CSEF
Centre for Studies in Economics and Finance

## Working Paper no. 789

# *Exchange-Rate Regimes and the Behaviour of Exporters*

**Cosimo Petracchi, Luca Riva, and Marco S. Petterson**

**July 2026**

**University of Naples Federico II** **University of Salerno** **Bocconi University, Milan**

---

**CSEF - Centre for Studies in Economics and Finance**
**Department of Economics and Statistics – University of Naples Federico II**
**80126 NAPLES - ITALY**
**Tel. and fax +39 081 675372 – e-mail: csef@unina.it**
**ISSN: 2240-9696**

Centre for Studies in Economics and Finance

# WORKING PAPER NO. 789

# *Exchange-Rate Regimes and the Behaviour of Exporters*

**Cosimo Petracchi[*], Luca Riva[†], and Marco S. Petterson[‡]**

## Abstract

This paper proposes a firm-level mechanism that explains why exchange-rate regimes are largely neutral with respect to real macro variables: exporters actively adjust marginal costs and markups to absorb nominal exchange-rate fluctuations. We quantify this mechanism using micro-level data from the European car market (1970–99). We show that floating regimes are associated with limited adjustment in destination-currency prices and limited response in quantities sold. We then estimate a structural demand-and-supply system to recover product-level markups and marginal costs. At breaks from pegged to floating regimes, producer-currency markups (marginal costs) fall on impact by around 11% (10%). A two-country real business cycle model with segmented financial markets, incorporating pricing-to-market and operational hedging, rationalises these patterns. Our model underscores the role of real micro rigidities, rather than nominal rigidities, in the weak transmission of exchange-rate fluctuations to real macro variables.

**Keywords:** European car market, exchange-rate regimes, demand estimation, pricing-to-market, variable markups, real rigidities.

**JEL Classification:** D22; F31; F41; F44; L11; L62; N14.

**Acknowledgments:** We thank Volha Audzei (discussant), Bo Becker, Gianluca Benigno, Pierpaolo Benigno, Luigi Bocola, Vasco Carvalho, Menzie D. Chinn, Luca Dedola, Sergio de Ferra, Harris Dellas, Jan De Loecker, Michael Devereux, Andrea Ferrero, Stefania Garetto, Alessandro Gavazza, Basile Grassi, Refet S. Gürkaynak, Pete Klenow, Matteo Maggiori, Kalina Manova, Alberto Martin, Tommaso Monacelli, Nicola Pavanini, Fabrizio Perri, Nicola Pierri, Natalia Ramondo, Cian Ruane, Felipe Saffie, Frank Verboven, Carolina Villegas-Sanchez, Iván Werning, and participants at seminars and conferences at the Central Bank of Ireland, the ECB WS2 ChaMP research network, the 19th CSEF-IGIER Symposium on Economics and Institutions, the 5th Sailing the Macro Workshop, the 27th INFER Annual Conference, the St. Louis Fed-SNB-Gerzensee-JEDC Conference on Monetary Policy Beyond Nominal Rigidities and the 14th EIEF-IGIER-Bologna Workshop in Industrial Organization for helpful comments and suggestions. All remaining errors are ours. The opinions expressed herein are those of the authors and do not necessarily reflect the views of the Central Bank of Ireland or the Eurosystem.

---

[*] Tor Vergata University of Rome. E-mail: cosimo.petracchi@uniroma2.eu

[†] Central Bank of Ireland and University College Dublin. E-mail: luca.riva@ucd.ie

[‡] University of Naples Federico II and CSEF. E-mail: marcostenborg.petterson@unina.it

Since Friedman (1953), a significant body of research in international macroeconomics and finance has aimed to evaluate how different exchange-rate regimes affect nominal and real economic variables. Seminal findings in this literature suggest that exchange-rate regimes are largely neutral with respect to real macro variables (Baxter and Stockman 1989), with the notable exception of the real exchange rate. Specifically, Mussa (1986) shows that the 1973 breakdown of the Bretton Woods system of pegged exchange rates increased the volatility of not only the nominal but also the real U.S. dollar exchange rate. This finding is referred to as the *Mussa puzzle*, since it suggests that nominal policy (the exchange-rate regime) can influence a real variable (the real exchange rate). As such, it has been regarded as one of the most convincing pieces of evidence for monetary non-neutrality (Nakamura and Steinsson 2018) and has traditionally been interpreted as suggestive evidence of nominal rigidities (Mussa 1986; Monacelli 2004). Yet, Baxter and Stockman (1989) find that the same episode left the behaviour of macro aggregates and international trade flows essentially unchanged.

In this paper, we propose and estimate an alternative explanation of these well-established facts that does not rely on nominal rigidities. We document that exporters actively adjust their marginal costs and markups to absorb nominal exchange-rate fluctuations. This firm-level hedging renders exchange-rate regimes non-neutral for *real micro* variables, marginal costs and markups, while leaving quantities sold – and hence macro aggregates and international trade flows – unaffected. The mechanism works as follows: exporters engage in pricing-to-market and are therefore limited in their ability to adjust destination-market prices in response to nominal exchange-rate fluctuations. As a consequence, these fluctuations induce changes in product-level real exchange rates. When aggregated across products, these changes account for the co-movement of nominal and real exchange rates, providing an explanation for the Mussa puzzle. Furthermore, quantities sold in destination markets remain largely unchanged, since nominal exchange-rate fluctuations are transmitted to prices only to a limited extent. At the aggregate level, this second fact explains the neutrality result of Baxter and Stockman (1989).

We quantify this mechanism by estimating the response of markups and marginal costs for multiproduct car exporters in five European markets – Belgium, France, Germany, Italy, and the United Kingdom – across six exchange-rate regime breaks. These breaks correspond to bilateral switches between floating and pegged exchange-rate regimes. In our estimation, we use the data on the European car market collected by Brenkers and Verboven (2006), covering approximately 350 car models over the period 1970–99.

European car markets are particularly well suited to analysing the effects of exchange-rate regimes on real micro variables: the rich product-level variation in precisely identified goods sold across five countries, each experiencing distinct exchange-rate regime breaks, allows us to disentangle markup adjustments from cost-pass-through responses (Van Biesebroeck and Verboven, 2025).

Our analysis proceeds in three steps. First, using the classification of exchange-rate regimes proposed by Petracchi (2022), we provide reduced-form evidence on how multiproduct car exporters adjust prices and quantities in response to exchange-rate regime breaks. We show that deviations from the law of one price for identical car models average 7% across our sample, but are systematically larger under floating regimes (11%) than under pegged ones (4%), in line with evidence of large price deviations outside of currency unions (Cavallo et al. 2014, 2015). Moreover, in floating regimes, a 1% increase in the growth rate of the nominal exchange rate is associated with only a 0.1% decline in the growth rate of relative local-currency prices, while quantities do not respond.[1]

Second, we estimate the flexible two-level nested-logit demand model of Brenkers and Verboven (2006) for European car markets, using the share-inversion and GMM logic of Berry et al. (1995). We use the system of first-order conditions together with the estimated demand elasticities to recover product-market-year-specific markups and marginal costs. Equipped with these structural estimates, we then trace the dynamic response of markups and marginal costs around exchange-rate regime breaks. In particular, we estimate an event study around transitions from pegged to floating regimes and show that producer-currency markups and marginal costs fall sharply at the break. The estimated decline is about 11% on impact and remains statistically significant in the two years after the break.

To assess the quantitative importance of these *real* patterns at the *micro* level for aggregate outcomes, we embed the results from the structural estimation into a

---

[1] Petracchi et al. (2026) provide related evidence on the volatility of product-level prices and real exchange rates. Fitzgerald et al. (2025) documents significant quantity insensitivity to exchange-rate fluctuations, proposing customer base accumulation as a potential source of stickiness. This mechanism is complementary to ours, reinforcing the role of real rigidities, and is in the same spirit as the distribution-cost channel proposed by Corsetti and Dedola (2005).

two-country real business cycle model in the final part of our analysis. The model incorporates three key features: pricing-to-market with variable markups (Kimball 1995; Klenow and Willis 2016; Aruoba et al. 2024); exporters that hedge against nominal exchange-rate fluctuations by adjusting their marginal costs (Petracchi 2026); and imperfect international financial markets to replicate the endogenous change in the volatility of exchange rates when transitioning from a pegged to a floating exchange-rate regime (Gabaix and Maggiori 2015; Maggiori 2022). We calibrate the degree of pricing-to-market and the extent of adjustment of the marginal cost of the representative exporter directly using our structural micro estimates. The calibration results show a strong correlation between changes in the nominal and real exchange rates (0.97), close to its empirical counterpart (0.91). The model also preserves the lack of transmission of exchange-rate fluctuations to real macro variables: nominal exchange rates are roughly twice as volatile as output, and net exports remain stable as well. Overall, our results show that the model successfully replicates the Mussa puzzle and the neutrality result of Baxter and Stockman (1989) without relying on nominal rigidities, which we show do not improve the quantitative fit of the model.

**Related literature.** A large empirical literature using product-level data documents local-currency price stability (Goldberg and Verboven 2001; Goldberg and Hellerstein 2013), as well as incomplete exchange-rate pass-through arising from pricing-to-market (Corsetti et al. 2022, 2026) and firm-level hedging (Amiti et al. 2014; Barbiero 2022; Blaum 2024).[2] In contrast to these studies, we explicitly examine *exchange-rate regimes*, empirically linking our results on real micro variables to the behaviour of macro aggregates.

Several contributions examine the relationship between exchange rates and real macro variables (Backus and Smith 1993, Devereux and Engel 2002, Collard and Dellas 2006, Benigno et al. 2007, Benigno and Thoenissen 2008, Corsetti et al. 2008a, Corsetti et al. 2008b, Colacito and Croce 2011, Amador et al. 2020, Lilley et al. 2022, Kekre and Lenel 2024, Itskhoki and Mukhin 2025, Chahrour et al. 2025, Acharya et al. 2026). In recent work, using household-level data to map household heterogeneity into measurable

---

[2] Close to our empirical setting, Garetto (2016) uses the same data from the European automobile market in Goldberg and Verboven (2001, 2005) and Brenkers and Verboven (2006) to test the predictions of a Ricardian model of trade and international price-setting. She shows that firms' strategic behaviour leads to incomplete pass-through of cost changes – including exchange-rate shocks – into prices. In a similar vein to the markup channel we propose, Fitzgerald and Haller (2014) show that, when prices are invoiced in local currency, the ratio of foreign to domestic markups adjusts one-for-one with nominal exchange-rate fluctuations, increasing in response to depreciations of the home currency relative to the foreign currency.

discount-factor wedges following Berger et al. (2023), Marin and Singh (2025) show that imperfect risk-sharing within countries can reconcile the aggregate cyclicality of exchange rates, provided that exchange rates are sufficiently risky with respect to idiosyncratic states. Our paper differs by focusing on the empirical relationship between exchange rates and *firm-level* micro variables. Our estimates show that exporters actively hedge against nominal exchange-rate fluctuations by adjusting their marginal costs and markups. When incorporated into a general equilibrium framework, this mechanism generates the Mussa puzzle while leaving the behaviour of macro aggregates and international trade flows essentially unaffected, even in the absence of nominal rigidities.

The remainder of the paper is structured as follows. Section 1 introduces a partial-equilibrium model that provides qualitative predictions regarding the response of prices and markups to breaks in exchange-rate regimes. Section 2 outlines the data and presents stylised facts on product-level prices and quantities across different exchange-rate regimes. Section 3 describes the framework for the structural estimation. Section 4 presents the main results. Section 5 assesses the quantitative importance of our estimates using a two-country international real business cycle model. Section 6 concludes.

