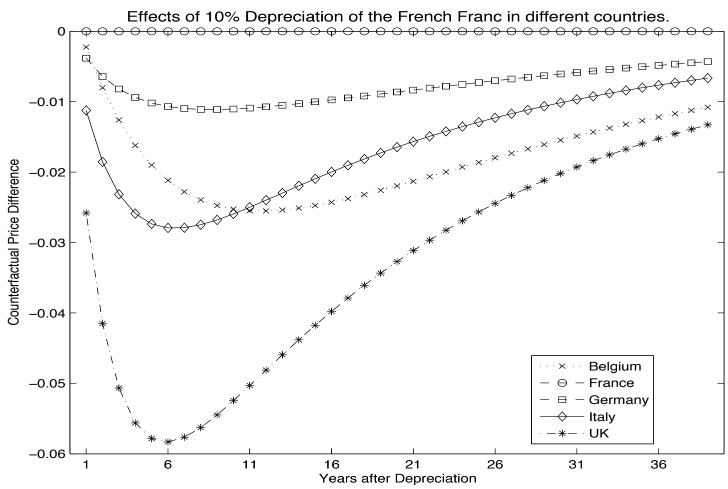
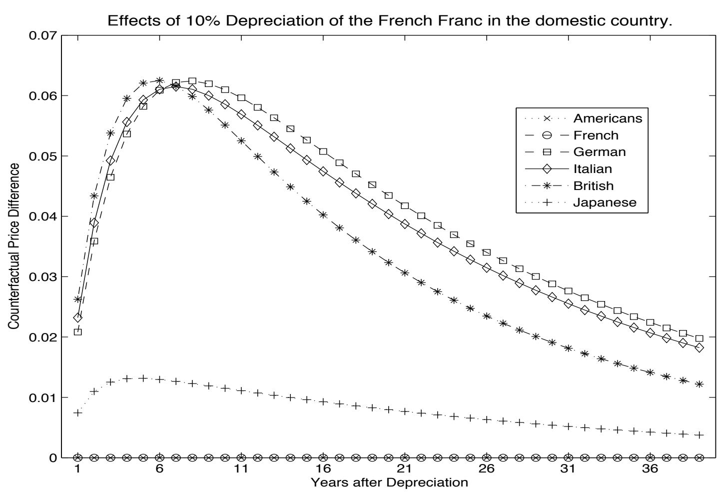


Figure 2: **Car prices in France after a 10% depreciation of the French Franc**



European producers react in similar terms regarding the size of the price change and its evolution. Instead, Japanese manufacturers change their prices by a smaller amount, and the evolution keep prices almost flat along the path of simulations.

Now I present the demand implications of the predicted prices in the impulse-response exercise. Recall that under the new set of prices, the consumer ranks the available choice set and chooses his best option, which includes not buying a car. Note that the depreciation of one currency may change the demand for all players due to the change in relative prices.

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

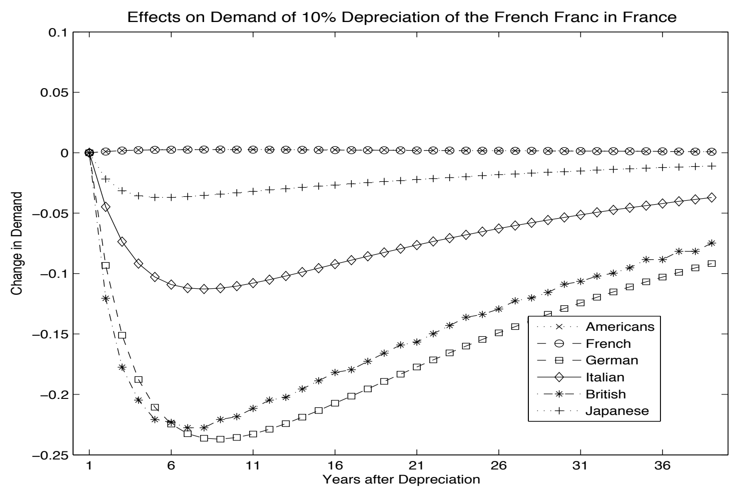


Figure 4: **Revenues in France after a 10% depreciation of the French Franc by producer**

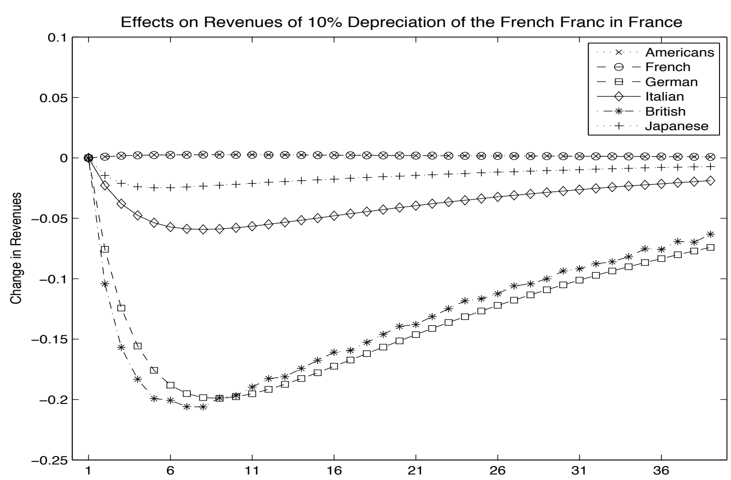


Figure 3 presents the percentage change in the demand after the price increase. The figure shows the pattern of substitution among French consumers. The demand for domestic cars is not quite affected, even though they are relatively cheaper after the depreciation because many consumers choose the outside option. Losses in demand of 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. Note that by using larger elasticities found in the literature, the predicted losses in revenues would be close to 50 percent. This is an important 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.

4.4 Structural Cost Parameters

This section presents the estimated structural cost parameters. Recall that BBL's second stage searches over the cost parameters to rationalize the behavior captured in the first stage estimates. Using these parameters, I identify the order of magnitude of the components consistent with the incomplete degree of exchange rate pass-through (destination-wage component), and the degree of price autocorrelation (price adjustment cost component).

The following cost structure estimation accounts for all the heterogeneity found in European markets. In fact, this estimation considers the heterogeneity of consumers, the heterogeneity of transition probabilities in exchange rates and wages, and the heterogeneity of players' pricing behavior in each destination market. A different cost structure allows for profitable deviations that would not support the data as an equilibrium play.

I assume the same technology for firms that are located in country f and sell to market m. Hence, the cost parameters are estimated for each (f, m) combination. The cost function is given as follows:

$$\begin{aligned} C_{jt}^{fm} &= \underbrace{\nu_0^j \cdot q_{jt}^{fm} + \nu_1^j \cdot [q_{jt}^{fm}]^2}_{\text{Model Fixed Effect}} + \underbrace{\nu_1^w \cdot W_{ft} \cdot q_{jt}^{fm} + \nu_2^w \cdot W_{ft} \cdot [q_{jt}^{fm}]^2}_{\text{Production Wage Cost}} \\ &\quad + \underbrace{\nu_3^w \cdot e_{fmt} \cdot W_{mt} \cdot q_{jt}^{fm} + \nu_4^w \cdot e_{fmt} \cdot W_{mt} \cdot [q_{jt}^{fm}]^2}_{\text{Destination Wage Cost}} \\ &\quad + \underbrace{\Psi_{fm} \cdot e_{fmt} \cdot |p_{jt}^{fm} - p_{jt-1}^{fm}|}_{\text{Price Adjustment Cost}} \end{aligned} \tag{13}$$

where W_{mt} and W_{ft} are the nominal wages in destination country m and producer country f, respectively; e_{fmt} is the nominal exchange rate between countries f and m. I have assumed a quadratic specification in quantities to account for economies of scale. Using this functional form the optimization can achieve a global minimum.

The first component is a model-specific fixed effect ($\nu_0^j, \nu_1^j \in \mathcal{F}_{fm}$). Since all the characteristics of model j remain fixed over the forward simulation stage, this specification is equivalent to a reduced form of costs.[33]

The second component includes the source-country wage terms, representing the standard modeling of direct labor production costs.

The third component includes terms with the destination-market wages for exported cars. The destination-wage component incorporates the idea of local costs into the destination currency as in Burstein, Neves, and Rebelo (2003). This cost component can rationalize the observed incomplete pass-through. As an example, suppose a French car model is sold in Italy; the respective revenues are expressed in Italian Lire. Suppose that the production cost (in French Francs) is 70 percent of total costs, and the local cost component is 30 percent (in Italian Lire). Hence, exchange rate fluctuations between the Franc and the Lire only affect the relative importance of the production cost with respect to the revenues. Therefore, if a French car manufacturer wanted to keep constant markups after a change in the relative price of the Franc and the Lire, then the exchange rate pass-through should only be about 70 percent. Since the 30 percent of local costs are not affected by exchange rate fluctuations, it explains an incomplete degree of exchange rate pass-through.

The fourth component is the price adjustment cost with parameters Ψ's. This component rationalizes the price autocorrelation observed in the data, differentiating between the autocorrelation due to the environment and the autocorrelation due to the cost structure of the firm. I consider a destination-market-specific coefficient for each source country, $\Psi_{s,m}$, since flows of revenues are in different currencies. Alternative specifications with the same coefficient across markets will miss the pricing-to-market behavior that is an important feature of the European car market.[34]

Abstracting from the entry and exit of car models, I keep the same market configuration (firms and models traded in 1985) in the forward simulation stage.[35] The fixed market configuration ensures that estimates are not contaminated by the composition effect, which is the endogenous market configuration caused by exchange rate shocks or macroeconomic conditions. This is the first empirical paper to account for this fact that I am aware of.

Let me present a brief and intuitive explanation of the second stage of the BBL methodology.[36] Consider a simplified single agent example, which is straightforward to generalize. Denote the estimated transition probabil-

[33]Estimating cost coefficients for each characteristic yields poor empirical results.

[34]Appendix H presents an alternative cost function given by $\Psi_{fm} \cdot |\log(p_{jt}^m) - \log(p_{jt-1}^m)|$.

[35]The estimates for other years yield qualitatively similar results.

[36]See Appendix A for details.

ity by $\mathbb{P}$ and the estimated policy function by $\sigma(s)$. $\sigma(s)$ yields the action (a single price in this example) for each state of the world. Given an initial cost parameter ν and an initial state, I draw a sequence of states over T periods using the estimated transition probability $\mathbb{P}$; denote the first drawn sequence by $\mathbf{s}_1 = \{s_{11}, s_{12}, .., s_{1T}\}$. For each of these states, I predict the respective price using the estimated policy function, σ, obtaining a price sequence $\mathbf{p}_1 = \sigma(\mathbf{s}_1) = \{p_{11}, p_{12}, .., p_{1T}\}$. Using the player's profit function, I compute the resulting first sequence of profits with generic element $\pi(p_{1t}, s_{1t}; \nu)$; based on that, I calculate the present discounted value of this first draw sequence of profits using $V(\mathbf{s}_1, \nu, \sigma) = \sum_{\tau=0}^{T} \beta^\tau \pi(p_{1\tau}, s_{1\tau}; \nu)$.

Repeating the previous steps for a large number R of alternative paths, I average the single player' discounted sum of profits over all the simulated paths of play. This yields an estimate of the expected value of the single player's payoff EV under policy σ and parameters ν:

$$EV(\nu, \sigma) = \frac{1}{R} \sum_{h=1}^{R} V(\mathbf{s_h}, \nu, \sigma) \tag{14}$$

Now, consider an alternative rule for the agent:

$$\widetilde{\sigma}(s) = \sigma(s) + \widetilde{u} \tag{15}$$

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 observed behavior σ. Therefore, redoing the same forward simulation for the alternative rule $\widetilde{\sigma}(s, \nu)$, I compute the alternative expected payoff $\widetilde{EV}$.

$$\widetilde{EV}(\nu, \widetilde{\sigma}) = \frac{1}{R} \sum_{h=1}^{R} V(\mathbf{s_h}, \nu, \widetilde{\sigma}) \tag{16}$$

Consequently, the structural parameter estimates, $\widehat{\nu}$, are those that rationalize the observed rule σ or, equivalently, those that minimize the profitable deviations generated by the alternative rule $\widetilde{\sigma}$. In other words, the BBL estimates, $\widehat{\nu}$, should maximize the likelihood of the optimality condition of the Markov perfect equilibrium assumption, which is $\widetilde{EV}(\widehat{\nu}, \widetilde{\sigma}) < EV(\widehat{\nu}, \sigma)$.

I simulate 1,000 different sequences of the state variables, and each path involves 40 periods of time for all models presented in the European markets in 1985. There is little presence of British cars in the sample, consistent with the fact that they eventually disappear from the dataset in the '90s. Hence, it is impossible to have reliable cost estimates for British producers.[37]

[37] See appendix C.5 for details about the car models considered in the forward simulations.

Cost Share by Components: This section presents empirical results for each cost component by producer's nationality. These cost components are not observable and we look for the function of state variables consistent with the observed price autocorrelation and the degree of exchange rate pass-through in the European car market.

For simplicity, instead of reporting the large number of model-specific fixed effects (ν_j's) or the currency-specific labor cost parameters, I present the share of each 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:

$$\begin{aligned}
\text{Prod. Cost Share} &= \frac{\nu_0^j \cdot q_{jt}^{fm} + \nu_1^j \cdot [q_{jt}^{fm}]^2 + \nu_1^w \cdot W_{ft} \cdot q_{jt}^{fm} + \nu_2^w \cdot W_{ft} \cdot [q_{jt}^{fm}]^2}{C_{jt}^m} \\
\text{Local Cost Share} &= \frac{\nu_3^w \cdot e_{fmt} \cdot W_{mt} \cdot q_{jt}^{fm} + \nu_4^w \cdot e_{fmt} \cdot W_{mt} \cdot [q_{jt}^{fm}]^2}{C_{jt}^m} \\
\text{Price Adj. Cost Share} &= \frac{\Psi_{fm} \cdot e_{fmt} \cdot |p_{jt}^{fm} - p_{jt-1}^{fm}|}{C_{jt}^m}
\end{aligned}$$

where the production cost share includes the fixed effects that are associated with the fixed-effect per model and the manufacturing wages in the producer country. Instead, the local cost share includes the cost terms associated with the destination-market wages.