## 1 A Partial-Equilibrium Model of Pricing-to-Market

In this section, we introduce a partial-equilibrium model of exporters to explain why breaks in exchange-rate regimes are associated with limited adjustments in product-level prices and no corresponding response in quantities sold. The model also provides a rationale for why markups may differ between pegged and floating exchange-rate regimes. Under a real *micro* rigidity in the form of pricing-to-market with variable markups – modelled using a Kimball (1995) aggregator as described by Klenow and Willis (2016) and Aruoba et al. (2024) – exporters adjust their optimal prices only partially in response to nominal exchange-rate fluctuations, as the curvature of demand compels them to price sufficiently close to the local prices of competitors in the destination market. In the simple model outlined below, this mechanism, together with the assumption that intermediate inputs are fully domestically sourced, implies that exporters primarily absorb such shocks through adjustments in markups.[3]

### 1.1 Assumptions

There are two countries – home (Germany) and foreign (Italy, denoted by an asterisk) – each with its own nominal unit of account in which local prices are quoted (e.g., the home wage rate, $W$, is denominated in Deutsche Marks, while the foreign wage rate, $W^*$, is denominated in Italian lira). The nominal exchange rate $\mathcal{E}$ is defined as the price of Italian lira in Deutsche Marks; thus, an increase in $\mathcal{E}$ corresponds to a nominal depreciation of the home currency (the Deutsche Mark).[4]

**Assumption 1**. There is a continuum of exporters of measure 1. The profits of German exporter $j$ are given by:

$$\Pi(j) = \left[P_H^*(j)\mathcal{E} - MC(j)\right] Y_H^*(j),$$

where $P_H^*(j)$ denotes the price of product $Y_H^*(j)$ expressed in Italian lira and sold in Italy, while $MC(j)$ is the marginal cost of production denominated in Deutsche Marks.

**Assumption 2**. The product $Y_H^*(j)$ supplied by exporter $j$ is demanded exclusively for final consumption in Italy, according to:

$$Y_H^*(j) = C_H^*(j) = \gamma^* \mathcal{H}\left(\frac{P_H^*(j)}{\mathcal{P}^*}\right) C^*,$$

where $\gamma^*$ governs Italy's degree of openness to international trade, $\mathcal{P}^*$ is an index of average prices in the foreign market, and $\mathcal{H}(\cdot) = \mathcal{G}'^{-1}(\cdot)$, where $\mathcal{G}$ is the aggregator function that implicitly defines a Kimball (1995) aggregator for the foreign consumption bundle $C^*$, which also includes foreign varieties $C_F^*(j)$:

$$\int_0^1 \left[(1-\gamma^*)\mathcal{G}\left(\frac{C_F^*(j)}{(1-\gamma^*)C^*}\right) + \gamma^* \mathcal{G}\left(\frac{C_H^*(j)}{\gamma^* C^*}\right)\right] \mathrm{d}j = 1.$$

Following Aruoba et al. (2024), we adopt the following specification for the aggregator

---

[3] In the estimation presented in Section 3 and the general-equilibrium model developed in Section 5, we relax the assumption of fully domestic intermediate inputs by allowing for the use of foreign intermediate inputs. This extension introduces a natural hedging mechanism that dampens the extent of markup adjustments.

[4] We use capital letters to denote variables in levels to distinguish them from their log-linearised counterparts introduced in Section 5. In this section and in Section 5, $i$ indexes varieties sold in the home market (produced by home domestic firms and foreign exporters) and $j$ indexes varieties sold in the foreign market (produced by home exporters and foreign domestic firms). The notation of Section 3, where $i$ indexes consumers and $j$ car models, is self-contained.

function $\mathcal{G}(\cdot)$:

$$\mathcal{G}\left(x\right) = \frac{\omega}{1+\omega\psi}\left[(1+\psi)x-\psi\right]^{\frac{1+\omega\psi}{\omega(1+\psi)}} + 1 - \frac{\omega}{1+\omega\psi}.$$

The two key parameters of the model are $\omega > 1$ and $\psi \leq 0$: the former represents the markup under a constant-elasticity-of-substitution (CES) aggregator, while the latter governs the degree of curvature in demand, generating a non-constant elasticity of substitution. Given this specification for $\mathcal{G}(\cdot)$, we have that:

$$\mathcal{H}\left(\frac{P_H^*(j)}{\mathcal{P}^*}\right) = \mathcal{G}'^{-1}\left(\frac{P_H^*(j)}{\mathcal{P}^*}\right) = \frac{1}{1+\psi}\left[\left(\frac{P_H^*(j)}{\mathcal{P}^*}\right)^{\frac{\omega(1+\psi)}{(1-\omega)}} + \psi\right].$$

It is important to note that the Kimball (1995) aggregator collapses to a CES aggregator when $\psi = 0$. In this case, the foreign consumption bundle is given by:

$$C^* = \left(\int_0^1 \left[(1-\gamma^*)^{\frac{\omega-1}{\omega}} C_F^*(j)^{\frac{1}{\omega}} + \gamma^{*\frac{\omega-1}{\omega}} C_H^*(j)^{\frac{1}{\omega}}\right] \mathrm{d}j\right)^{\omega}.$$

The (constant) elasticity of substitution is given by $\frac{\omega}{\omega-1}$, and the corresponding markup is given by $\omega$. Moreover, in this case the demand for each home variety satisfies:

$$C_H^*(j) = \gamma^*\mathcal{H}\left(\frac{P_H^*(j)}{\mathcal{P}^*}\right)C^* = \gamma^*\left(\frac{P_H^*(j)}{\mathcal{P}^*}\right)^{\frac{\omega}{(1-\omega)}} C^*.$$

**Assumption 3**. Production is linear in labour, so that $Y_H^*(j) = L_H(j)$, which implies $MC(j) = W$ in a competitive labour market.

### 1.2 Results

The German exporter $j$ maximises profits and, given Assumption 1, solves:[5]

$$\frac{\partial\Pi}{\partial P_H^*} = \frac{\partial}{\partial P_H^*}\left[\left(P_H^*\mathcal{E} - MC\right)Y_H^*\right] = 0.$$

Under Assumption 3, we can write:

$$\frac{\partial\Pi}{\partial P_H^*} = \frac{\partial}{\partial P_H^*}[(P_H^*\mathcal{E} - W)Y_H^*] = 0.$$

---

[5] Since all exporters are identical, we drop the index $j$.

By Assumption 2, this condition can be rewritten as:

$$\frac{\partial \Pi}{\partial P_H^*} = \frac{\partial}{\partial P_H^*}\left[(P_H^*\mathcal{E} - W)\gamma^* \frac{\left(\frac{P_H^*}{\mathcal{P}^*}\right)^{\frac{\omega(1+\psi)}{(1-\omega)}} + \psi}{1+\psi} C^*\right] = 0.$$

The optimal $\tilde{P}_H^*$ then satisfies:

$$\frac{1+\omega\psi}{1-\omega}\mathcal{E} - \frac{\omega(1+\psi)}{1-\omega}\frac{W}{\tilde{P}_H^*} + \psi\mathcal{E}\left(\frac{\tilde{P}_H^*}{\mathcal{P}^*}\right)^{-\frac{\omega(1+\psi)}{(1-\omega)}} = 0 \tag{1}$$

Equation (1) illustrates the importance of the degree of pricing-to-market in the *micro* foundations of the unresponsiveness of local prices to exchange-rate regimes and of the neutrality of real macro variables with respect to nominal exchange-rate fluctuations.

If $\psi = 0$, Equation (1) simplifies to the standard optimal pricing condition with a constant markup over marginal cost:

$$\tilde{P}_H^* = \frac{\omega}{\mathcal{E}} W.$$

In this case, nominal exchange-rate fluctuations are fully passed through into the exporters' optimal price.

In contrast, when $\psi < 0$, fluctuations in the nominal exchange rate are only partially transmitted to $\tilde{P}_H^*$. Instead, exporters absorb part of these movements through adjustments in markups. The more negative $\psi$ is, the stronger this absorption mechanism becomes, as pricing-to-market constrains firms to keep prices sufficiently close to the index of average prices in the destination market, $\mathcal{P}^*$.

In the empirical analysis of Section 3, we estimate this degree of pricing-to-market directly using product-level data, thereby quantifying the importance of this channel across exchange-rate regimes in which the volatility of $\mathcal{E}$ is regime dependent. We then use these estimates to calibrate the general-equilibrium model presented in Section 5.

# 2 Data and Motivating Evidence

## 2.1 Data

**The European Car Market.** Our empirical analysis relies on a large panel dataset of the European automobile market spanning the period 1970–99, used, among others, by Brenkers and Verboven (2006). The data contain detailed information on approximately 150 models per year across five major European markets: Belgium, France, Germany, Italy, and the United Kingdom. These five countries collectively account for over 85% of total car sales in Europe annually and display substantial heterogeneity along several dimensions, as the summary statistics reported in Table 1 show.

Market size varies from approximately 1.5 million cars sold per year in the U.K. to nearly 2.3 million vehicles in Germany. Import penetration ranges from around 27% in Germany to almost 45% in Italy. Similarly, the market for economy cars (segments A and B) in Italy constitutes 60% of sales in a typical year, while in Germany and the U.K. it covers less than 30%.

For each vehicle make, the dataset includes sales volumes (measured as new car registrations), pre-tax and post-tax list prices corresponding to the base model specification available in each market, and a comprehensive set of physical characteristics. Price data are drawn from consumer catalogues published in each country. Physical characteristics, also sourced from consumer catalogues, include dimensions (weight, length, width, height), engine attributes (horsepower, displacement), and performance measures (speed, acceleration time, fuel efficiency at various speeds). These characteristics can vary across markets for the same model, but such differences are rare. The dataset also contains variables identifying the model name, brand, manufacturer, country of origin and production location, and market segment classification. The total number of observations is around 12,000, implying that on average approximately 80 distinct models are sold in each market every year.

The dataset is further augmented with complementary sources of information, such as data on production location (Pemberton Associates), brand ownership and market segment for each model, as well as macroeconomic variables to control for market-level conditions.

**Exchange-rate regime breaks**. In our analysis, we adopt the classification of

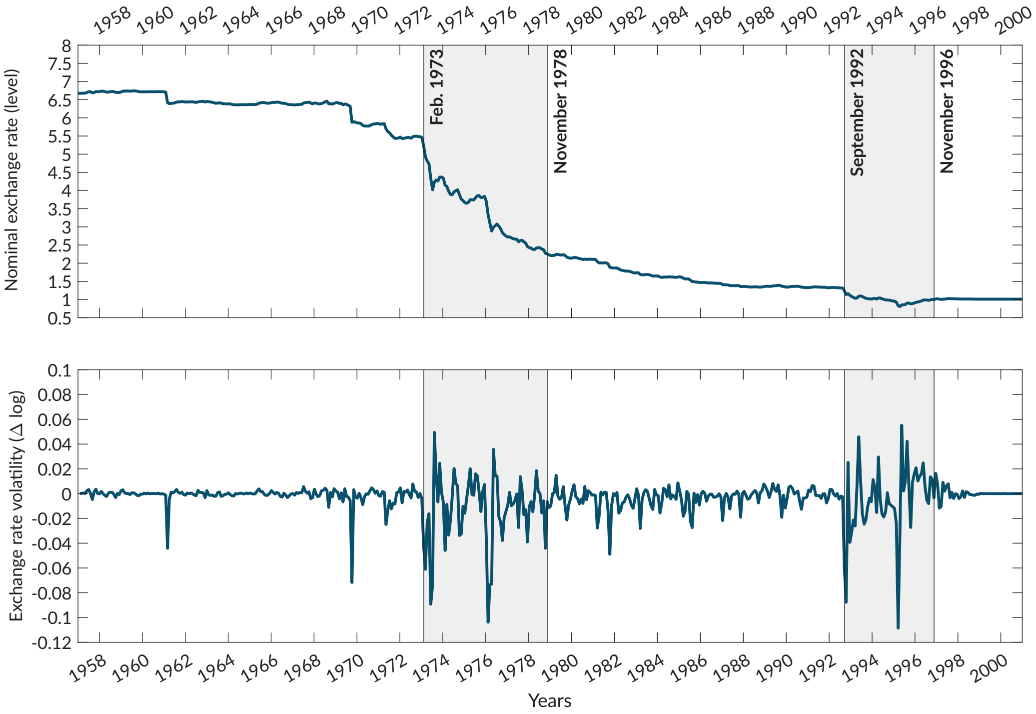
Table 1: Summary statistics for the European car market

| | Belgium | France | Germany | Italy | U.K. | All |
|---|---|---|---|---|---|---|
| Average price (local currency) | 563,258.9 | 102,117.4 | 29,441.0 | 26,502.3 | 11,060.1 | - |
| | (734,339.7) | (132,640.7) | (33,109.5) | (37,091.7) | (14,135.8) | |
| Average price (ECU) | 15,271.3 | 17,546.5 | 15,731.8 | 18,077.3 | 18,164.8 | 16,896.6 |
| | (19,933.8) | (21,753.0) | (18,689.9) | (21,750.1) | (21,192.7) | (20,694.8) |
| Foreign market share (%) | 100.0 | 30.6 | 26.8 | 42.4 | 39.1 | 47.8 |
| | (0.0) | (9.8) | (5.5) | (13.0) | (11.7) | (28.3) |
| Horsepower (HP) | 71.8 | 74.3 | 74.4 | 78.3 | 76.4 | 74.9 |
| | (45.3) | (47.9) | (47.1) | (52.0) | (47.9) | (48.0) |
| Weight (kg) | 1,039.7 | 1,049.0 | 1,054.9 | 1,062.0 | 1,057.6 | 1,052.1 |
| | (270.0) | (273.2) | (275.0) | (282.9) | (270.2) | (274.1) |
| Annual sales by segment (1,000 units) | | | | | | |
| Mini and Small | 102.0 | 822.3 | 487.4 | 945.1 | 452.5 | 2,809.3 |
| | (16.5) | (92.6) | (177.3) | (188.5) | (120.3) | (449.2) |
| Medium and Large | 189.8 | 748.4 | 1,280.8 | 576.8 | 903.1 | 3,699.0 |
| | (49.7) | (217.1) | (358.0) | (207.0) | (201.6) | (924.4) |
| Executive, Luxury, and Sport | 68.3 | 205.7 | 693.9 | 136.9 | 222.2 | 1,327.1 |
| | (14.8) | (66.6) | (105.6) | (54.8) | (44.2) | (176.9) |
| All segments | 360.2 | 1,776.4 | 2,462.2 | 1,658.8 | 1,577.8 | 7,835.4 |
| | (53.9) | (237.7) | (485.4) | (397.1) | (349.3) | (1,280.2) |
| Observations | 3,475 | 3,042 | 3,047 | 2,794 | 3,092 | 15,450 |

*Notes*: Sales represent average quantities sold annually in each market and segment (1,000 units). Prices in Italy are expressed in 1,000 Italian Liras. Standard deviation in parentheses. Sample: 1970–99.

exchange-rate regimes established by Petracchi (2022). The reference country is Germany and the exchange-rate regime – a binary pegged or floating – is defined for the bilateral nominal exchange rates between Germany and each of the other European countries in our sample. Figure 1 provides an illustration for the case of Italy.

Figure 1: Nominal exchange rate between Italy and Germany



*Notes*: Top panel: monthly nominal exchange rate (Deutsche marks per Italian lira) in levels. Bottom panel: monthly log-differences of the nominal exchange rate. White areas denote pegged exchange-rate regimes, grey shaded areas floating regimes, and vertical lines mark regime breaks identified by Petracchi (2022).

This classification was obtained by combining a narrative approach (Eichengreen 2008 and James 2014) and an econometric approach based on structural-break tests and a generalised GARCH model. Pegged (floating) exchange-rate regimes are identified as periods of low (high) volatility of nominal exchange rates. We summarise the six exchange-rate regime breaks of the classification considered in our analysis in Table 2.

Table 2: Exchange-Rate Regime Breaks

| Country | Breaks |
|---|---|
| Belgium | No Break<br>*Pegged Exchange-Rate Regime* |
| France | November 20, 1978<br>*Introduction of the Exchange Rate Mechanism* |
| Italy | February 13, 1973<br>*Exit from the Snake* |
| | November 20, 1978<br>*Introduction of the Exchange Rate Mechanism* |
| | September 17, 1992<br>*Exit from the Exchange Rate Mechanism* |
| | November 25, 1996<br>*Re-accession into the Exchange Rate Mechanism* |
| United Kingdom | June 23, 1972<br>*Exit from the Snake* |

*Notes*: The classification of exchange-rate regimes and corresponding breaks are taken from Petracchi (2022). The classification is obtained by combining both a narrative and an econometric approach. The former is based on several historical sources (primarily, Eichengreen 2008 and James 2014), whereas the econometric approach is based on two structural-break tests and a generalised autoregressive conditional heteroskedasticity (GARCH) model. Intuitively, pegged (floating) exchange-rate regimes are identified as periods of low (high) volatility of nominal exchange rates.

## 2.2 Law of One Price

We begin our analysis by examining the extent of deviations from the law of one price (LOP) at the product level. Table 3 reports the conditional means of real exchange rates for identical car models sold across different European markets. Formally, we evaluate $Q_{jmt} = \frac{P_{jt}^m}{P_{jt}^{DE}}\mathcal{E}_{mt}$, where $P_{jt}^m$ is the price of car model $j$ in market $m$ at time $t$, $P_{jt}^{DE}$ is the price of the same car model in Germany (our reference market), and $\mathcal{E}_{mt}$ is the nominal exchange rate between market $m$ and Germany. If the law of one price held exactly, $Q_{jmt}$ would equal one for all car models, markets, and time periods. Instead, we observe that prices are systematically higher in foreign markets than in Germany, with the real exchange rate averaging above one across all specifications. This indicates persistent deviations from the law of one price.

Table 3: Real exchange rates at product level

| | Exchange-rate Regime | | |
|---|---|---|---|
| Car segment | All | Pegged | Floating |
| Mini and Small | 1.007<br>(0.007) | 0.960<br>(0.009) | 1.080<br>(0.014) |
| Medium and Large | 1.054<br>(0.008) | 1.003<br>(0.010) | 1.143<br>(0.015) |
| Executive, Luxury, and Sport | 1.105<br>(0.010) | 1.078<br>(0.012) | 1.151<br>(0.016) |
| All | 1.067<br>(0.009) | 1.044<br>(0.012) | 1.106<br>(0.016) |
| Observations | 8,236 | 5,139 | 3,097 |

*Notes*: The table reports the conditional means of real exchange rates between market $m$ (Belgium, Italy, France, U.K.) and Germany at product level ($Q_{jmt} = P_{jt}^m / P_{jt}^{DE}\mathcal{E}_{mt}$), by exchange rate regime and car segment. 'All' reports the unconditional means. Pegged and floating regimes are defined between country $m$ and Germany. Standard error in parentheses.

The magnitude of these deviations varies considerably across car segments and exchange-rate regimes. Across the full sample, deviations from the LOP average around 7%, but this aggregate figure masks substantial heterogeneity. Mini and small cars exhibit the smallest deviations at approximately 1%, while executive, luxury, and sport cars display the largest deviations at around 11%. More strikingly, these cross-segment differences become more pronounced under floating exchange-rate regimes. Comparing the second and third columns of Table 3, we observe that deviations from the LOP are systematically larger under floating regimes than under pegged regimes across all car segments. For instance, real exchange rates for executive, luxury, and sport cars average 1.08 under pegged regimes but rise to 1.15 under floating regimes.

Consistent with the results in Cavallo et al. (2014), we also show that LOP deviations are due to differences in relative international prices at the time products are first introduced. Indeed, Table A.1 in Appendix A, which reports the real exchange rates only for the years in which a product is introduced, indicates that LOP deviations are already present at the introduction, with magnitudes similar to those in Table 3.

Having established these persistent deviations from the LOP, we now examine how changes in relative local-currency prices – and in sales volumes ($Y_{jmt}$) – co-move with nominal exchange-rate fluctuations.

Specifically, we estimate the following specification:

$$\Delta\tilde{p}_{jmt} = \alpha + \beta\Delta\varepsilon_{mt} + \gamma_{mot} + \delta_{jm} + \eta_{jmt},$$

where $\Delta\tilde{p}_{jmt} \equiv \ln(P^{m}_{jt}/P^{DE}_{jt}) - \ln(P^{m}_{jt-1}/P^{DE}_{jt-1})$, $\Delta\varepsilon_{mt} \equiv \ln(\mathcal{E}_{mt}) - \ln(\mathcal{E}_{mt-1})$, $\gamma_{mot}$ are year-regime fixed effects, and $\delta_{jm}$ are destination market by car model fixed effects that control for time-invariant characteristics of each model-market pair. Standard errors are clustered by destination market, car segment, and manufacturer to account for potential correlations within these groups.[6] We estimate the same specification with $\Delta\tilde{y}_{jmt} \equiv \ln(Y_{jmt}) - \ln(Y_{jmt-1})$.

Panel A of Table 4 presents the key findings. The estimated coefficient on the nominal exchange rate is significantly different from minus one across almost all the specifications, and not significantly different from zero in most specifications, indicating incomplete pass-through of exchange-rate changes to local currency prices. Across the full sample, a 1% depreciation of the destination country's currency leads to about a 0.1% decrease in relative local-currency prices, implying that exporters absorb approximately 90% of the exchange-rate shock through margin adjustments rather than fully passing it through to consumers. This incomplete pass-through is even more pronounced under floating exchange-rate regimes, where the estimated coefficient is -0.114 (not

---

[6] By expressing the specification in first differences, we ensure that both relative prices and nominal exchange rates are stationary processes, thereby eliminating the risk of identifying a spurious relationship between them.

statistically significant), compared to -0.381 under pegged regimes. This pattern suggests that exporters engage even more actively in pricing-to-market behaviour when exchange-rate volatility is higher.

Similarly, Panel B of Table 4 shows that sales volumes do not respond significantly to nominal exchange-rate fluctuations. The estimated coefficients are small in magnitude and statistically indistinguishable from zero across all specifications.

Together, these findings indicate that exporters leave destination-market prices largely unchanged in response to exchange-rate shocks, absorbing part of the movement through variable markups and marginal costs while maintaining relatively stable market shares.[7]

Table 4: Relative prices and quantities by car segment

| | A. Δ Ln prices ($\Delta\tilde{p}^m_{jt}$) | | | B. Δ Ln sales | | |
|---|---|---|---|---|---|---|
| | All sample | Pegged regimes | Floating regimes | All sample | Pegged regimes | Floating regimes |
| Mini and Small | -0.127 | -0.230 | -0.070 | -0.265 | 1.686 | 0.400 |
| | (0.073) | (0.247) | (0.133) | (0.320) | (1.194) | (0.791) |
| Medium and Large | -0.095 | -0.707 | -0.142 | 0.227 | 1.359 | 0.754 |
| | (0.050) | (0.241) | (0.173) | (0.293) | (1.087) | (0.737) |
| Executive, Luxury, | -0.095 | -0.241 | -0.123 | 0.024 | -1.523 | 0.230 |
| and Sport | (0.046) | (0.232) | (0.147) | (0.286) | (1.166) | (0.734) |
| All | -0.104 | -0.381 | -0.114 | 0.023 | 0.200 | 0.460 |
| | (0.030) | (0.139) | (0.091) | (0.172) | (0.687) | (0.486) |
| Obs. | 8,236 | 5,139 | 3,097 | 7,651 | 4,843 | 2,808 |
| N. clusters | 380 | 267 | 233 | 378 | 266 | 229 |

*Notes*: Figures report conditional marginal effects of the change in the nominal exchange rate on relative prices in local currency ($\Delta\tilde{p}_{jmt}$, Panel A) or sales (Panel B) by car segment and exchange rate regime. "All" reports effects pooled across regimes (or segments in the bottom row). Fixed effects are year by regime and destination market by car model. Robust standard errors, in parentheses, are clustered by destination market, car segment, and manufacturer.