In terms of identification, the marginal production costs are measured through the latent costs that can be linked to model fixed-effects and wage fluctuations. Variation across time of wages shed light on the size of this component for each producer f.

The share of price adjustment costs only includes the penalty for a price change and it is independent of marginal cost of production.[38] Variation (or the lack of it) of prices provides the sense of size of the price adjustment cost component.

Table 2 presents the share of each component by the producer's nationality.[39]

The destination-wage components required to explain the incomplete degree of exchange rate pass-through are in the third column of table 2. The column with local costs suggests that American cars have 17 percent of their costs in the destination currency, whereas for Italian cars the destination wage component needs to be as high as 59 percent to rationalize the low pass-through observed in the data.

The estimates of price adjustment costs show that German car producers have almost no cost to adjusting prices, so their price autocorrelation

[38] No fixed cost of repricing is estimated.

[39] Obviously, the destination market component appears in the exported cars only.

is mostly due to autocorrelation in the economic environment they face. Instead, a large price adjustment cost is needed to rationalize the massive price persistence of Japanese manufacturers.[40]

Table 2: **Different Components (%) over Total Cost in 1985**

Exports	Production Cost	Local Labor Cost	Price Adj. Cost
American	83.17	16.68	0.15
French	77.91	20.11	1.98
German	62.10	37.58	0.31
Italian	35.33	59.17	5.50
Japanese	60.12	28.91	10.97
Sold Domestically	**Production Cost**		**Price Adj. Cost**
American	99.99		6e-04
French	97.42		2.58
German	99.99		3e-05
Italian	88.59		11.41

There are three main insights that emerge from the structural estimates of this paper. First, the destination-wage components need to be about one-third of total costs to rationalize the observed incomplete exchange rate pass-through. In the same spirit, Goldberg and Verboven (2001) find local costs to be around 40 percent in the European car market. Still, the foreign component for Italian producers is too high to be plausible. Substitution of intermediate inputs may play a role; unfortunately, a lack of model-level input data does not allow me to explore this or other further hypotheses.

Second, the adjustment cost component is small and sometimes economically insignificant. The findings in table 2 show that autocorrelation in the American, French and German cases are mostly due to autocorrelation in the economic environment and not due to the cost structure of the firm. Instead, a larger price adjustment cost is needed to rationalize the persistent pricing behavior of Italian and Japanese firms.

To compare this conclusion with the related literature, my price adjustment cost represents at most 3 percent of total revenues.[41] These results are similar to those reported by Zbaracki, Ritson, Levy, Dutta, and Bergen (2004), who provide direct evidence of price adjustment costs for a manufacturing firm. Consistent with their findings, the adjustment cost

[40]These charts for the alternative specification of price adjustment costs are replicated in appendix H with qualitatively similar results.

[41]Assuming an adjustment cost of 10 percent of total cost and a markup of 70 percent.

component seems more important in exports.[42]

Table 3: **Cost Share of Price Adjustment Costs by Destination Market**

	Belgium	France	Germany	Italy	UK
Americans	0.0031	0.4257	0.0001	0.0004	0.0012
French	0.0004	2.2131	0.0001	7.4330	0.0601
German	0.0640	1e-07	0.0001	0.8197	0.0800
Italian	12.8699	1.9420	0.0482	10.2082	2.0707
Japanese	0.0452	1.4394	3.8181	-	37.2213

Table 4: **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	0.00	1.00	0.00	1.78	0.08
German	3.57	0.00	1.00	1.31	1.49
Italian	0.37	0.02	0.02	1.00	0.23
Japanese	0.00	0.25	1.00	-	14.28

Third, there is a clear heterogeneity in the price adjustment cost by destination markets. Tables 3 and 4 explore the order of magnitude of price adjustment costs for each producer-destination pair. To be consistent with the heterogeneous pricing and transition probabilities, the adjustment costs need to be market specific for each producer's nationality. Similar heterogeneity is found when comparing the ratio of coefficients with the relative importance of the cost share. A uniform cost structure cannot rationalize the pricing behavior of the players. To justify the observed uneven pricing behavior we require pair-country specific features (e.g., relative inflation or exchange rate volatility). Since price adjustment costs can be understood as the amount of money firms are willing to forego to follow a persistent pricing strategy, this evidence could capture the different destination-specific, long-run strategies of the firms. The literature has not, so far, explored timing decisions in the European car market. This paper introduces a new dimension of pricing heterogeneity that complements

[42] Other papers have estimated menu-costs only: Nakamura and Zerom (2010) find that the adjustment cost represents 0.23 percent of total revenues in the coffee industry using a different dynamic approach. Using a static framework, Goldberg and Hellerstein (2007) find that it is less than 1 percent of total revenues in the beer industry.

the previous static framework that focused on the degree of exchange rate pass-through across destinations.

Now I turn to implications of the cost estimates in terms of variable profits. Dynamic considerations challenge the usual size of markups found in static settings. In static models, the first order conditions of the problem have a closed form that allow a markup rule based on marginal costs and demand parameters. This paper does not use a structural pricing rule to uncover marginal costs because the dynamic problem with a large state space does not allow a closed solution. As shown and discussed in equation 7, the lack of a structural policy function implies that this paper can not provide neither a formula to compute equilibrium markups nor a relationship between static and dynamic markups. Still, it can empirically show the size of estimated marginal costs with respect to actual prices by computing estimated variable profits over prices $\left(\frac{p_{jt}^m - \widehat{c}_{jt}^m}{p_{jt}^m}\right)$. Although these calculations are not the result of a structural markup equation, they are still informative about the size of variable profits. Table 5 presents the implied variable profits for the subsample of cars used in the simulation stage.

Table 5: **Implied Variable Profits in 1985**

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

The estimated variable profits are higher in this study than in previous static studies. Let me illustrate the underlying intuition with an example. Suppose a firm suffers a large adverse currency shock. I refer to this event as a "bad year". After the adverse shock, we observe small changes in prices and the firm remains in business. In the framework of this paper, this is because the marginal cost of production is low enough. The low estimate of marginal cost implies large variable profits in "normal years" when there are less adverse shocks. Consequently, if a firm stays in business in all periods, it must be the case that marginal costs are low enough in every period. The limited entry/exit of car manufacturers, despite the large adverse shocks that we see in the data, is only consistent with very low marginal costs of production.

This paper argues that the smaller markups found in static papers are not consistent with long-term survival in an environment with frequent adverse shocks and slow price adjustments. Markups of 30 percent, as found in the static literature, may yield losses under the typical exchange rate shocks in the European car market. However, these losses can be dampened if firms receive governmental subsidies to allow them to survive during "bad years." In addition, if the cost of exiting a market is very high, car manufacturers may be willing to take on losses in a given year to avoid exiting and then re-entering the market.[43]

5 Conclusions

This paper identifies the price adjustment costs that rationalize pricing behavior in the European automobile industry. In particular, it characterizes price adjustment costs that are consistent with the observed timing and the degree of exchange rate pass-through, while accounting for the heterogeneous dynamics of each economic environment.

The structural estimation is conducted using a dynamic game of multi-currency pricing with price adjustment costs. I use the methodology of Bajari, Benkard, and Levin (2007) (BBL) that circumvents solving the intractable game.

This paper is a first attempt at estimating price adjustment costs using BBL. This approach overcomes two limitations of the existing literature on price adjustment cost estimations. First, the estimates separately identify the price adjustment costs from the environmental inertia; this cannot be achieved through a reduced form approach. Second, the estimates are consistent with a dynamic model, which is intractable to solve due to the large state space.

There are three main results. First, the incomplete pass-through is consistent with local costs being one-third of total costs. Second, 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. Third, price adjustment costs seem to be specific to each producer-destination combination. In other words, uniform price adjustment costs are not consistent with the different pricing behaviors observed in the data. This finding adds an unexplored time dimension to the established pricing-to-market behavior.

In general, the methodology of BBL seems quite suitable for studying price adjustment costs in a wide range of markets. In particular, 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 (S, s) rules or Markov-switching models. Second, a larger dataset

[43]Notice that these insights are based on variable profits only. Statements about the total profitability of the industry in the long run need to account for fixed costs as well.

could be used to test changes in the cost structure of firms due to exogenous changes in the environment such as the adoption of the Euro.

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APPENDIX SECTIONS

A Summary of BBL

This subsection presents the general methodology used in this paper. The methodology was originally developed by Bajari, Benkard, and Levin (2007)(BBL). The BBL algorithm has two stages. The first stage estimates two functions: the evolution of the economic environment and players' choice of action. The evolution of the economic environment over time is given by transition probabilities denoted $\mathbb{P}(s_{t+1}|s_t)$). It can depend on the actions of players. The way players decide on actions in each state of the world is given by policy functions denoted $\sigma_f(s)$. The second stage uses equilibrium conditions to estimate structural parameters that rationalize the first stage estimates.

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

Second, to analyze equilibrium behavior, I focus on pure strategy Markov perfect equilibria (MPE). In a MPE, each firm's behavior depends only on the current state $\mathbf{s}_t$ although the function may be firm specific. Since the definition of Markov Perfect equilibrium requires that players only care about the current state of the world and not about "how the state was reached," I rule out the possibility of "state path dependence." We should think of the price decision as any other "investment decision" that only depends on the current environment and the last decision.[44]

Formally, in this setting, a Markov strategy for firm f is a function $\sigma_f : S \to P_f$, where S is the set of relevant state variables and P_f is the action space for firm f. A profile of Markov strategies is a vector $\sigma = (\sigma_1, .., \sigma_F)$, where $\sigma : S \to P = (P_1, ..P_F)$. If the behavior is given by a Markov strategy profile σ, firm f's expected profit $V_f(s, \sigma)$ given a state $\mathbf{s}$ can be written recursively:[45]

$$V_f(s, \sigma_f) = \mathbb{E}\left[\pi_f(\sigma_f(s), s) + \beta_f \int V_f(s', \sigma) d\mathbb{P}(s'|\sigma, s)|s\right]. \tag{17}$$

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

[44]The same logic can be found in other BBL applications that studies entry/exit decisions or investment decisions: current decisions depend on what happened last period, but do not depend on how the current state was reached.

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

σ'_f,

$$V_f(s, \sigma) = V_f(s, \sigma_f, \sigma_{-f}) \geq V_f(s, \sigma'_f, \sigma_{-f}). \tag{18}$$

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 deviations.

Suppose the profit function for firm f, is a known function, π_f.[46] It is indexed by a finite cost parameter vector ν_f, so the structural parameters of the model are given by the profit functions $\pi_1(p, s; \nu_1), ..., \pi_F(p, s; \nu_F)$. Assuming the data is generated by a unique MPE of the model, the goal is to recover the true value of $\nu = (\nu_1, .., \nu_F)$, denoted ν_0.

The first step of the BBL approach is to estimate the policy functions $\sigma_f : S \times \nu_f \to p_f$ for $f = \{1, .., F\}$ and 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. Forward simulations are used to estimate firms' value functions for the strategy profiles (including the equilibrium profile) given an estimate of the transition probabilities $\mathbb{P}$.

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

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

2.- Draw a sequence of states over T periods using the estimated transition probabilities $\mathbb{P}(\cdot|s_t)$, hence 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, $p_t = \sigma_f(\mathbf{s}_t)$. Hence, I generate the respective sequence $\{\mathbf{p}_1, \mathbf{p}_2, .., \mathbf{p}_T\}$ for every player.

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

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

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

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

$$\widehat{\mathbb{E}}(V(\nu_f, \sigma_f, \mathbb{P})) = \frac{1}{NR} \sum_{h=1}^{NR} \left[\widehat{V}_f^h(\nu_f, \sigma_f, \mathbb{P}) \right]. \tag{19}$$

[46] I assume the player-specific discount factor β_f is known. I use average inflation over 30 years to account for differences in the inflation rates of the countries.

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

Such an estimate can be obtained for any (σ, ν_f) pair, including $(\widehat{\sigma}, \nu_f)$, where $\widehat{\sigma}$ is the policy profile estimated in the first stage. Since the first stage estimation $\widehat{\sigma}$ is based on actual data, it should represent the optimal policy function under the true parameters ν_0 and equilibrium beliefs.

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

Based on the definition of MPE, optimality requires the absence of profitable deviations:

$$V_f(s|\sigma_f, \sigma_{-f}, \nu_f) \geq V_f(s|\sigma'_f, \sigma_{-f}, \nu_f) \quad \forall \sigma'_f. \tag{20}$$

Let $x \in X$ index the equilibrium conditions, so that each x denotes a particular (f, s, σ'_f) combination. Denote the first stage parameters by α. Define

$$g(x, \nu, \alpha) = V_f(s, \sigma_f, \sigma_{-f}, \nu, \alpha) - V_f(s, \sigma'_f, \sigma_{-f}, \nu, \alpha). \tag{21}$$

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

Define the function

$$Q(\theta, \alpha) \equiv \int (\min\{g(x, \nu, \alpha), 0\})^2 dH(x), \tag{22}$$

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

$$Q(\nu_0, \alpha_0) = 0 = \min_{\nu \in \Theta} Q(\nu, \alpha). \tag{23}$$

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

$$\widetilde{\sigma}_f(s) = \sigma_f(s, \widehat{\alpha}) + u, \tag{24}$$

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

$$\widetilde{g}(x, \nu, \widehat{\alpha}_n) = V_f(s, \sigma_f, \sigma_{-f}, \nu, \widehat{\alpha}_n) - V_f(s, \widetilde{\sigma}_f, \sigma_{-f}, \nu, \widehat{\alpha}_n) = V_f - \widetilde{V}_f. \tag{25}$$

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

Finally the second stage estimator is

$$\widehat{\nu} = \arg\min_{\nu \in \Theta} \frac{1}{n_I} \sum_{k=1}^{n_I} (\min\{\widetilde{g}(x_k, \nu, \widehat{\alpha}), 0\})^2. \qquad (26)$$

B First Stage Estimates

This section presents the tables associated with the first stage estimates presented in subsections 4.2 and 4.3.