Taken together, these reduced-form results establish three key empirical patterns. First, deviations from the law of one price are persistent and economically significant, averaging around 7% across our sample. Second, these deviations are systematically larger under floating exchange-rate regimes, particularly for higher-end vehicle

---

[7] Table A.2 in Appendix A reports similar results using a more restrictive set of fixed effects (car-year regime and model-market pair - regime fixed effects).

segments. Third, when faced with exchange-rate shocks, exporters do not adjust prices – exhibiting even stronger pricing-to-market behaviour under floating regimes – while leaving quantities essentially unchanged. These patterns motivate our structural analysis in the following sections, where we recover product-level markups and marginal costs and examine how they adjust across exchange-rate regimes.

## 3 Structural Estimation

We estimate a structural model of automobile demand and firm pricing around exchange-rate regime breaks. The demand side follows the flexible two-level nested-logit specification of Brenkers and Verboven (2006), estimated using the share-inversion and GMM logic of Berry et al. (1995). On the supply side, we use a direct multiproduct Bertrand-pricing benchmark. Relative to the full vertical model in Brenkers and Verboven (2006), we abstract from manufacturer-retailer double marginalisation and recover composite marginal costs from firms' pricing first-order conditions.

Consider manufacturers $f \in \mathcal{F}$, each selling products $j \in \mathcal{J}_{mt}$ in destination market $m \in \mathcal{M}$ and year $t \in \mathcal{T}$. Let $p_{jmt}$ denote the consumer price of product $j$ in market $m$ and year $t$, expressed in destination-market currency. For each firm $f$, let $\mathcal{J}_{fmt} \subseteq \mathcal{J}_{mt}$ denote the set of products sold by firm $f$ in market-year $(m, t)$. Demand in each market-year depends on the vector of prices

$$\mathbf{p}_{mt} \equiv (p_{kmt})_{k \in \mathcal{J}_{mt}},$$

and is independent of prices in other markets. This market-by-market structure is motivated by the frictions that segmented European car markets during our sample period, including national type-approval systems, registration requirements, transportation costs, information frictions, and language barriers.[8]

### 3.1 Demand

For consumer $i$ in market $m$ and year $t$, indirect utility from product $j$ is

$$u_{ijmt} = \delta_{jmt} - \alpha_i p_{jmt} + \nu_{ijmt}, \qquad \alpha_i = \frac{\alpha}{y_{imt}},$$

---

[8] Goldberg and Verboven (2005) provide additional evidence that European car markets were segmented along national lines during this period.

where $y_{imt}$ denotes consumer income. Mean utility is specified as

$$\delta_{jmt} = x'_{jmt}\beta + \xi_j + \xi_{mt} + \eta_{jmt}.$$

The vector $x_{jmt}$ includes observed vehicle characteristics, such as horsepower, fuel inefficiency, width, height, and an indicator for foreign origin relative to the destination market. Product fixed effects $\xi_j$ absorb time-invariant unobserved model attributes, while market-year fixed effects $\xi_{mt}$ absorb market-level variation in the value of purchasing a new car relative to the outside option. The residual $\eta_{jmt}$ captures remaining unobserved product-market-year demand shocks.

The error term $\nu_{ijmt}$ follows the two-level nested-logit structure of Brenkers and Verboven (2006). Cars are first grouped by segment and then, within each segment, divided into domestic and foreign subgroups. We use the flexible version of the model, in which the nesting parameters vary by segment. Domestic and foreign subgroups within a segment are restricted to share the same subgroup parameter, as in Brenkers and Verboven (2006). This structure allows substitution to be stronger within segments, and stronger still within segment-origin subgroups.

Aggregate market shares are obtained by integrating individual choice probabilities over the empirical income distribution:

$$s_{jmt}(\mathbf{p}_{mt}) = \int s_{ijmt}(\mathbf{p}_{mt})\, dF_{mt}(y),$$

and quantities are

$$q_{jmt}(\mathbf{p}_{mt}) = L_{mt} s_{jmt}(\mathbf{p}_{mt}),$$

where $L_{mt}$ denotes potential market size. The model is estimated pooling product-level observations across market-years, while allowing each market-year to have its own choice set and demand shocks.[9]

For any candidate value of the nonlinear parameters, mean utilities are recovered by matching predicted market shares to observed shares using a BLP-style contraction mapping. The recovered demand residuals satisfy

$$\eta_{jmt} = \delta_{jmt} - x'_{jmt}\beta - \xi_j - \xi_{mt}.$$

---

[9] Defining the choice set separately for each destination market-year accommodates the unbalanced nature of the panel, as car models enter and exit markets over time.

The parameters are estimated by GMM using moment conditions

$$E[Z_{jmt}\eta_{jmt}] = 0.$$

The instrument set follows Brenkers and Verboven (2006). It includes observed own product characteristics and excluded BLP-style markup shifters constructed from the characteristics of other vehicles in the same market-year: other products sold by the same firm in the same subgroup, rival products in the same subgroup, and rival products in the same group. These instruments shift equilibrium prices through the surrounding product mix, while the identifying restriction requires them to be orthogonal to $\eta_{jmt}$.

The estimated demand system delivers the product-market-year demand derivatives

$$D_{kj,mt} \equiv \frac{\partial q_{kmt}(\mathbf{p}_{mt})}{\partial p_{jmt}},$$

evaluated at observed prices and estimated parameters. These derivatives are the key input into the supply-side inversion. Additional details on the share inversion and derivative computation are reported in Appendix B.

### 3.2 Supply and Marginal-Cost Recovery

Firms compete in prices in a static multiproduct Bertrand-Nash equilibrium. Let $o(j)$ denote the origin country of product $j$. We introduce an origin-destination-year revenue shifter

$$\varepsilon_{jmt} \equiv \varepsilon_{o(j)mt},$$

which converts revenues earned in destination market $m$ into the producer's currency.[10] Hence $\varepsilon_{jmt}p_{jmt}$ is the producer-currency revenue per unit sold. Marginal cost is allowed to contain both a common product-year component and a destination-specific component.

For product $j \in \mathcal{J}_{fmt}$, the first-order condition is

$$\varepsilon_{jmt}q_{jmt} + \sum_{k \in \mathcal{J}_{fmt}} \left(\varepsilon_{kmt}p_{kmt} - c_{kmt}\right) D_{kj,mt} = 0. \tag{2}$$

The summation is over products sold by the same firm in the same destination

---

[10] For domestic sales, $\varepsilon_{jmt} = 1$. Other market-wide revenue distortions, such as tariffs, could be incorporated in the same way.

market-year, reflecting the internalisation of substitution patterns within the firm's product portfolio. Since demand is segmented by destination market, prices in other markets do not enter (2).

Stacking the first-order conditions within market-year $(m, t)$, define the ownership-adjusted derivative matrix

$$\Omega_{kj,mt} = \mathbf{1}\{f(k) = f(j)\} D_{kj,mt}.$$

Let $\mathbf{q}_{mt}$, $\mathbf{p}_{mt}$, $\mathbf{c}_{mt}$, and $\boldsymbol{\varepsilon}_{mt}$ denote the vectors of quantities, prices, composite marginal costs, and revenue shifters. The implied marginal-cost vector is

$$\widehat{\mathbf{c}}_{mt} = \boldsymbol{\varepsilon}_{mt} \circ \mathbf{p}_{mt} + \left(\widehat{\Omega}'_{mt}\right)^{-1} (\boldsymbol{\varepsilon}_{mt} \circ \mathbf{q}_{mt}), \tag{3}$$

where $\circ$ denotes element-by-element multiplication. The corresponding producer-currency markup is then

$$\widehat{\mu}^{prod}_{jmt} = \varepsilon_{jmt} p_{jmt} - \widehat{c}_{jmt},$$

and the markup rate is

$$\widehat{\rho}_{jmt} = \frac{\varepsilon_{jmt} p_{jmt} - \widehat{c}_{jmt}}{\varepsilon_{jmt} p_{jmt}}.$$

### 3.3 Event-Study Specification

We also estimate the dynamic response of the recovered producer-currency markups and marginal costs around pegged-to-floating exchange-rate regime breaks. The event-study sample contains all feasible origin-destination pair events in the structural sample in which there was a pegged-to-floating regime break. The main event window is $r \in \{-3, -2, -1, 0, 1, 2, 3\}$, where $r = 0$ denotes the break year and $r = -1$ is the omitted pre-break year.

Let $e$ index a directed origin-destination event pair. We align events using a sign $\varsigma_e \in \{-1, 1\}$ in order to be able to stack several possible events and maintain an intuitive interpretation of the results. When the destination currency depreciates relative to the producer currency, the results enter with their original sign, while appreciations are multiplied by $-1$. Negative coefficients therefore correspond to declines in the producer-currency outcome in the direction associated with a destination-currency depreciation. Table A.3 reports the signs and the estimation windows for each event.

For each structural outcome

$$y_{jmt} \in \left\{ \widehat{\mu}_{jmt}^{prod}, \widehat{c}_{jmt} \right\},$$

where $\mu_{jmt}^{prod}$ is the markup in producer currency and $c_{jmt}$ is the marginal cost in producer currency, we estimate

$$y_{jer}^{z} = \sum_{\ell=-3, \ell \neq -1}^{3} \beta_{\ell}^{z} \mathbf{1}\{r = \ell\} + \phi_{je}^{z} + u_{jer}^{z},$$

where $\phi_{je}^{z}$ are product-by-event fixed effects. Observations are weighted by unit sales, and standard errors are clustered at the product-by-event level.

# 4 Results

## 4.1 Structural Markups and Marginal Costs around Exchange-rate Regime Breaks

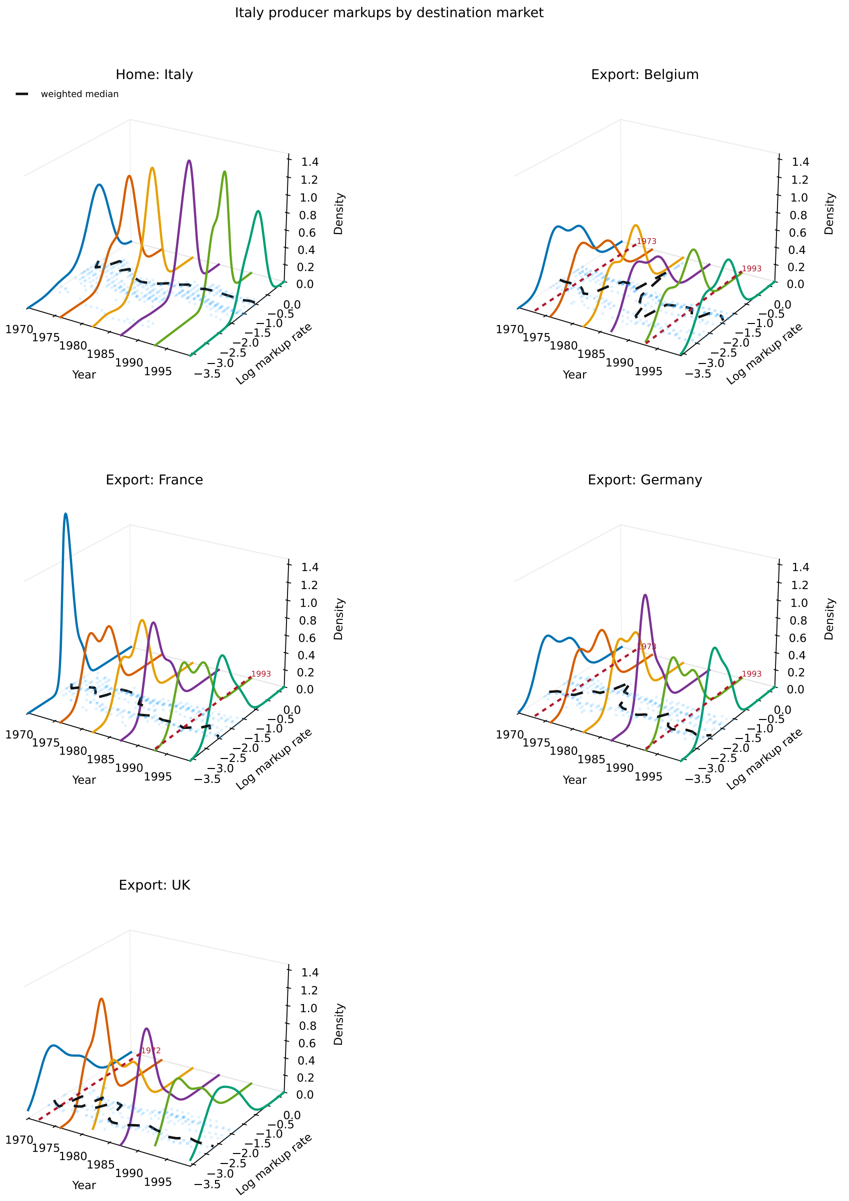
We start by showing, as an example, the distribution of markup rates for Italian producers selling in different markets over time in Figure 2.[11] The markup distribution in the home market provides a useful benchmark for interpreting the export-market panels. Looking at domestic sales, the median markup rate is relatively stable over the sample and does not show the sharp movements visible in some export destinations. The cross-product distribution shifts over time, but these shifts are gradual rather than concentrated around single dates. This pattern suggests that changes in Italian producers' export markups around exchange-rate regime breaks do not mirror a contemporaneous change in their domestic markup distribution. Instead, the home-market evidence is consistent with a relatively smooth evolution of domestic pricing margins. The export-market responses can therefore be read as the result of the changes in destination-specific exchange-rate conditions.

We next formalise this evidence by examining the dynamic behaviour of the recovered structural components of producer-currency prices around exchange-rate regime breaks with an event study as described in Section 3.3. The coefficients are interpreted as changes relative to the omitted pre-break level.

---

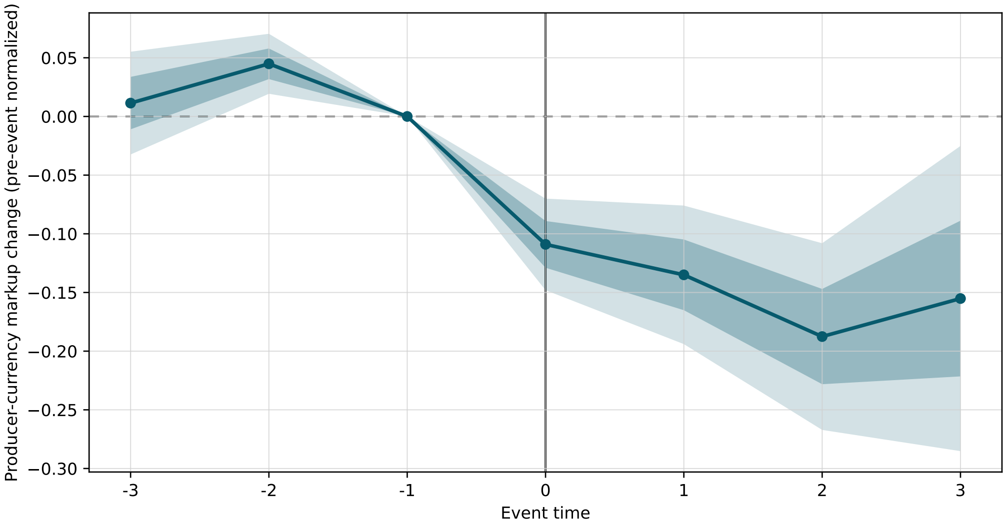
[11] The estimated coefficients of the model are reported in Appendix D.3.

Figure 2: Markup distribution of cars produced in Italy



*Notes*: The figure reports the conditional distribution of log markup rates for Italian producers. Each coloured curve is the quantity-weighted kernel density of log markup rates in a selected calendar year. Blue points show the underlying product-year observations projected onto the year-markup plane. The black dashed line traces the quantity-weighted median log markup rate by year.

Figure 3: Producer-currency markups around exchange-rate regime breaks



*Notes*: The figure reports event-study estimates for recovered producer-currency markups around exchange-rate regime breaks. The outcome is the producer-currency markup recovered from the demand system and pricing first-order conditions. Events are signed so that negative coefficients correspond to declines in producer-currency markups in the direction associated with a destination-currency depreciation relative to the producer currency. The omitted event time is $r = -1$, and $r = 0$ denotes the break year. Observations are weighted by unit sales. The specification includes product-by-event fixed effects. Standard errors are clustered at the product-by-event level. Dark and light shaded bands report 68% and 95% confidence intervals, respectively.

Figure 3 shows a decline in producer-currency markups at the break. The impact coefficient is $-0.113$, so markups fall by about 11 percent with respect to the pre-break mean. The decline remains large and persistent in the following years: the coefficient is $-0.128$ at $r = 1$, $-0.149$ at $r = 2$, and $-0.129$ at $r = 3$. The estimates are statistically significant throughout the period.

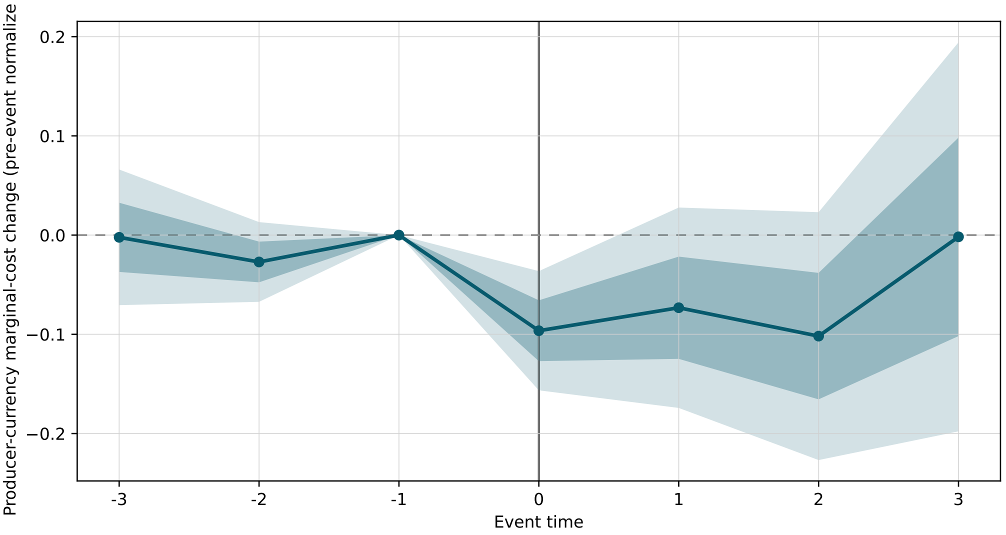
Figure 4 reports the corresponding response of recovered composite producer-currency marginal costs. Marginal costs also fall at the break. The impact coefficient is $-0.100$, implying a decline of about 10 percent of the event-pair pre-break mean. The response remains negative and statistically significant in the next two years, with coefficients of $-0.093$ at $r = 1$ and $-0.132$ at $r = 2$. By $r = 3$, the point estimate is smaller, $-0.054$, and is no longer statistically distinguishable from zero.

The marginal-cost figure completes the picture: both recovered components move down after the regime break, but the evidence for marginal-cost adjustment fades by the end of the event window.[12]

---

[12] We run the same specification using the instruments proposed by Gandhi and Houde (2026) and report results in Appendix D.4. The patterns of both markups and marginal costs remain qualitatively the same.

Figure 4: Producer-currency marginal costs around exchange-rate regime breaks



*Notes*: The figure reports event-study estimates for recovered producer-currency marginal costs around exchange-rate regime breaks. The outcome is the producer-currency marginal cost recovered from the demand system and pricing first-order conditions. Events are signed so that negative coefficients correspond to declines in producer-currency marginal costs in the direction associated with a destination-currency depreciation relative to the producer currency. The omitted event time is $r = -1$, and $r = 0$ denotes the break year. Observations are weighted by unit sales. The specification includes product-by-event fixed effects. Standard errors are clustered at the product-by-event level. Dark and light shaded bands report 68% and 95% confidence intervals, respectively.

Analyzing the two figures together, we can interpret the results as follows. In the break year, both producer-currency markups and recovered marginal costs fall by similar magnitudes. The response remains visible in both components through the first two post-break years. By $r = 3$, however, the marginal-cost effect starts to come back up and is no longer statistically significant, while markups remain significantly below their pre-break level. The evidence is therefore consistent with an initial adjustment through both recovered costs and margins, followed by a more persistent compression of producer-currency markups.

These estimates provide the structural interpretation of the reduced-form evidence of Section 2.2. Destination-market prices and quantities respond weakly to exchange-rate movements. The structural decomposition shows that producer-currency adjustment is shared between markups and marginal costs in the short run, while the more persistent response is more visible in an adjustment of markups. The magnitude and timing of these responses discipline the pricing-to-market channel in the general-equilibrium model below.

# 5 General-Equilibrium Model

Our model builds on an international real business cycle framework with productivity shocks and incorporates three key features: a real *micro* rigidity in the form of pricing-to-market with variable markups (Kimball 1995; Klenow and Willis 2016; Aruoba et al. 2024); exporters that hedge against nominal exchange-rate fluctuations by adjusting their marginal costs (Petracchi 2026); and imperfect international financial markets to model the endogenous change in the volatility of both nominal and real exchange rates when transitioning from a pegged to a floating exchange-rate regime (Gabaix and Maggiori 2015; Maggiori 2022).

Section 5.1 presents the model, Section 5.2 the solution method, and Section 5.3 the calibration and results.

## 5.1 Model

Time is discrete with an infinite horizon: $t = 0, 1, 2, \ldots$ There are two countries – home (Germany) and foreign (Italy, denoted by an asterisk) – each with its own nominal unit of account in which local prices are quoted. The nominal exchange rate $\mathcal{E}_t$ is the price of Italian lira in Deutsche Marks: an increase in $\mathcal{E}_t$ corresponds to a nominal depreciation of the home currency (the Deutsche Mark). The real exchange rate, $\mathcal{Q}_t \equiv (P_t^* \mathcal{E}_t)/P_t$, is the relative consumer price level in the two countries, with $P_t^*$ being the consumer price index in the foreign country and $P_t$ being the consumer price index in the home country. An increase in $\mathcal{Q}_t$ corresponds to a real depreciation of the home currency. The economy of each country is populated by households, two types of firms (domestic firms and exporters), and a government.

The countries are symmetric with the exception of their exchange-rate regime: the foreign country always conducts its monetary policy according to a Taylor rule by targeting inflation (a floating regime), while the home country conducts its monetary policy according to a Taylor rule that switches from targeting the nominal exchange rate (a pegged regime) to targeting inflation (a floating regime). In the following description, we focus on the home country.