Table 6: **Estimates of Nominal Exchange Rates**

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

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

Table 7: **Correlation Matrix of Exchange Rate Shocks**

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

Table 8: **Estimates for Nominal Wages and GDP per capita**

	GDP Equation			Wage Equation			Corr.
	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***	

* significant at 5% ; ** significant at 1% ; *** significant at 0.1% NS denotes non-significant estimates that were replaced by zero. GDP equation for Japan is not required. $\Gamma = \mathbb{E}(v_{1,ft}v_{2,rp}) \neq 0$ if and only if same country $f = r$ and time $t = p$.

C Data Details

This appendix section presents details on the data: the evolution of car characteristics by country, the considered nationalities, the entry/exit behavior in the industry, the sample used for policy function estimations, and the sample used in the forward simulation stage.

C.1 Evolution of the car characteristics.

Figure 5: **Car size by country**

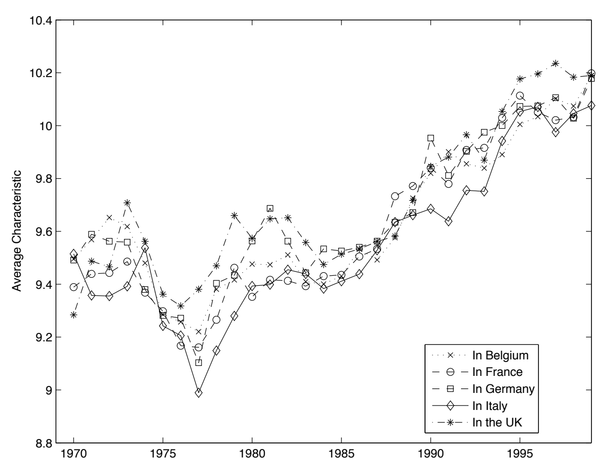


Figure 6: **Inverse of Motor Power by country**

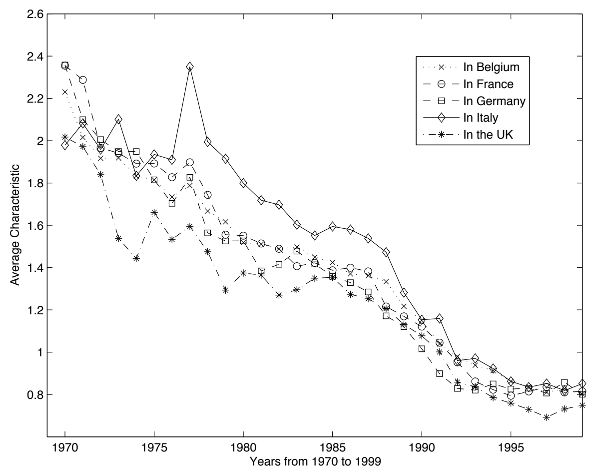
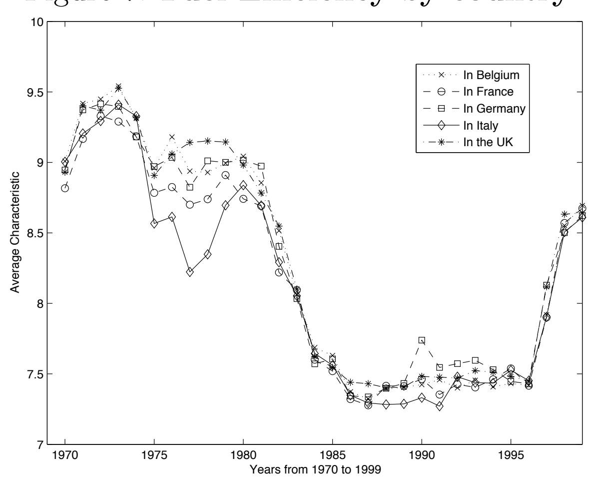


Figure 7: **Fuel Efficiency by country**



C.2 Nationalities

This appendix subsection presents the two criteria for classifying the nationalities of each car model. The first one was used for the demand side of the model and the second for supply side.

First, I define the relevant nationality from the consumer's point of view. I use the brand to assign nationality on the demand side because it is the most relevant factor for European consumers and it is invariant to changes in ownership. This assignment follows Goldberg and Verboven (2001).

Table 10 shows the nationality considered for each brand in detail. Tables 9 and 11 present the market shares and the share of total models available under this criterion.

Table 9: **Available models by Brand's nationality**

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

Since a firm's revenues must be expressed in a single currency, we use the location of a firm's headquarters as its nationality to construct the profit function. This nationality does not necessarily match the nationality perceived by consumers. Table 12 presents firms and their nationalities; these are based on the historical nationality of a firm's headquarters. Tables 13 and 14 present the market shares and the share of total models available in each market by nationality and destination market.

Table 10: **Brand's Nationalities**

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

Table 11: **Shares of cars by Brand's nationality**

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

Table 12: **Headquarter's Nationality**

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

Table 13: **Models available by Headquarter's Nationality**

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

Table 14: **Shares of cars by Headquarter's 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 %
Netherlands	0.20 %	0.24 %

C.3 Entry/Exit Behavior

This subsection discusses the assumption of no entry or exit for firms and car models. If large exchange rate fluctuations change the configuration of the market (i.e. the set of relevant players or models), then we would have an endogenous choice set. No empirical papers has addressed the composition effect, which is this potential problem of endogeneity.[47] To address this issue, we would require a framework able to deal with mergers, the entry of new firms, and the exit of incumbents.

I argue that the average percentage of new firms is low, with small firms being absorbed by bigger players. The share of new firms over the 30 years studied in this paper is less than 7 percent. Weighted by market shares, the relevance of new firms is even less significant. Figure 8 illustrates how the percentage of new firms has evolved.

To deal with the entry/exit of car models, I need to identify both exiting models and characteristics of entering models. This seems intractable given the multidimensional characteristics of the auto industry. I argue that new models are not a big share of the market, with an average percentage of new models close to 5 percent. Figure 9 shows the percentage of new models over the 30-year period studied.

To deal with this simplification, the car characteristics and the available car models remain fixed in each market in the BBL's second stage. Doing so ensures that the results are not contaminated by the composition effect. Thus, this paper focuses on the pricing behavior and cost structure of firms for a given choice set and market configuration of European cars.

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

Figure 8: **Percentage of new firms by country**

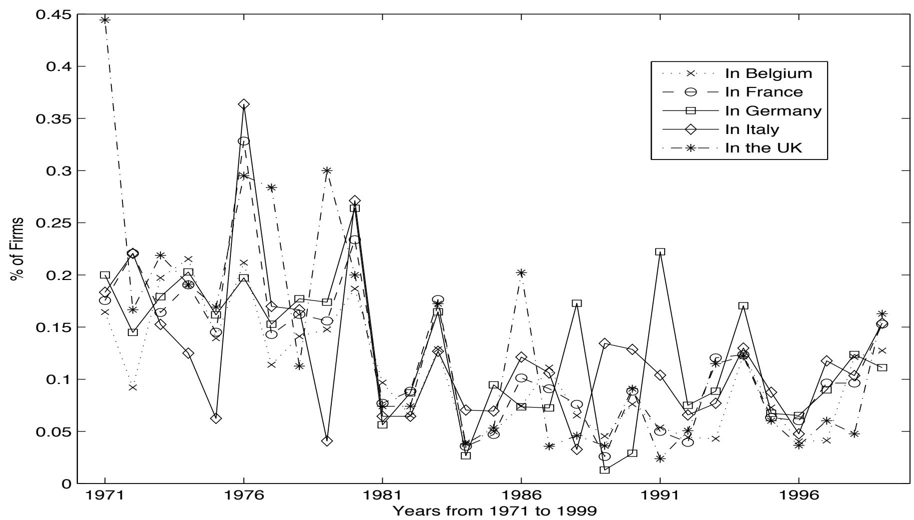
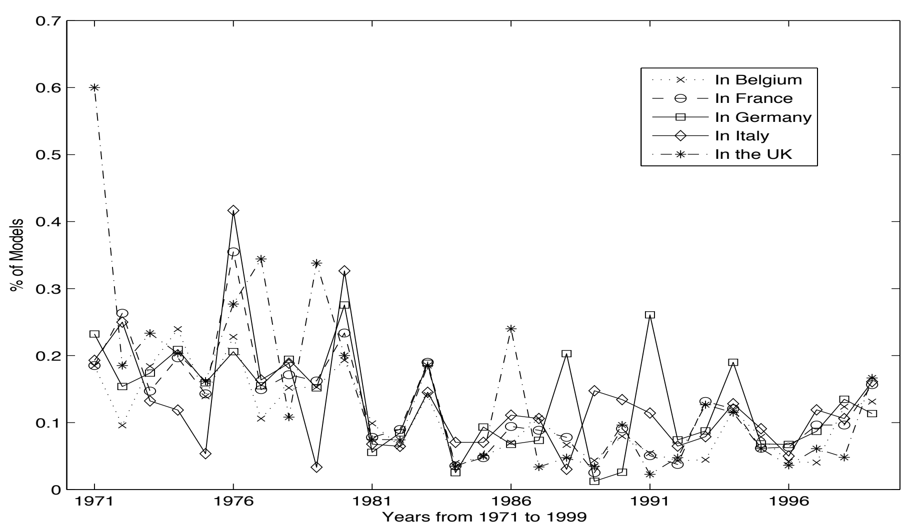


Figure 9: **Percentage of new models by country**



C.4 Policy Function Sample Details

From the initial 11,549 observations, I have to reduce the sample for various reasons. First, I only use producers that belong to the six nationalities.[48] Second, I need information from at least two consecutive periods to estimate the respective lagged price coefficient. Third, I only include cars produced in the domestic headquarter country, even though some firms have some manufacturing plants in different locations. I discard data on these other locations because there are not enough observations to avoid the strong assumption of a common policy function and common cost parameters with the headquarters' production. There is an exception with the American cars, which are made in the UK for the British market and in Germany for other markets. The number of observations available for each policy function estimation is given in table 15.

Table 15: **Final Sample for Policy Function Estimation**

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

C.5 Forward Simulation Sample Details

I 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 16 presents the car models I consider in the forward simulations. As you can see, there are few British cars in the sample and even those eventually disappear in the 90's. This makes it impossible to obtain reliable cost estimates for British producers.

[48] Due to the small sample size, I leave out car models from the Netherlands, Czechoslovakia, Sweden, Spain, Korea, Russia, and Yugoslavia.

Table 16: **Models considered in Forward Simulations**

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

D 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.[49]

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

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

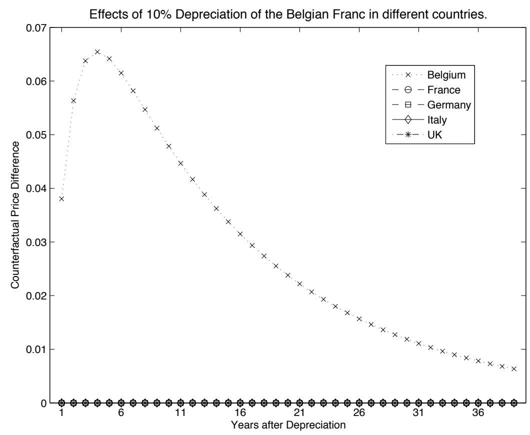


Figure 11: **Price Reactions in Europe after a 10% depreciation of the French Franc**

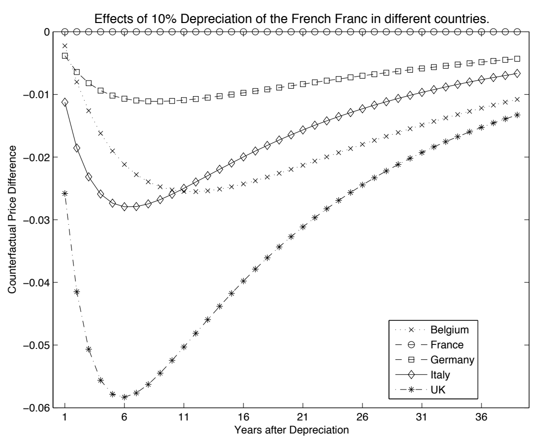


Figure 12: **Price Reactions in Europe after a 10% depreciation of the German Mark**

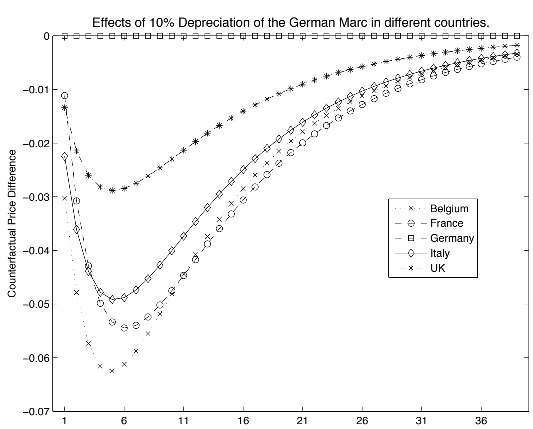


Figure 13: **Price Reactions in Europe after a 10% depreciation of the Italian Lire**

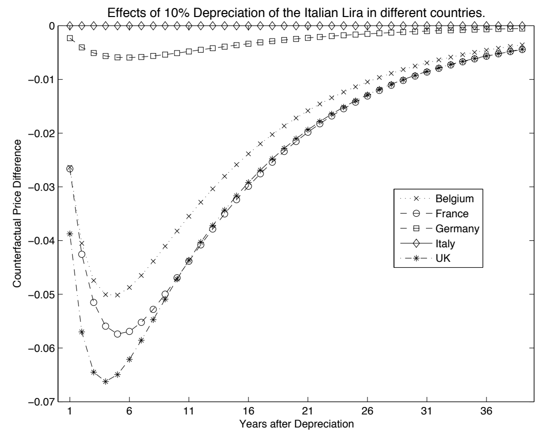


Figure 14: **Price Reactions in Europe after a 10% depreciation of the British Pound**

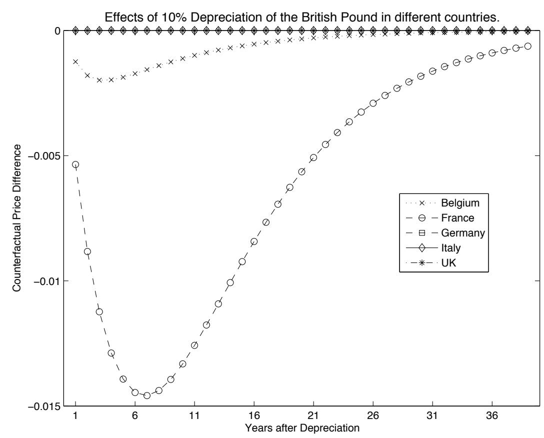
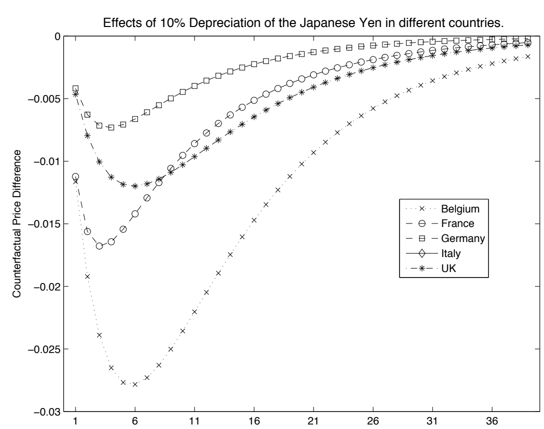


Figure 15: **Price Reactions in Europe after a 10% depreciation of the Japanese Yen**



E Domestic Effects of Exchange Rate Depreciation

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

This subsection presents 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.[50]

[50] 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 16: **Price, Demand and Revenues in Belgium after a 10% depreciation of the Belgian Franc**

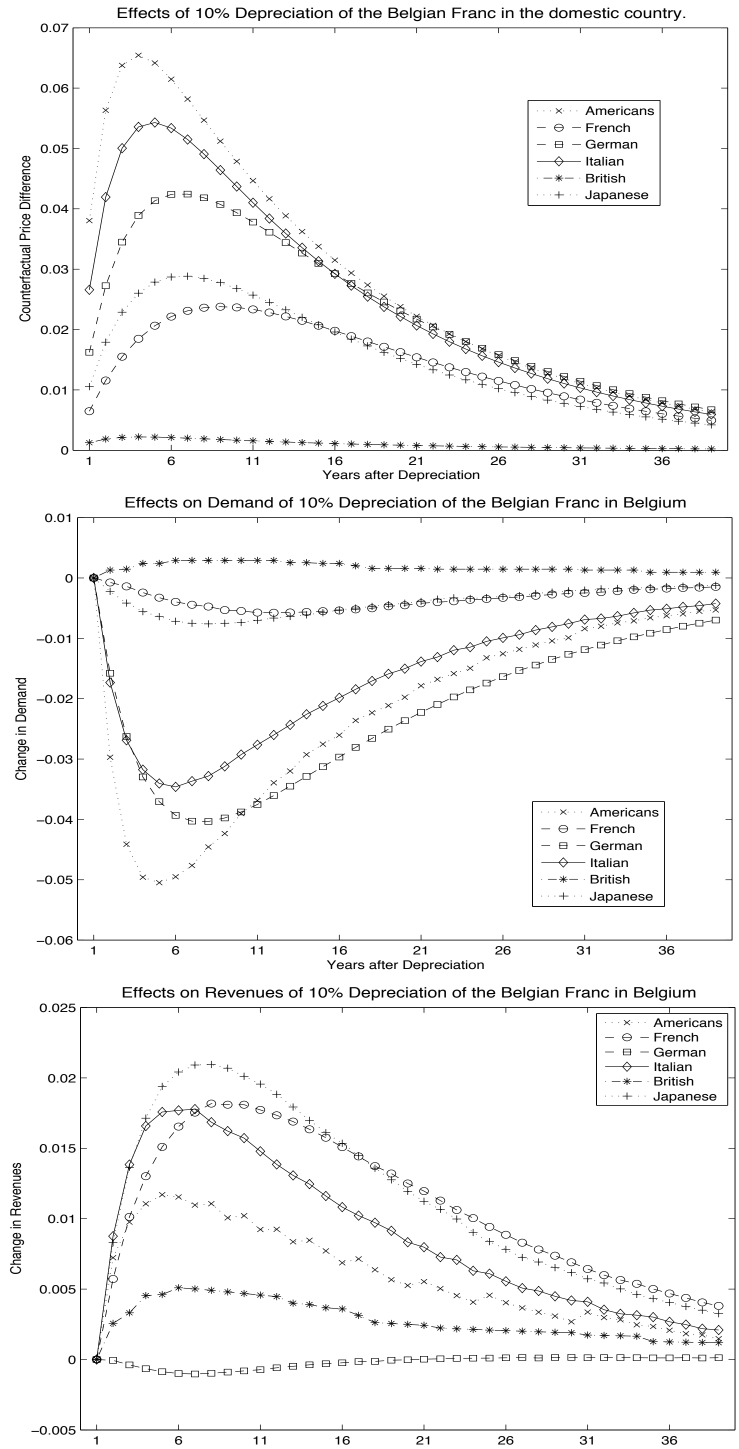


Figure 17: **Price, Demand and Revenues in France after a 10% depreciation of the French Franc**

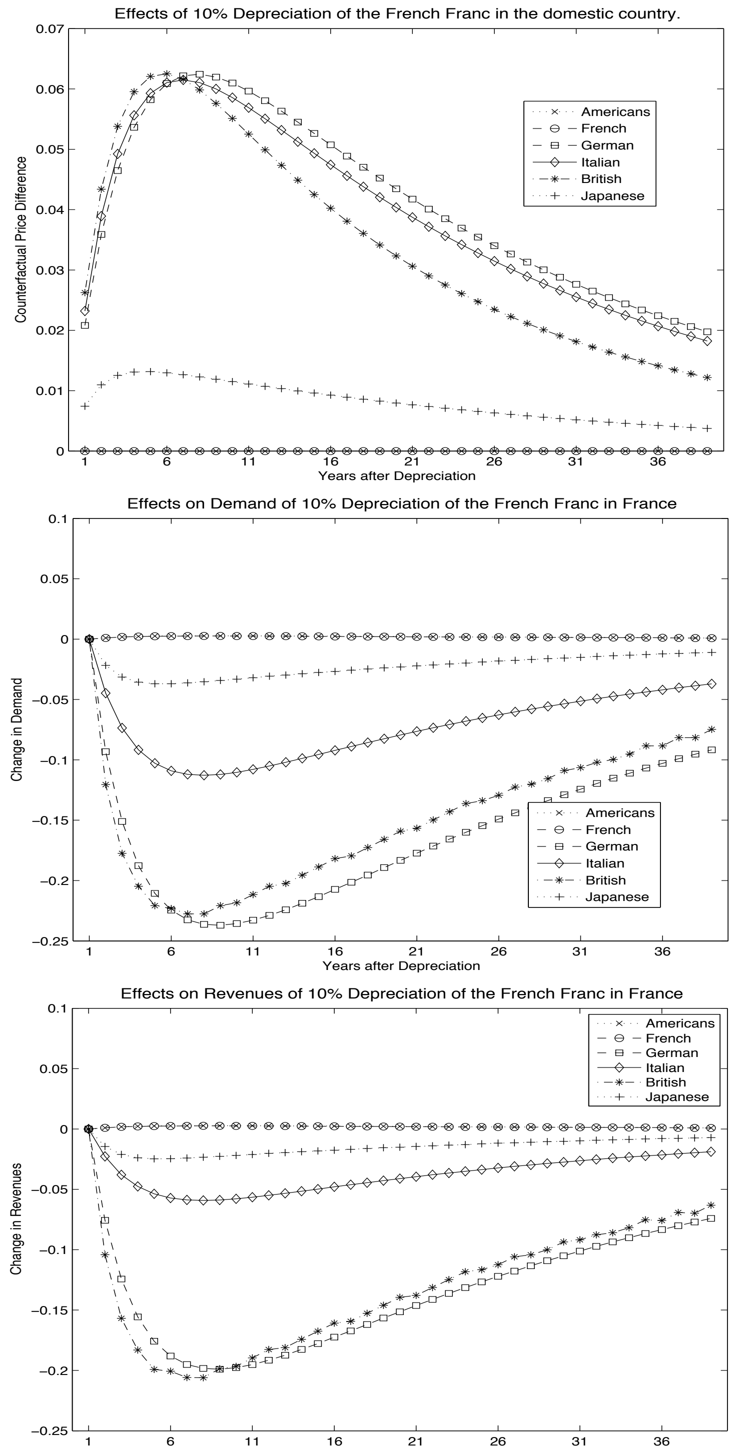


Figure 18: **Price, Demand and Revenues in Germany after a 10% depreciation of the German Mark**

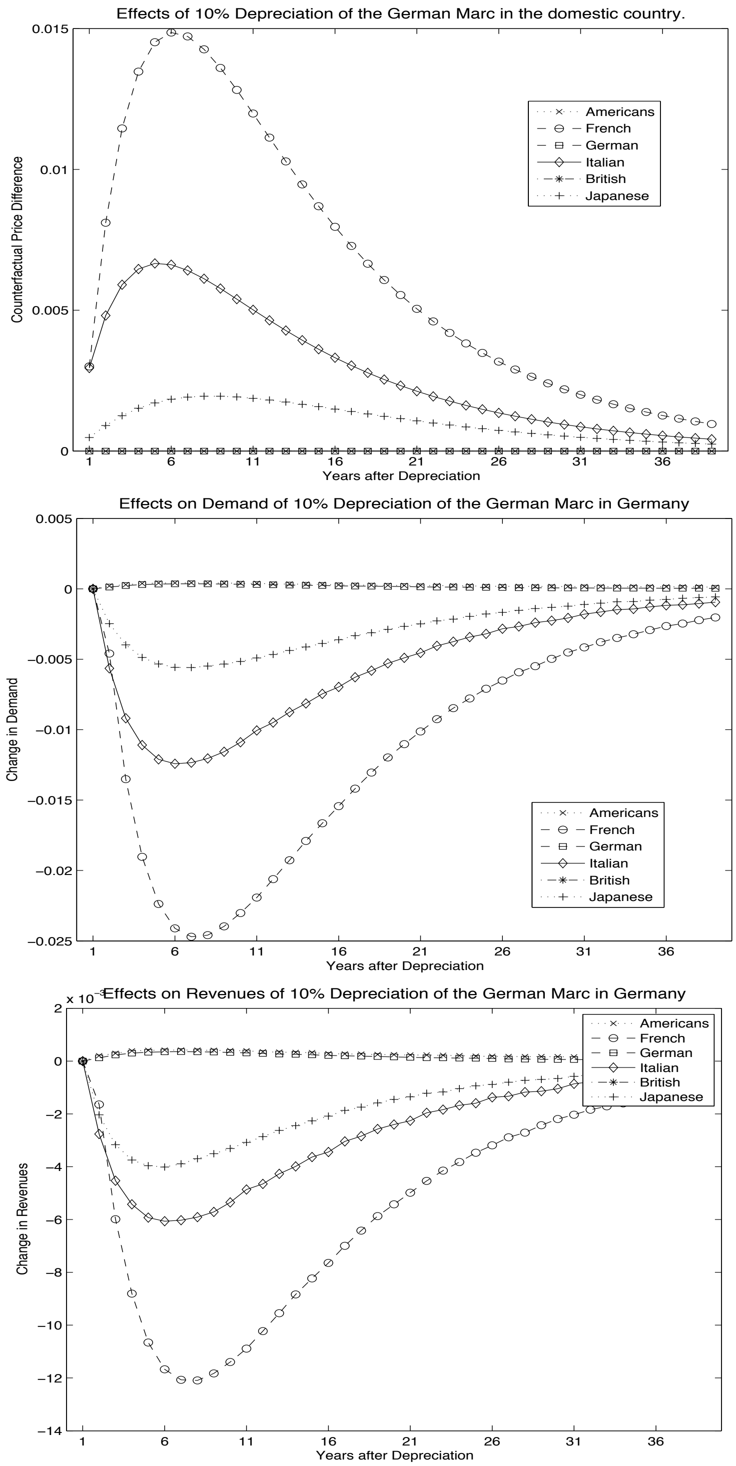


Figure 19: **Price, Demand and Revenues in Italy after a 10% depreciation of the Italian Lire**