### 5.1.1 The Home Country

**Households.** There is a continuum of identical households of measure 1. The representative household solves a consumption-savings problem, maximising its discounted expected utility over final consumption $C_t$ and labour $L_t$, given the discount factor $\beta$, the coefficient of relative risk aversion $\sigma$, and the inverse Frisch elasticity of labour supply $\varphi$:

$$\max_{\{C_t, L_t, Z_t, B_{t+1}\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left( \frac{1}{1-\sigma} C_t^{1-\sigma} - \frac{1}{1+\varphi} L_t^{1+\varphi} \right).$$

The household is subject to the following budget constraint:

$$P_t C_t + P_t Z_t + \frac{B_{t+1}}{R_t} \leq W_t L_t + R_t^K K_t + B_t + \Pi_{Dt} + \Pi_{Et},$$

where $Z_t$ is gross investment in the capital stock $K_t$, $B_t$ the quantity of risk-free bonds paying one unit of home currency at time $t$, $R_t$ the gross nominal interest rate, $W_t$ the nominal wage rate, $R_t^K$ the nominal rental rate of capital, and $\Pi_{Dt}$ and $\Pi_{Et}$ the profits of domestic firms and exporters. We assume that the household trades only home-currency bonds and owns only domestic firms and exporters.

The within-period consumption expenditure $P_t C_t$, between the home good $C_{Ht}$ and the foreign good $C_{Ft}$, is allocated to minimise expenditure on final consumption $C_t$:

$$P_t C_t = \int_0^1 \left[ P_{Ht}(i) C_{Ht}(i) + P_{Ft}(i) C_{Ft}(i) \right] di,$$

where $P_{Ht}(i)$ and $P_{Ft}(i)$ are the home-currency prices of the home and foreign varieties. Final consumption $C_t$ is implicitly defined by the Kimball (1995) aggregator as follows:

$$\int_0^1 \left[ (1-\gamma) \mathcal{G}\left( \frac{C_{Ht}(i)}{(1-\gamma) C_t} \right) + \gamma \mathcal{G}\left( \frac{C_{Ft}(i)}{\gamma C_t} \right) \right] di = 1.$$

In this expression, the parameter $\gamma$ governs the degree of openness to international trade and the function $\mathcal{G}(\cdot)$ is defined as in Aruoba et al. (2024), which is increasing and concave with $-\mathcal{G}''(1) \in (0, 1)$ and $\mathcal{G}(1) = \mathcal{G}'(1) = 1$:

$$\mathcal{G}(x) = \frac{\omega}{1+\omega\psi} \left[ (1+\psi) x - \psi \right]^{\frac{1+\omega\psi}{\omega(1+\psi)}} + 1 - \frac{\omega}{1+\omega\psi}.$$

This minimisation results in the following demand schedules:

$$C_{Ht}(i) = (1-\gamma)\mathcal{H}\left(\frac{P_{Ht}(i)}{\mathcal{P}_t}\right)C_t \qquad \text{and} \qquad C_{Ft}(i) = \gamma\mathcal{H}\left(\frac{P_{Ft}(i)}{\mathcal{P}_t}\right)C_t,$$

where the function $\mathcal{H}(\cdot) = \mathcal{G}'^{-1}(\cdot)$ controls the curvature of demand.[13]

The consumer price index $P_t$ and the auxiliary variable $\mathcal{P}_t$ are implicitly defined by the consumption-expenditure equation and by the Kimball (1995) aggregator, after substituting out home demand:

$$P_t = \int_0^1 \left[(1-\gamma)P_{Ht}(i)\mathcal{H}\left(\frac{P_{Ht}(i)}{\mathcal{P}_t}\right) + \gamma P_{Ft}(i)\mathcal{H}\left(\frac{P_{Ft}(i)}{\mathcal{P}_t}\right)\right] di, \tag{4}$$

$$\int_0^1 \left\{(1-\gamma)\mathcal{G}\left[\mathcal{H}\left(\frac{P_{Ht}(i)}{\mathcal{P}_t}\right)\right] + \gamma\mathcal{G}\left[\mathcal{H}\left(\frac{P_{Ft}(i)}{\mathcal{P}_t}\right)\right]\right\} di = 1. \tag{5}$$

Gross investment $Z_t$ is, like final consumption $C_t$, a Kimball (1995) bundle of domestic and foreign varieties, with demand schedules analogous to those above. It accumulates according to the following rule – quadratic capital adjustment costs – with depreciation $\delta$ and capital adjustment cost $\kappa$:

$$K_{t+1} = (1-\delta)K_t + \left[Z_t - \frac{\kappa}{2}\frac{(\Delta K_{t+1})^2}{K_t}\right].$$

**Domestic firms.** There is a continuum of identical domestic firms of measure 1. The representative domestic firm $i$ produces using a Cobb-Douglas technology with labour $L_{Dt}$, capital $K_{Dt}$, and intermediate inputs $X_{Dt}$:

$$Y_{Ht} = \left(e^{a_t}K_{Dt}^{\vartheta}L_{Dt}^{1-\vartheta}\right)^{1-\phi} X_{Dt}^{\phi}.$$

The term $a_t$ is the logarithm of total factor productivity and follows an AR(1) process:

$$a_t = \rho_a a_{t-1} + \sigma_a \epsilon_t^a, \qquad \epsilon_t^a \sim \mathcal{N}(0,1),$$

where $\rho_a \in [0,1]$ governs persistence and $\sigma_a \geq 0$ the volatility of the innovation. The intermediate input $X_{Dt}$ is an analogous Kimball (1995) bundle of domestic and foreign varieties.

---

[13] See subsection 1.1 for the details of this specification of the Kimball (1995) aggregator.

The associated marginal cost of production for the domestic firm is

$$MC_{Dt} = \frac{1}{\varpi}\left[e^{-a_t} R_t^{K^{\vartheta}} W_t^{1-\vartheta}\right]^{1-\phi} P_t^{\phi}, \qquad \text{where} \qquad \varpi \equiv \phi^{\phi}\left[(1-\phi)\vartheta^{\vartheta}(1-\vartheta)^{1-\vartheta}\right]^{1-\phi}.$$

In serving the home market, the domestic firm maximises profits,

$$\Pi_{Dt}(i) = (P_{Ht}(i) - MC_{Dt})\,Y_{Ht}(i),$$

by optimally setting $P_{Ht}(i)$.

Under the Kimball (1995) aggregator, profit maximisation yields variable-markup pricing with a common price across all domestic firms $i$:

$$P_{Ht}(i) = P_{Ht} = \mu\left(\frac{P_{Ht}}{\mathcal{P}_t}\right) MC_{Dt}. \tag{6}$$

The markup function $\mu(x) = \frac{-\frac{\partial \ln \mathcal{H}(x)}{\partial \ln x}}{-\frac{\partial \ln \mathcal{H}(x)}{\partial \ln x} - 1}$ is derived from the demand schedules of $C_t$, $Z_t$, and $X_t$ in the home country. The aggregate profits, $\Pi_{Dt} = \int_0^1 \Pi_{Dt}(i)di$, are distributed to the households.

**Exporters.** There is a continuum of exporters of measure 1. The representative exporter-importer firm $j$ still produces using a Cobb-Douglas technology with labour $L_{Et}$, capital $K_{Et}$, and intermediate inputs $X_{Et}$ but also directly imports intermediate inputs $E^*_{Ft}$ from the foreign country:

$$Y^*_{Ht} = \left[\left(e^{a_t} K_{Et}^{\vartheta} L_{Et}^{1-\vartheta}\right)^{1-\phi} X_{Et}^{\phi}\right]^{1-\phi^e} \left(E^*_{Ft}\right)^{\phi^e}.$$

Total factor productivity $a_t$ follows the same AR(1) process as for domestic firms. The intermediate input $X_{Et}$ is again an analogous Kimball (1995) bundle, whereas $E^*_{Ft}$ consists of foreign varieties produced by the foreign country's domestic firms.

Given the foreign-currency price of the foreign good $P^*_{Ft}$, the associated marginal cost of production is

$$MC_{Et} = \frac{1}{\varpi^e}\left\{\left[e^{-a_t} R_t^{K^{\vartheta}} W_t^{1-\vartheta}\right]^{1-\phi} P_t^{\phi}\right\}^{1-\phi^e} \left(\mathcal{E}_t P^*_{Ft}\right)^{\phi^e}, \quad \text{where}$$

$$\varpi^e \equiv \phi^{e\phi^e}\left\{(1-\phi^e)\phi^{\phi}\left[(1-\phi)\vartheta^{\vartheta}(1-\vartheta)^{1-\vartheta}\right]^{1-\phi}\right\}^{1-\phi^e}.$$

In serving the foreign market, the exporter-importer firm maximises profits by optimally setting $P^*_{Ht}(j)$:

$$\Pi_{Et}(j) = \left(P^*_{Ht}(j)\mathcal{E}_t - MC_{Et}\right) Y^*_{Ht}(j).$$

As for domestic firms, profit maximisation yields variable-markup pricing with a common price across all exporter-importer firms $j$:

$$P^*_{Ht}(j) = P^*_{Ht} = \mu_E\left(\frac{P^*_{Ht}}{\mathcal{P}^*_t}\right)\frac{MC_{Et}}{\mathcal{E}_t}. \tag{7}$$

The markup function $\mu_E(x) = \frac{-\frac{\partial \ln \mathcal{H}(x)}{\partial \ln x}}{-\frac{\partial \ln \mathcal{H}(x)}{\partial \ln x} - 1}$ is derived from the demand schedules of $C^*_t$, $Z^*_t$, and $X^*_t$ in the foreign country. The aggregate profits, $\Pi_{Et} = \int_0^1 \Pi_{Et}(j)dj$, are distributed to the households.

**Government in the home country.** The fiscal authority is fully passive, in the sense that we abstract from government spending and taxation, whereas the monetary authority conducts monetary policy according to the following Taylor rule:

$$i_t = \rho\, i_{t-1} + (1-\rho)[\omega_\pi \pi_t + \omega_e(e_t - \bar{e})],$$

where $i_t = \ln(R_t)$, $\bar{e}$ is the targeted nominal exchange rate (in logs), $0 \leq \rho < 1$, $\omega_\pi > 1$, and $\omega_e \geq 0$. The parameter $\rho$ represents interest rate smoothing in the monetary-policy rule, whereas the parameters $\omega_\pi$ and $\omega_e$ respectively represent the weights of the two monetary-policy objectives, inflation targeting and nominal-exchange-rate targeting. When $\omega_e = 0$, the monetary authority implements a floating regime; when $\omega_e > 0$, a pegged regime.

### 5.1.2 The Foreign Country

The foreign country is fully symmetric to the home country except that the monetary authority conducts monetary policy according to the following Taylor rule:

$$i^*_t = \rho\, i^*_{t-1} + (1-\rho)\omega_\pi \pi^*_t.$$

Unlike in the home country, the monetary authority always implements a floating regime.

### 5.1.3 International Financial Markets

The international financial markets are segmented since the home and foreign households cannot directly trade any bonds with each other (Gabaix and Maggiori 2015; Maggiori 2022). Their international financial positions are intermediated by a unit mass of global financial firms, each managed by a financier.

The representative financier solves the following constrained problem:

$$\max_{\mathcal{F}_t} V_t = \beta\,\mathbb{E}_t\left[R_t - R_t^*\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right]\mathcal{F}_t, \quad \text{subject to} \quad V_t \geq \Gamma_t\frac{\mathcal{F}_t^2}{\mathcal{E}_t},$$

where $\mathcal{F}_t$ is the balance-sheet position of the financier in Deutsche Marks and $\Gamma_t = \xi\left[\mathbb{V}\text{ar}_t(\mathcal{E}_{t+1})\right]^{\iota}$, with $\xi \geq 0$ and $\iota \geq 0$, captures the financiers' risk-bearing capacity. For simplicity, we assume that financiers rebate their profits and losses to the foreign households, not the home ones.

**Goods market.** In the home country, clearing the goods market requires that production by the domestic firms is allocated to supplying the home market, while production by exporters is allocated to supplying the foreign market. This ensures that demand in both markets is satisfied:

$$Y_{Ht} = C_{Ht} + X_{Ht} + Z_{Ht} + E_{Ht} = (1-\gamma)\mathcal{H}\left(\frac{P_{Ht}}{\mathcal{P}_t}\right)\left[C_t + X_t + Z_t\right] + E_{Ht}, \text{ and}$$

$$Y_{Ht}^* = C_{Ht}^* + X_{Ht}^* + Z_{Ht}^* = \gamma\mathcal{H}\left(\frac{P_{Ht}^*}{\mathcal{P}_t^*}\right)\left[C_t^* + X_t^* + Z_t^*\right],$$

where $P_tX_t = P_tX_{Dt} + P_tX_{Et} = \phi MC_{Dt}Y_{Ht} + (1-\phi^e)\phi MC_{Et}Y_{Ht}^*$.

Finally, we derive the home country's budget constraint:

$$\frac{B_{t+1}}{R_t} - B_t = \text{NX}_t \qquad \text{with} \qquad \text{NX}_t = (\mathcal{E}_tP_{Ht}^*Y_{Ht}^* + P_{Ht}E_{Ht}) - (P_{Ft}Y_{Ft} + \mathcal{E}_tP_{Ft}^*E_{Ft}^*),$$

where $\text{NX}_t$ denotes net exports in units of the home currency.

**International financial markets.** Clearing the international financial markets requires that the balance sheet position of the financiers in Deutsche Marks $\mathcal{F}_t$ equals $\frac{B_{t+1}}{R_t}$ and the balance sheet position of the financiers in Italian lira $\mathcal{F}_t^*$ equals $-\frac{\mathcal{F}_t}{\mathcal{E}_t}$.

## 5.2 Solution Method

In Appendix C.2, we define an equilibrium in the nonlinear model. We solve the model by log-linearisation around a symmetric steady state with steady-state markup $\bar{\mu} = 1$ and, from now on, we denote all the expressions in terms of deviations from the symmetric steady-state equilibrium; for example $y_t \equiv \ln(Y_t) - \ln(\bar{Y})$.

## 5.3 Calibration

Table 5: Model Parameters

| Non-Calibrated Parameter | Variable | Value | Source |
|---|---|---|---|
| Household discount factor | $\beta$ | 0.99 | |
| Relative risk aversion | $\sigma$ | 2 | |
| Inverse Frisch elasticity | $\varphi$ | 1 | |
| Intermediate input share | $\phi$ | 0.617 | Diehl (2001) |
| Capital share | $\vartheta$ | 0.38 | Goldberg and Verboven (2001) |
| Import intensity of exporter | $\phi^e$ | 0.37 | Goldberg and Verboven (2001) |
| Openness to trade | $\gamma$ | 0.157 | |
| Elasticity of substitution | $\frac{\omega}{\omega-1}$ | 1.5 | |
| Interest rate smoothing | $\rho$ | 0.95 | |
| Inflation rate targeting | $\omega_\pi$ | 2.15 | |
| Persistence of the shocks | $\rho_a$, $\rho_{a^*}$, $\rho_\zeta$ | 0.97 | |
| Std. dev. of financial shocks | $\chi_1\sigma_\zeta$ | 1 | |
| Coefficient of net foreign asset | $\chi_2$ | 0.001 | |
| Calvo probability for price reset | $\lambda_p$ | 0.75 | |
| Calvo probability for wage reset | $\lambda_w$ | 0.85 | |

| Calibrated Parameter | Variable | | Targeted Moment |
|---|---|---|---|
| Capital adjustment cost | $\kappa$ | → | $std(\Delta z_t)/std(\Delta y_t) = 2.5$ |
| Std. dev. of productivity shocks | $\sigma_a$, $\sigma_{a^*}$ | → | $corr(\Delta q_t, \Delta c_t - \Delta c_t^*) = -0.4$ |
| Correlation of productivity shocks | $\rho_{a,a^*}$ | → | $corr(\Delta y_t, \Delta y_t^*) = 0.35$ |

*Notes:* The non-calibrated parameters are taken from Petracchi (2026) unless noted; the degree of openness to trade is calibrated on the ratio of imports to GDP of Germany (0.31); for details on the values of the calibrated parameters see Table 6; $\kappa$, $\sigma_a$, and $\rho_{a,a^*}$ are selected to match the targeted moments $std(\Delta z_t)/std(\Delta y_t) = 2.5$, $corr(\Delta q_t, \Delta c_t - \Delta c_t^*) = -0.4$, and $corr(\Delta y_t, \Delta y_t^*) = 0.35$.

We follow the assumptions and calibration of Petracchi (2026) to match the macro moments of Germany. We generally adopt the same model parameters, as summarised in Table 5, with some notable exceptions. First, and most importantly, we calibrate the degree of pricing-to-market based on our empirical evidence on markup readjustment around exchange-rate regime breaks (Section 4).

To implement this calibration, we linearise Equation (7) to obtain:

$$p^*_{Ht}(j) = (1-\tau)(mc_{Et} - \varepsilon_t) + \tau p^*_t,$$

where $\tau \equiv \frac{\psi\omega}{\psi\omega-1}$. Defining $\mu_t \equiv [(1-\tau)(mc_{Et} - \varepsilon_t) + \tau p^*_t] - [mc_{Et} - \varepsilon_t]$, we have:

$$\tau = \frac{\mu_t}{p^*_t + \varepsilon_t - mc_{Et}}. \tag{8}$$

Equation (8) expresses the degree of pricing-to-market ($\tau$) as a function of observable variables: the percentage changes in the exporter's markups ($\mu_t$) and marginal costs ($mc_{Et}$), bilateral nominal exchange-rate appreciation/depreciation ($\varepsilon_t$), and inflation in the destination market ($p^*_t$).

We estimate $\tau$ by focusing on the exchange-rate regime breaks between Germany and Italy of February 1973 and September 1992. We treat 1972 and 1991 as the steady states. We measure $p^*$ using a quality-adjusted destination-market car price index. For each event and horizon, we compare the pre-break year $t = -1$ to the horizon year by estimating a quantity-weighted hedonic regression of log prices on a post-horizon indicator, log vehicle characteristics, segment fixed effects, and origin fixed effects. The coefficient on the post-horizon indicator gives the quality-adjusted change in destination car prices. Using our estimates for percentage changes in markups and marginal costs for German carmakers exporting to Italy, together with exchange-rate and inflation data, yields:

$$\hat{\tau} = \frac{-4.7\%}{19.4\% - 28.4\% + 0.2\%} = 0.53$$

For the remaining parameters, we calibrate the intermediate inputs share of $\phi = 0.617$ from Diehl (2001) to be consistent with the German car industry from 1970 to 1999; we set the openness-to-international-trade parameter at $\gamma = 0.157$, aligned with the mean import-to-GDP ratio of Germany in the same time period; third, we modify the capital-adjustment-cost parameter $\kappa$ to match the relative volatility of investment and output, $std(\Delta z_t)/std(\Delta y_t) = 2.5$; finally, we choose $\phi^e = 0.37$ following the empirical evidence presented in Goldberg and Verboven (2001).

Our model features three exogenous shocks for which we need to calibrate the covariance matrix: two country-specific productivity shocks $(a_t, a^*_t)$ and a financial shock $(\zeta_t)$. We assume that $\zeta_t$ is orthogonal to $(a_t, a_t^*)$, whereas $a_t$ and $a_t^*$ have the same variance (that is, $\sigma_a = \sigma_{a^*}$), and a nonzero correlation ($\rho_{a,a^*}$). We always choose the relative volatility of the shocks, $\sigma_a/\sigma_\zeta$, to match $corr(\Delta q_t, \Delta c_t - \Delta c_t^*) = -0.4$, while we always set the cross-country correlation of productivity shocks, $\rho_{a,a^*}$, to match $corr(\Delta y_t, \Delta y_t^*) = 0.35$. Table 6 reports the simulation results, for 10,000 simulations of 120 quarters, where we choose values for $\kappa$, $\sigma_a$, and $\rho_{a,a^*}$ to match $std(\Delta z_t)/std(\Delta y_t) = 2.5$, $corr(\Delta q_t, \Delta c_t - \Delta c_t^*) = -0.4$, and $corr(\Delta y_t, \Delta y_t^*) = 0.35$, respectively.

### 5.3.1 Calibration Results

Table 6 presents our main findings. First, the table shows that the volatility of the real exchange rate ($\Delta q_t$) is strongly correlated with nominal exchange rate volatility ($\Delta e_t$), replicating the Mussa (1986) puzzle. Notably, a comparison of the first row in the second and third columns indicates that our model performs well even without price and wage stickiness à la Calvo. This result represents a departure from the literature, which has traditionally interpreted the Mussa (1986) puzzle as evidence of nominal rigidities (e.g., Monacelli 2004).

Table 6: Model results for Germany

| | Data | Model | |
|---|---|---|---|
| | | Flexible | Sticky |
| $corr(\Delta e_t, \Delta q_t)$ | 0.91 | 0.97<br>(0.01) | 1.00<br>(0.00) |
| $\sigma(\Delta e_t)/\sigma(\Delta y_t)$ | 2.80 | 1.89<br>(0.17) | 1.32<br>(0.11) |
| $\sigma(\Delta e_t)/\sigma(\Delta c_t)$ | 2.80 | 2.72<br>(0.23) | 3.80<br>(0.35) |
| $\sigma(\Delta nx_t)/\sigma(\Delta q_t)$ | 0.56 | 0.57<br>(0.02) | 0.39<br>(0.01) |

*Notes:* The table represents a set of data moments generated by the model calibrated on Germany under fully flexible prices and wages (second column) and nominal sticky prices and wages à la Calvo (third column). The first row shows the correlation between real and nominal exchange rates. The second (third) row shows the relative volatility of output (consumption) and nominal exchange rates. The fourth row displays the relative volatility of net exports and the real exchange rate. Each cell in the second and third columns is the median value of moments across 10,000 simulations of 120 quarters (standard errors in parentheses); Model parameters $\kappa$, $\sigma_a$, and $\rho_{a,a^*}$ are chosen to match the following targeted moments: $std(\Delta z_t)/std(\Delta y_t) = 2.5$, $corr(\Delta q_t, \Delta c_t - \Delta c_t^*) = -0.4$, and $corr(\Delta y_t, \Delta y_t^*) = 0.35$. In the calibration in the second column, we set $\kappa = 14$, $\sigma_a = 3.02$, and $\rho_{a,a^*} = 0.29$; in the calibration in the third column, we set $\kappa = 2.5$, $\sigma_a = 2.4$, and $\rho_{a,a^*} = 0.39$. The data for Germany are sourced from national accounts (trade-weighted average figures 1970–99).

Second, our model is able to maintain the muted reaction of macro variables to exchange rates, thanks to exporters actively hedging against exchange-rate fluctuations. The second and third rows of Table 6 report the ratios of the standard deviation of the nominal exchange rate ($\Delta e_t$) to the standard deviations of output and consumption ($\Delta y_t$ and $\Delta c_t$), in log differences. These moments highlight the ability of our model – without introducing nominal price and wage rigidities – to generate a higher volatility of the nominal exchange rate compared to output and consumption, as observed in the data. Lastly, the fourth row shows the ratio between the standard deviation of net exports ($\Delta nx_t$) and the real exchange rate ($\Delta q_t$). Again, the model produces a higher volatility of the real exchange rate relative to net exports, consistent with the data, regardless of whether prices and wages are sticky.