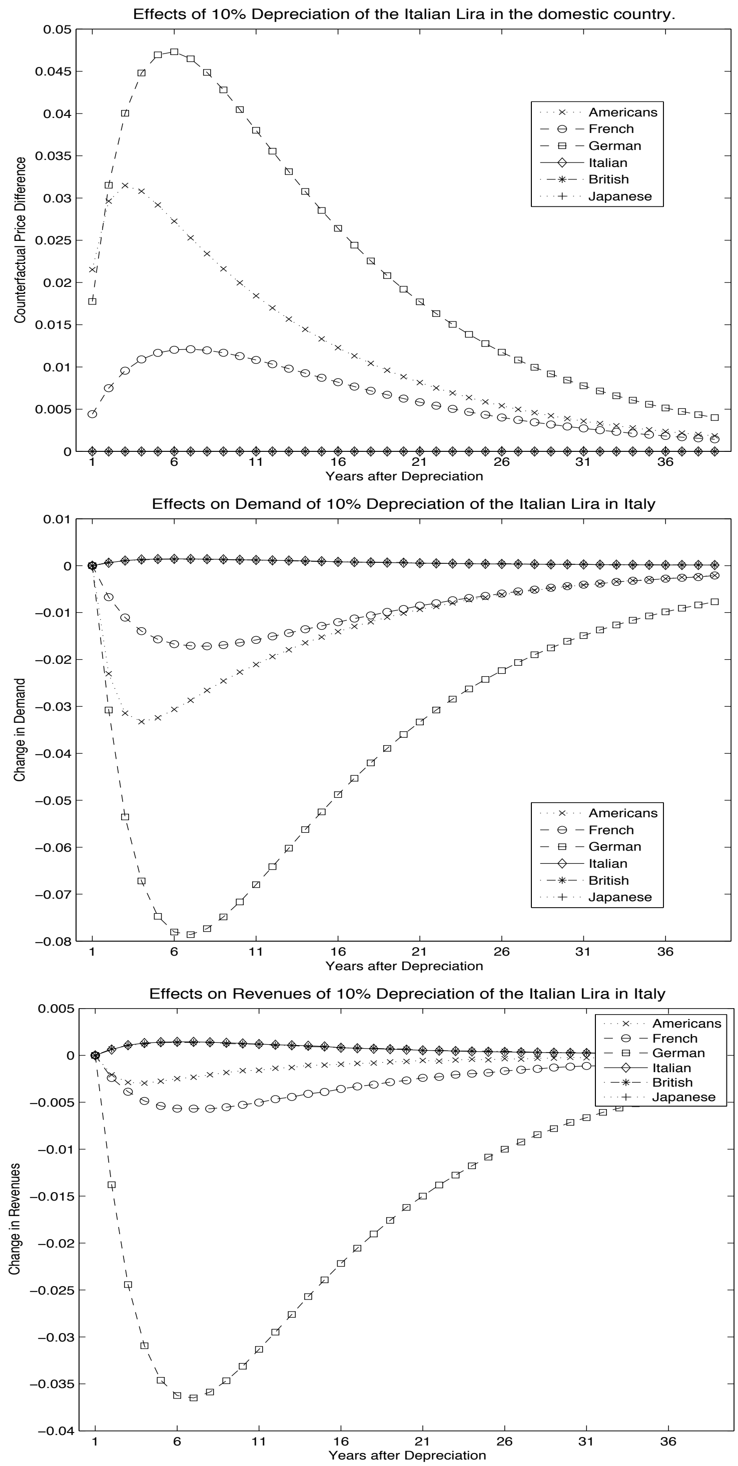
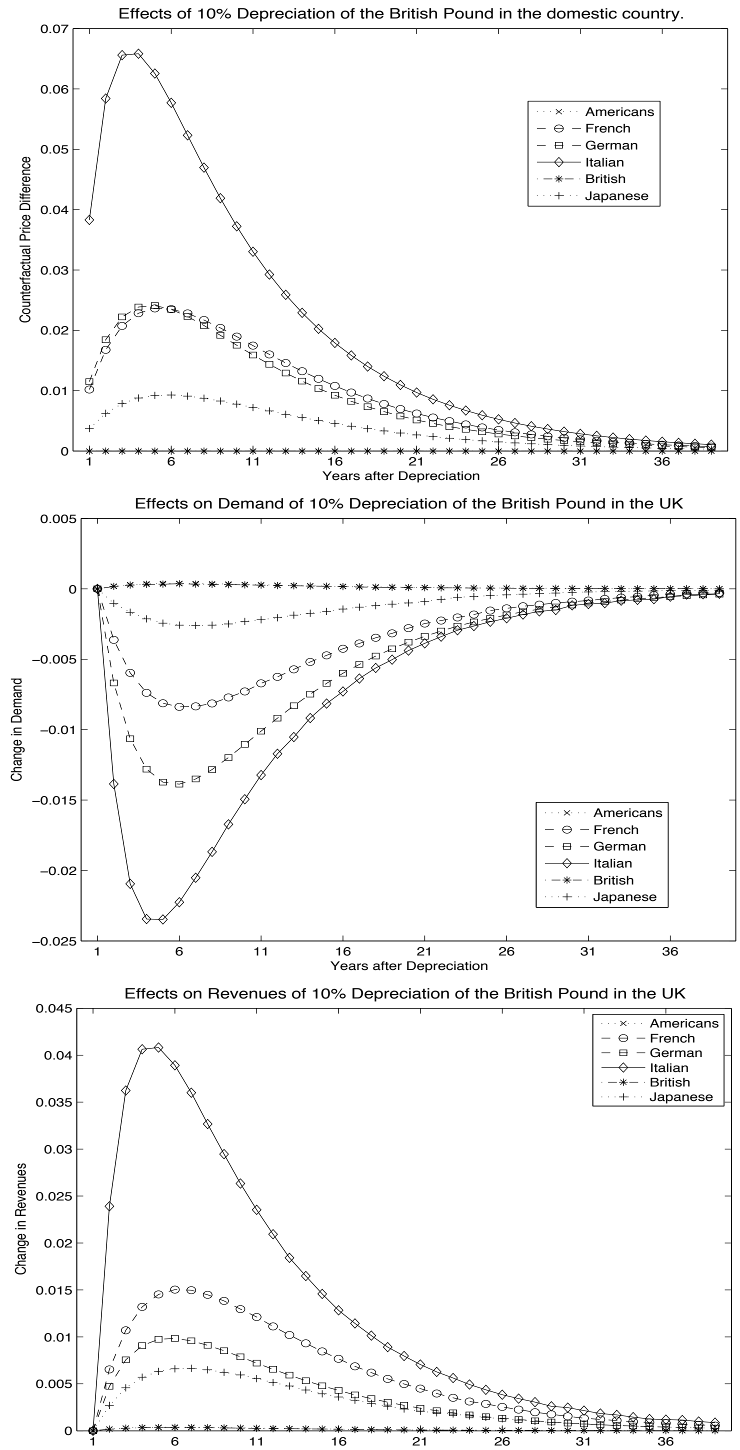


Figure 20: **Price, Demand and Revenues in the UK after a 10% depreciation of the British Pound**

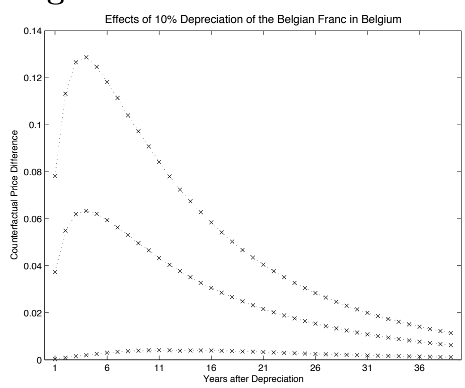


F Confidence Intervals for Policy Functions

This appendix presents confidence intervals of the impulse-response exercises. We focus on the 10 percent depreciation of European currencies as explained in section 4.3. The figures present bootstrapping exercises for each price panel in the appendix section. They present both the international effects of domestic depreciation on domestic producers and the domestic effects of domestic depreciation on foreign producers.[51]

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

Figure 21: **Confidence Interval for Price reactions in Europe after a 10% depreciation of the Belgian Franc**



[51]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 22: **Confidence Interval for Price reactions in Europe after a 10% depreciation of the French Franc**

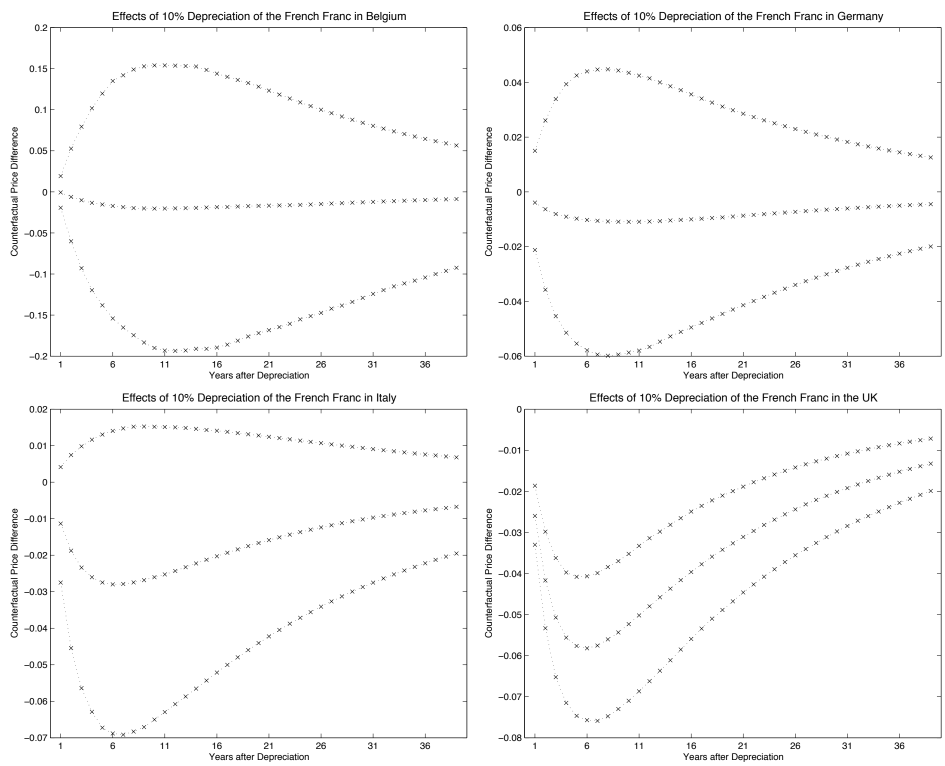


Figure 23: **Confidence Interval for Price reactions in Europe after a 10% depreciation of the German Mark**

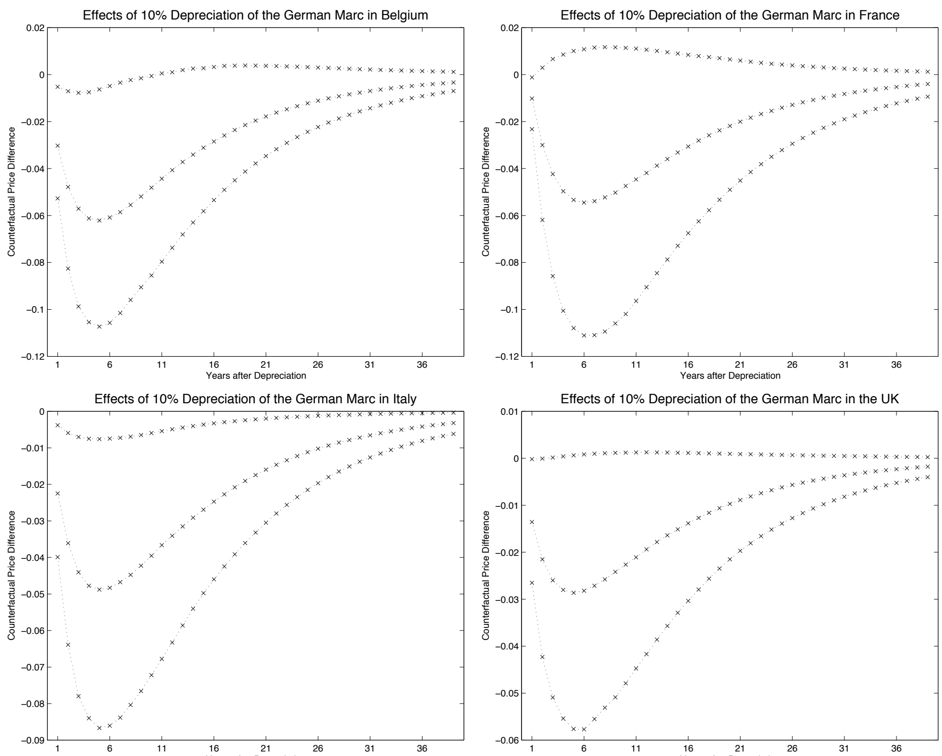


Figure 24: **Confidence Interval for Price reactions in Europe after a 10% depreciation of the Italian Lire**

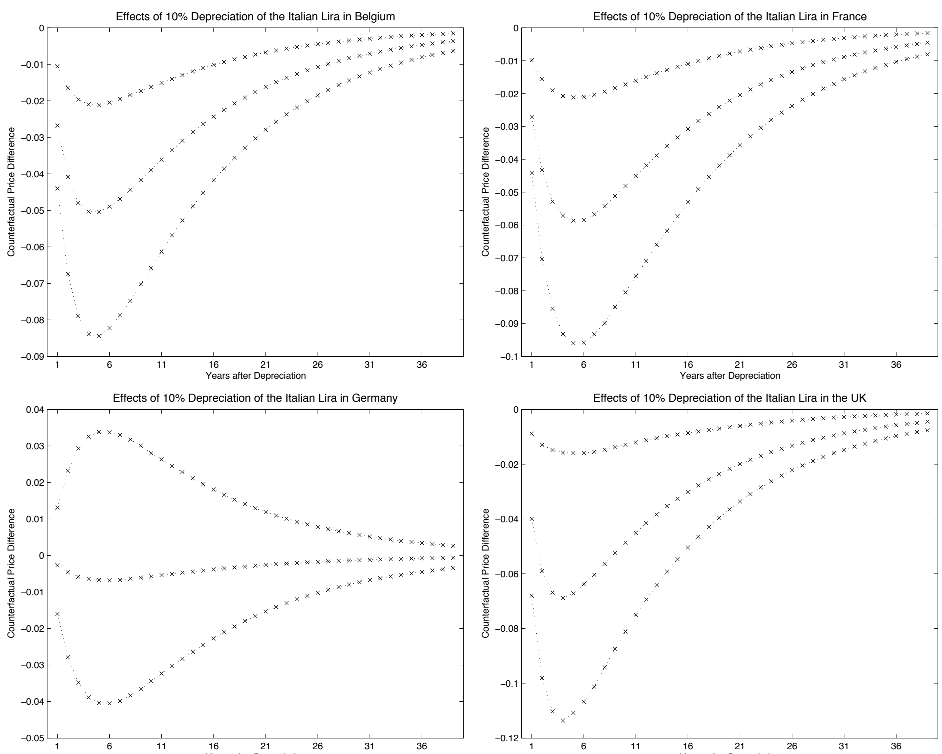


Figure 25: **Confidence Interval for Price reactions in Europe after a 10% depreciation of the British Pound**

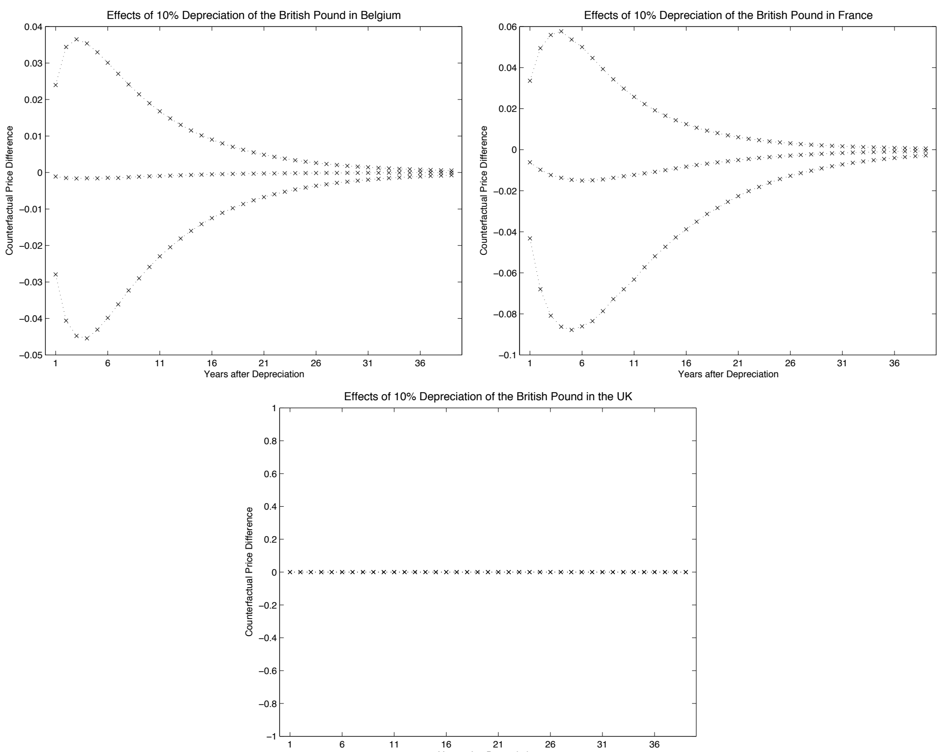
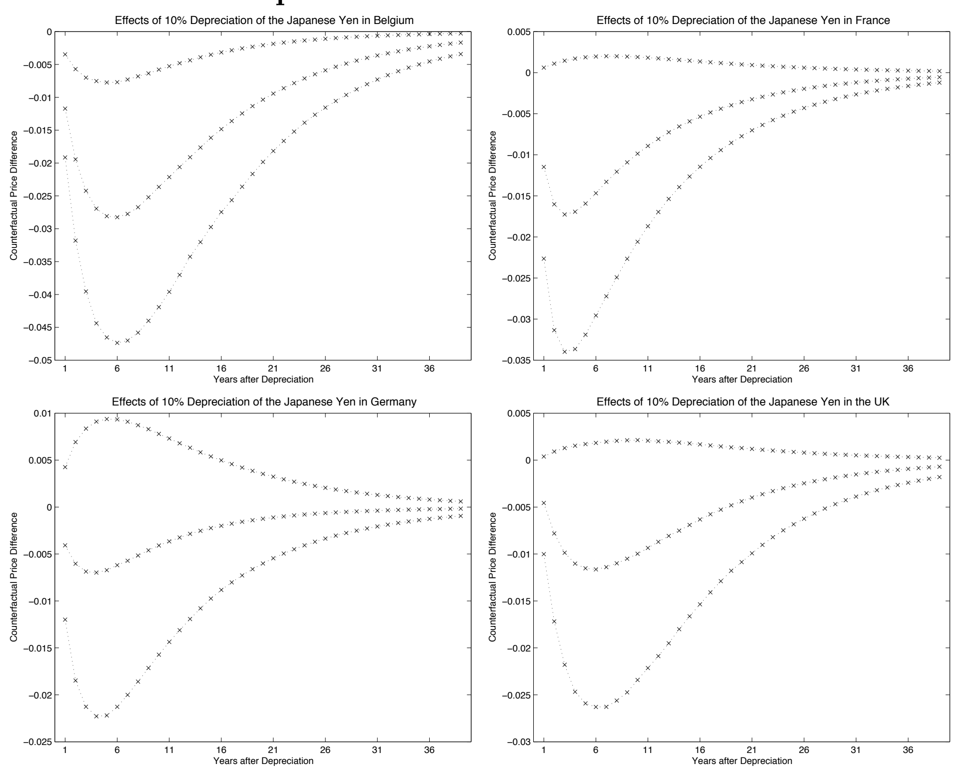


Figure 26: **Confidence Interval for Price reactions in Europe after a 10% depreciation of the Japanese Yen**



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

Figure 27: **Confidence Intervals for Price Reactions in Belgium after a 10% depreciation of the Belgian Franc**

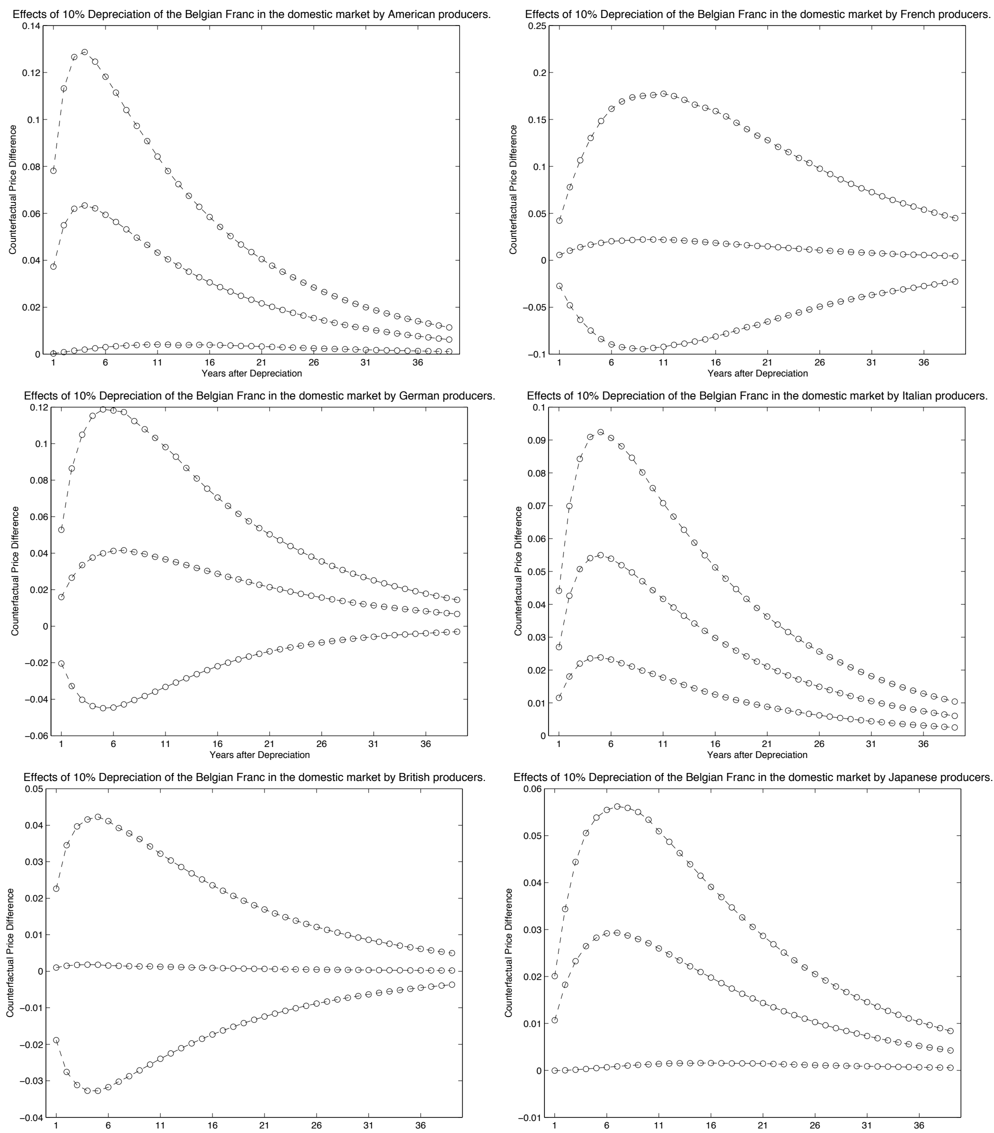


Figure 28: **Confidence Interval for Price Reactions in France after a 10% depreciation of the French Franc**

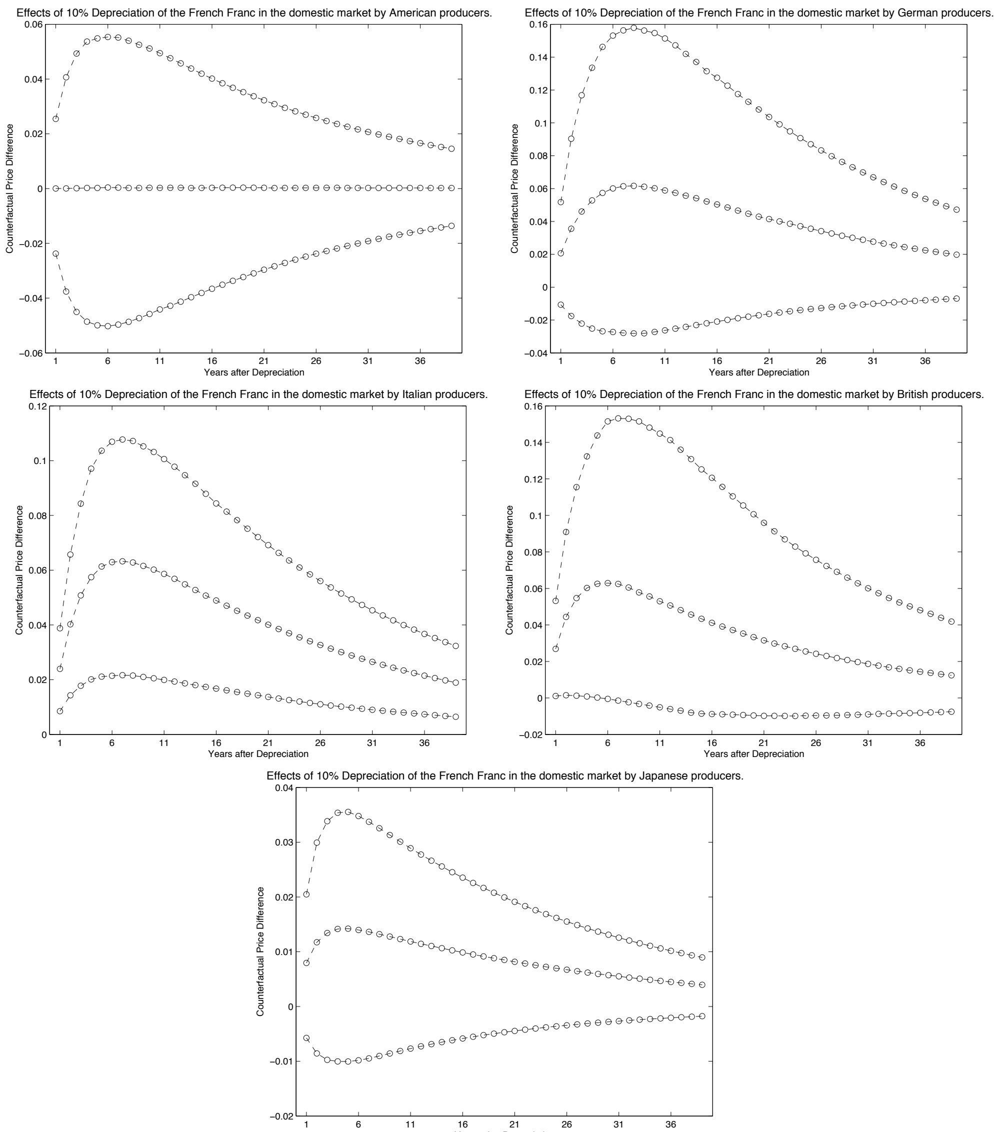


Figure 29: **Confidence Interval for Price Reactions in Germany after a 10% depreciation of the German Mark**

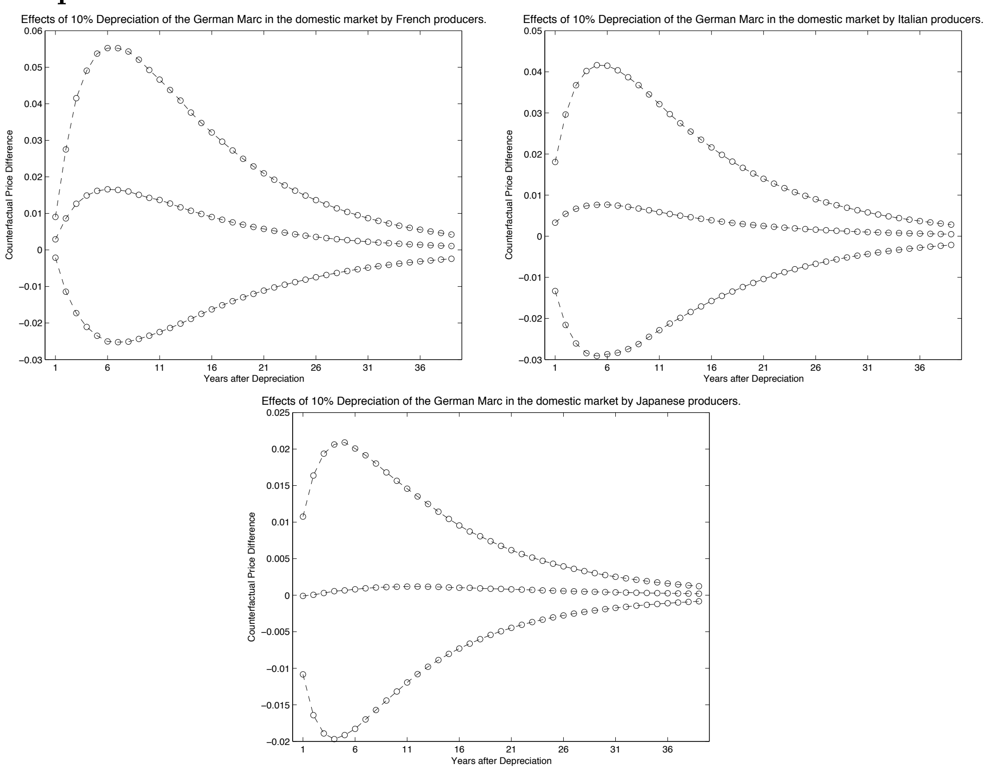


Figure 30: **Confidence Interval for Price Reactions in Italy after a 10% depreciation of the Italian Lire**

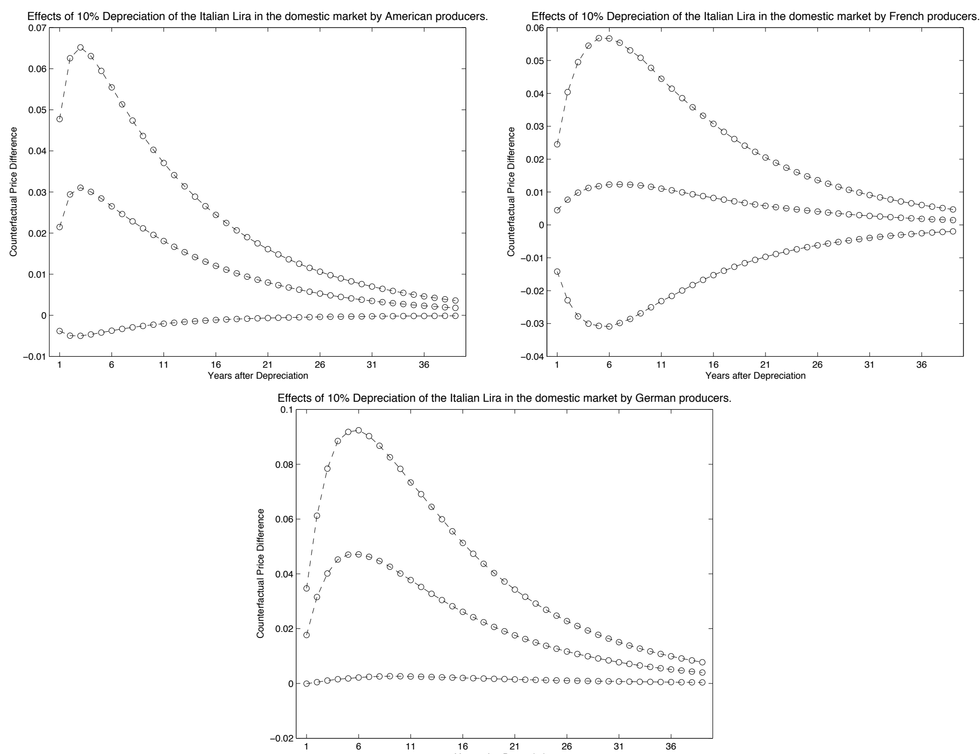
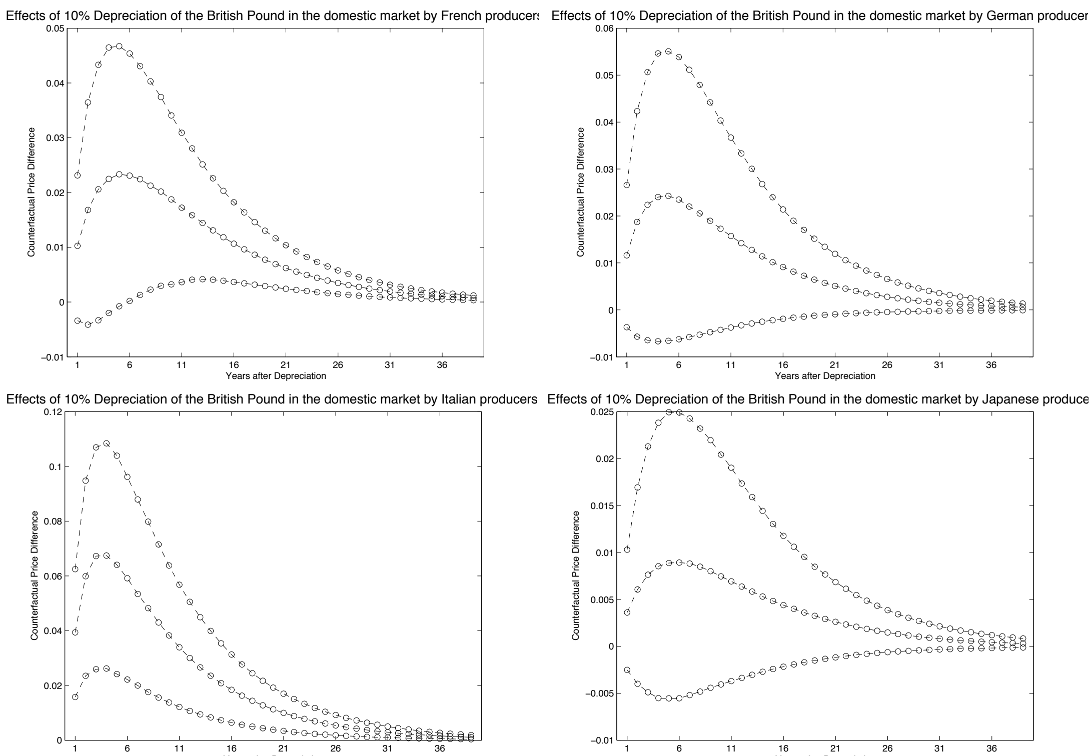


Figure 31: **Confidence Interval for Price Reactions in the UK after a 10% depreciation of the British Pound**



G 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. Each figure presents the percentage difference between the altered and steady state paths of predicted prices. Prices are computed through the estimated policy functions, which use the nominal wages predicted by an initial 10 percent increase and 39 subsequent periods predicted by their respective estimated transition probabilities. The figures present bootstrapping exercises to compute confidence intervals.

This section presents the effects of a wage increase in each of the destination markets. There are no Belgian producers and I do not analyze the Japanese domestic market.

Figure 32: **Price Reactions across Europe after a 10% increase in French wages**

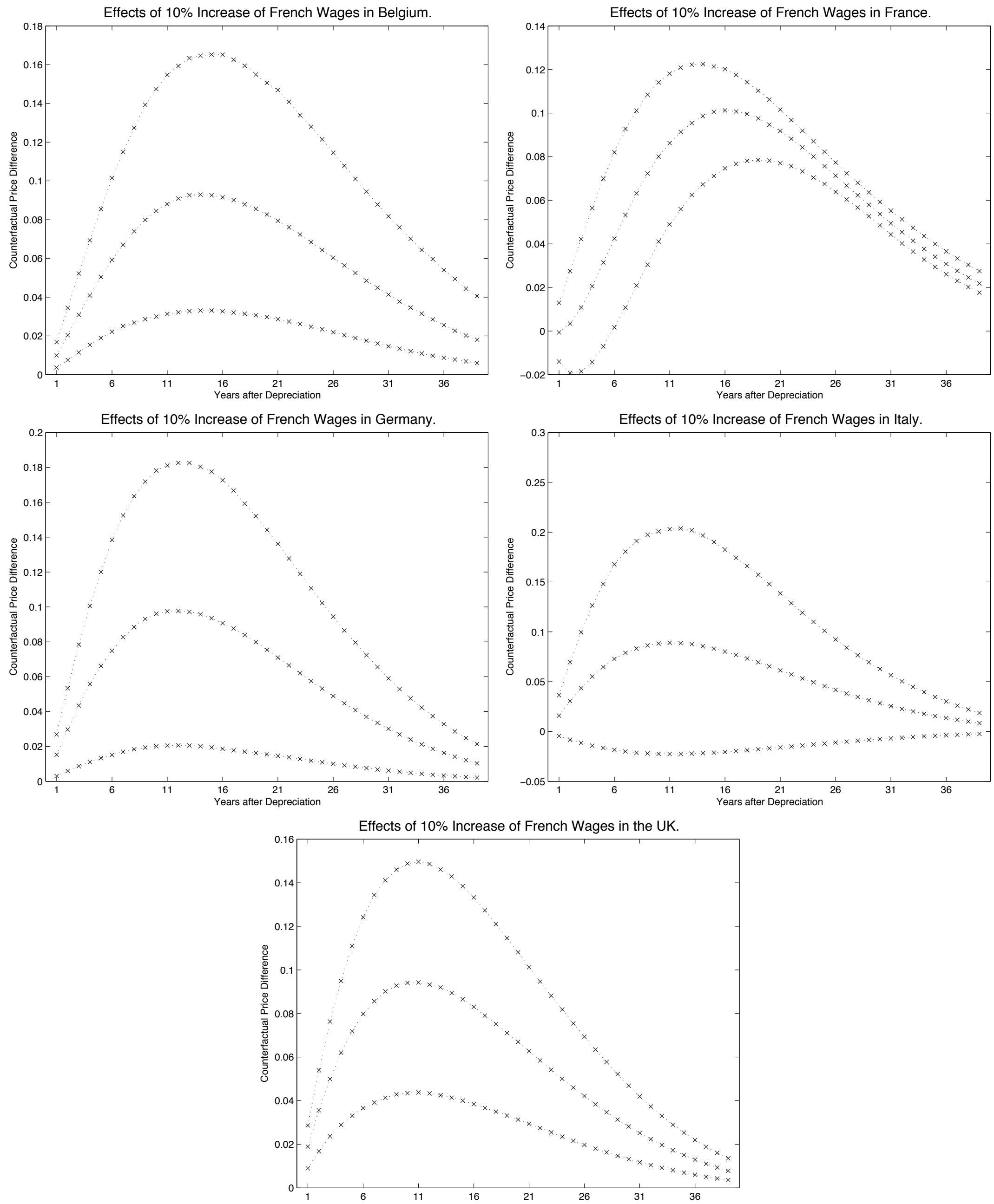


Figure 33: **Price Reactions across Europe after a 10% increase in German wages**

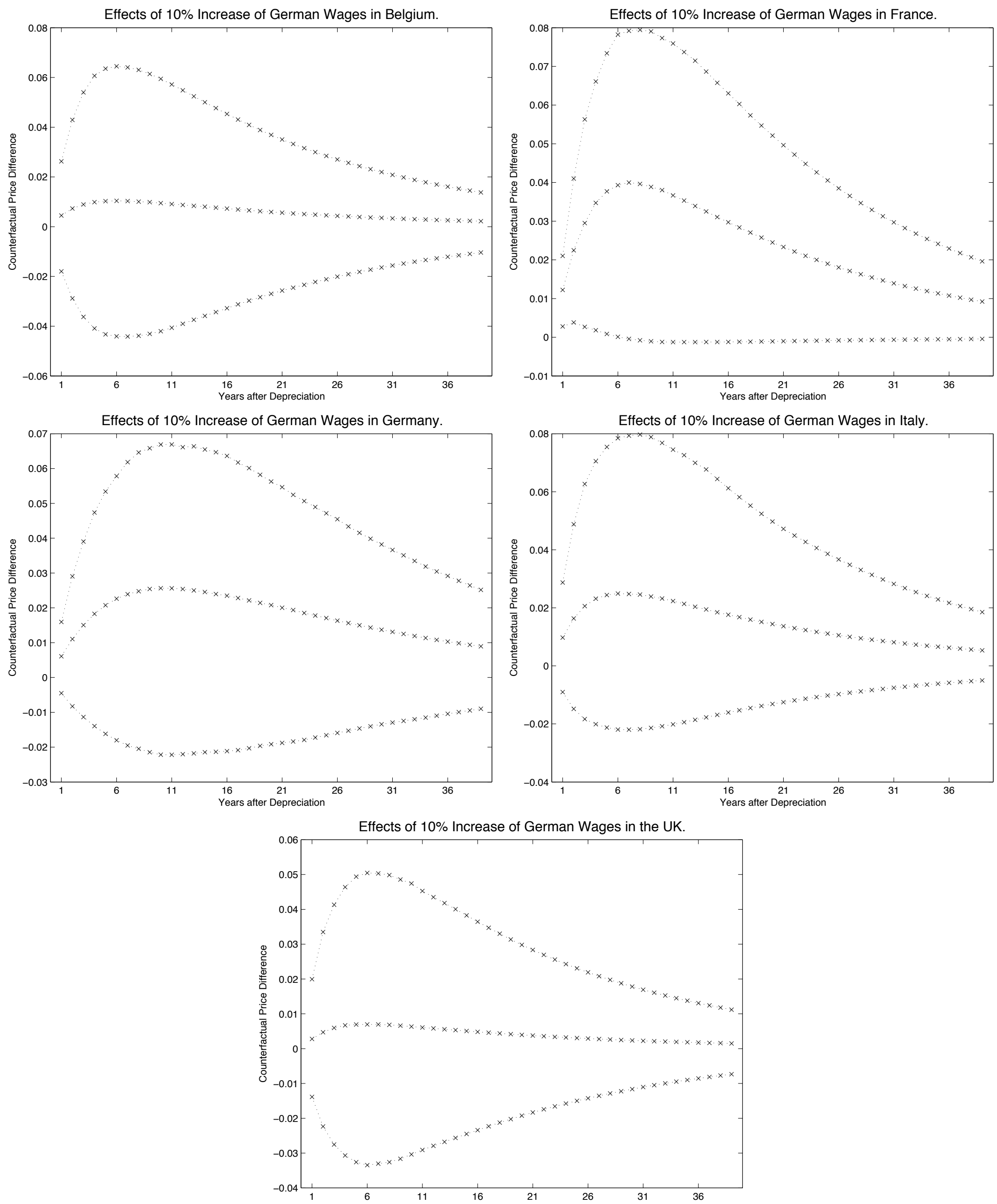


Figure 34: **Price Reactions across Europe after a 10% increase in Italian wages**

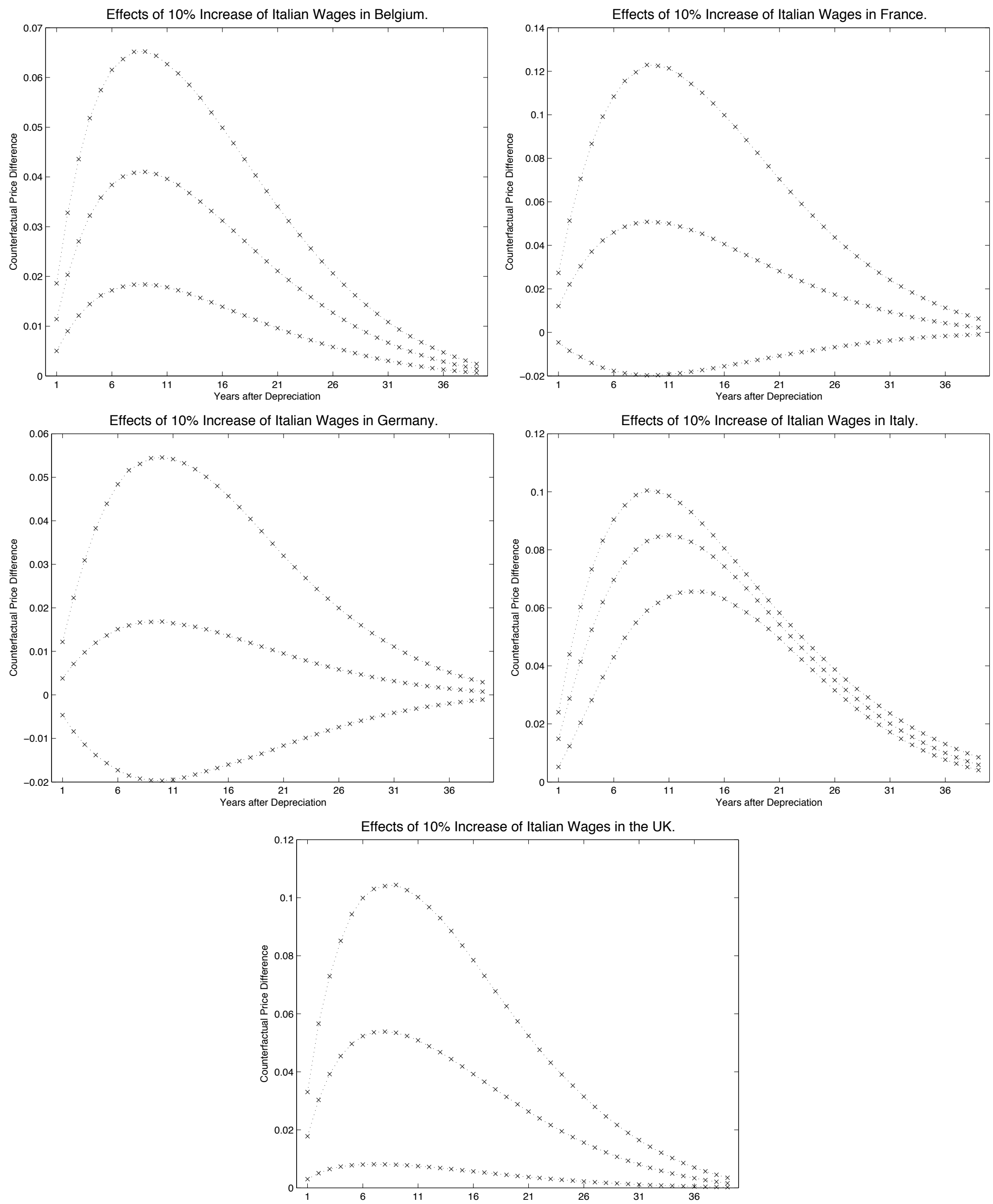


Figure 35: **Price Reactions across Europe after a 10% increase in British wages**

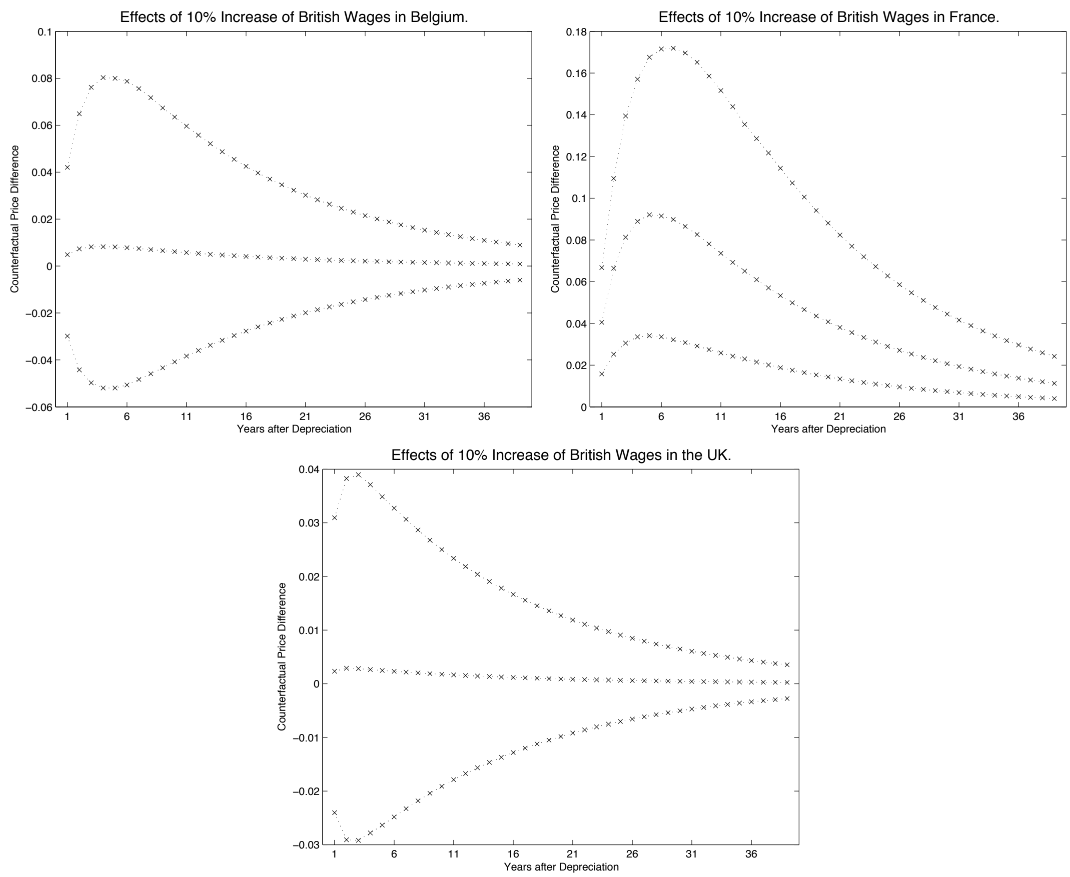
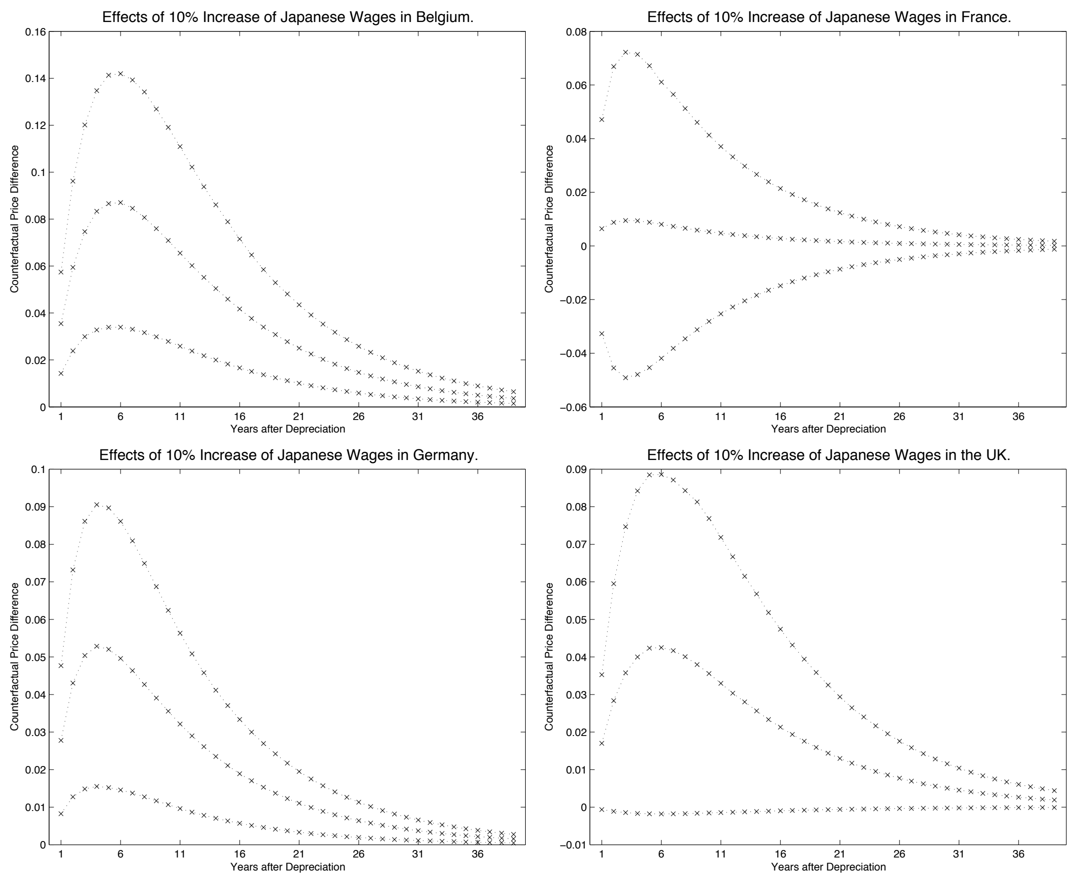


Figure 36: **Price Reactions across Europe after a 10% increase in Japanese wages**



H Alternative Price Adjustment Cost Function

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

$$\widetilde{AC}_{ft} = \sum_{m} \sum_{j \in \mathcal{F}_{fm}} \Psi_{fm} \cdot |\log(p_{jt}^{fm}) - \log(p_{jt-1}^{fm})|$$

The following tables replicate the results of tables 2, 3, 4 and 5 using the alternative specification for the price adjustment cost function. The main findings still hold, although the rankings or estimates may change.

Table 17: **Different Components (%) over Total Cost in 1985 using alternative adjustment cost function**

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

Table 18: **Adjustment Cost Share by Destination Market using alternative adjustment cost function**

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

Table 19: **Ratio of Adjustment Cost Parameters using alternative adjustment cost function:** Ψ_{fm}/Ψ_{ff}

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

Table 20: **Implied Markups in 1985 using alternative adjustment cost function**

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

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