Overall, our model incorporates the estimates for markup and marginal cost readjustment across regimes, as discussed in Section 4, within a general equilibrium framework of exchange-rate determination. In doing so, we not only replicate the Mussa (1986) puzzle but also maintain the muted reaction of real macro variables to exchange rates, offering a perspective on exchange-rate dynamics through the lens of exporter hedging behaviour. Our results underscore the role of exporters as shock absorbers, insulating domestic consumers and firms from nominal exchange-rate fluctuations.

## 6 Conclusions

This paper investigates how exchange-rate regimes affect the pricing and production decisions of multiproduct exporting firms. We contribute to the literature by providing novel evidence on the micro-level adjustments of prices, quantities, markups, and marginal costs in response to switches between pegged and floating exchange-rate regimes, and by rationalising these patterns through the lens of a quantitative general equilibrium model.

Using detailed information on approximately 350 car models across five major European markets, we structurally estimate a supply-and-demand system and recover product-level markups and marginal costs. Markup and marginal-cost readjustments in response to exchange-rate regime breaks reveal three stylised facts: markups fall by about 11% on impact; marginal costs fall by about 10%; and markup compression is more persistent than marginal-cost adjustment.

We embed the structural estimates of aggregate markup adjustment into a two-country international real business cycle model – featuring pricing-to-market, operational hedging, and segmented financial markets – calibrated to match the German economy. Our simulations show that the model successfully matches the volatility of real consumption, output, and net exports, and validate the quantitative importance of the estimated degree of pricing-to-market.

Taken together, our results support the presence of a mechanism rationalising the strong co-movement between nominal and real exchange rates (the Mussa puzzle) and the relative insulation of aggregate real macro variables from exchange-rate fluctuations. This mechanism operates through real micro rigidities at the product level that shape optimal pricing decisions for multiproduct exporters.

Our analysis focuses on the European car market spanning the period 1970–99. While this setting is specific to one industry and a period now several decades past, automobile manufacturers provide an ideal laboratory for studying the pricing behaviour of large multiproduct firms that export a substantial share of their output to multiple destinations. Despite the temporal and sectoral specificity of our data, our findings speak directly to the growing interest in how large exporting manufacturers adjust their pricing strategies in response to major external shocks – changes in trade policy, tariffs, or shifts in the long-run stance of monetary policy – questions that remain highly relevant in today's policy environment.

## References

Acharya, S., E. Challe, and L. Coulibaly (2026). The international RBC model finally works! Working paper.

Amador, M., J. Bianchi, L. Bocola, and F. Perri (2020). Exchange rate policies at the zero lower bound. *The Review of Economic Studies 87*(4), 1605–1645.

Amiti, M., O. Itskhoki, and J. Konings (2014). Importers, Exporters, and Exchange Rate Disconnect. *American Economic Review 104*(7), 1942–78.

Aruoba, S. B., E. Oue, F. Saffie, and J. Willis (2024). Reviving Micro Real Rigidities: The Importance of Demand Shocks. Working Paper 32518, NBER.

Backus, D. K. and G. W. Smith (1993). Consumption and Real Exchange Rates in Dynamic Economies with Non-Traded Goods. *Journal of International Economics 35*(3), 297–316.

Barbiero, O. (2022). The Valuation Effects of Trade. Working paper.

Baxter, M. and A. C. Stockman (1989). Business Cycles and the Exchange-Rate Regime: Some International Evidence. *Journal of Monetary Economics 23*(3), 377–400.

Benigno, G., P. Benigno, and F. Ghironi (2007). Interest Rate Rules for Fixed Exchange Rate Regimes. *Journal of Economic Dynamics and Control 31*(7), 2196–2211.

Benigno, G. and C. Thoenissen (2008). Consumption and Real Exchange Rates with Incomplete Markets and Non-Traded Goods. *Journal of International Money and Finance 27*(6), 926–948.

Berger, D., L. Bocola, and A. Dovis (2023). Imperfect risk sharing and the business cycle. *The Quarterly Journal of Economics 138*(3), 1765–1815.

Berry, S., J. Levinsohn, and A. Pakes (1995). Automobile prices in market equilibrium. *Econometrica 63*(4), 841–890.

Blaum, J. (2024). Global Firms in Large Devaluations. *The Quarterly Journal of Economics 139*(4), 2427–2474.

Brenkers, R. and F. Verboven (2006). Liberalizing a Distribution System: The European Car Market. *Journal of the European Economic Association 4*(1), 216–251.

Cavallo, A., B. Neiman, and R. Rigobon (2014). Currency Unions, Product Introductions, and the Real Exchange Rate. *The Quarterly Journal of Economics 129*(2), 529–595.

Cavallo, A., B. Neiman, and R. Rigobon (2015). The Price Impact of Joining a Currency Union: Evidence from Latvia. *IMF Economic Review 63*(2), 281–297.

Chahrour, R., V. Cormun, P. D. Leo, P. Guerron-Quintana, and R. Valchev (2025). Exchange Rate Disconnect Revisited. Working paper.

Colacito, R. and M. M. Croce (2011). Risks for the Long Run and the Real Exchange Rate. *Journal of Political Economy 119*(1), 153–181.

Collard, F. and H. Dellas (2006). Price Rigidity and the Selection of the Exchange Rate Regime. *Open Economies Review 17*(1), 5–26.

Corsetti, G., M. Crowley, and L. Han (2022). Invoicing and the Dynamics of Pricing-to-Market: Evidence from UK Export Prices around the Brexit Referendum. *Journal of International Economics 135*, 103570.

Corsetti, G. and L. Dedola (2005). A Macroeconomic Model of International Price Discrimination. *Journal of International Economics 67*(1), 129–155.

Corsetti, G., L. Dedola, and S. Leduc (2008a). High Exchange-Rate Volatility and Low Pass-Through. *Journal of Monetary Economics 55*(6), 1113–1128.

Corsetti, G., L. Dedola, and S. Leduc (2008b). International Risk Sharing and the Transmission of Productivity Shocks. *The Review of Economic Studies 75*(2), 443–473.

Corsetti, G., L. Han, M. Crowley, and H. Song (2026). Markets and Markups: Evidence on the Rising Market Power of Exporters from China. Working paper.

Devereux, M. B. and C. Engel (2002). Exchange rate pass-through, exchange rate volatility, and exchange rate disconnect. *Journal of Monetary Economics 49*(5), 913–940.

Diehl, M. (2001). International trade in intermediate inputs: The case of the automobile industry. Working paper no. 1027, Kiel Institute of World Economics.

Eichengreen, B. (2008). *Globalizing Capital: A History of the International Monetary System*. Princeton University Press.

Fitzgerald, D. and S. Haller (2014). Pricing-to-Market: Evidence From Plant-Level Prices. *The Review of Economic Studies 81*(2), 761–786.

Fitzgerald, D., Y. Yedid-Levi, and S. Haller (2025). Can Sticky Quantities Explain Export Insensitivity to Exchange Rates? *IMF Economic Review 73*(1), 20–44.

Friedman, M. (1953). The Case for Flexible Exchange Rates. In *Essays in Positive Economics*. University of Chicago Press.

Gabaix, X. and M. Maggiori (2015). International Liquidity and Exchange Rate Dynamics. *The Quarterly Journal of Economics 130*(3), 1369–1420.

Gandhi, A. and J.-F. Houde (2026). Measuring Substitution Patterns in Differentiated-Products Industries. Working paper.

Garetto, S. (2016). Firms' Heterogeneity, Incomplete Information, and Pass-Through. *Journal of International Economics 101*, 168–179.

Goldberg, P. K. and R. Hellerstein (2013). A Structural Approach to Identifying the Sources of Local Currency Price Stability. *The Review of Economic Studies 80*(1), 175–210.

Goldberg, P. K. and F. Verboven (2001). The Evolution of Price Dispersion in the European Car Market. *The Review of Economic Studies 68*(4), 811–848.

Goldberg, P. K. and F. Verboven (2005). Market Integration and Convergence to the Law of One Price: Evidence from the European Car Market. *Journal of International Economics 65*(1), 49–73.

Itskhoki, O. and D. Mukhin (2025). Mussa Puzzle Redux. *Econometrica 93*(1), 1–39.

James, H. (2014). *Making the European Monetary Union*. The Belknap Press of Harvard University Press.

Kekre, R. and M. Lenel (2024). Exchange Rates, Natural Rates, and the Price of Risk. Working paper.

Kimball, M. S. (1995). The Quantitative Analytics of the Basic Neomonetarist Model. *Journal of Money, Credit and Banking 27*(4), 1241–1277.

Klenow, P. J. and J. L. Willis (2016). Real Rigidities and Nominal Price Changes. *Economica 83*(331), 443–472.

Lilley, A., M. Maggiori, B. Neiman, and J. Schreger (2022). Exchange Rate Reconnect. *The Review of Economics and Statistics 104*(4), 845–855.

Maggiori, M. (2022). International Macroeconomics with Imperfect Financial Markets. In G. Gopinath, E. Helpman, and K. Rogoff (Eds.), *Handbook of International Economics*, Volume 6, pp. 199–236. Elsevier.

Marin, E. A. and S. R. Singh (2025). Incomplete Markets and Exchange Rates.

Monacelli, T. (2004). Into the Mussa Puzzle: Monetary Policy Regimes and the Real Exchange Rate in a Small Open Economy. *Journal of International Economics 62*(1), 191–217.

Mussa, M. (1986). Nominal Exchange Rate Regimes and the Behavior of Real Exchange Rates: Evidence and Implications. *Carnegie-Rochester Conference Series on Public Policy 25*, 117–214.

Nakamura, E. and J. Steinsson (2018). Identification in Macroeconomics. *Journal of Economic Perspectives 32*(3), 59–86.

Petracchi, C. (2022). The Mussa Puzzle: A Generalization. *European Economic Review 149*, 104222.

Petracchi, C. (2026). The Macro Neutrality of Exchange-Rate Regimes in the presence of Exporter-Importer Firms. Working paper.

Petracchi, C., M. Mello, and J. Kim (2026). Monetary Regimes and Real Exchange Rates: Product-Level Evidence over Five Decades. Working paper.

Van Biesebroeck, J. and F. Verboven (2025). Demand, competition and public policy in the automobile industry. *Journal of Economic Literature*.

# Appendix

## A Motivating Evidence – Additional Results

Table A.1: Real exchange rates at product level at year of introduction

| | Exchange-rate Regime | | |
|---|---|---|---|
| Car segment | All | Pegged | Floating |
| Mini and Small | 1.065 | 1.041 | 1.110 |
| | (0.013) | (0.016) | (0.020) |
| Medium and Large | 1.084 | 1.056 | 1.130 |
| | (0.009) | (0.011) | (0.017) |
| Executive, Luxury, | 1.140 | 1.115 | 1.181 |
| and Sport | (0.019) | (0.021) | (0.026) |
| All | 1.103 | 1.092 | 1.121 |
| | (0.012) | (0.013) | (0.017) |
| Observations | 1,175 | 762 | 413 |

*Notes*: The table reports the conditional means of real exchange rates between market $m$ (Belgium, Italy, France, U.K.) and Germany at product level ($Q_{jmt} = P^{m}_{jt}/P^{DE}_{jt}\mathcal{E}_{mt}$), by exchange rate regime and car segment. The sample is restricted to the first observed year for each product. "All" reports the unconditional means. Pegged and floating regimes are defined between country $m$ and Germany. Standard error in parentheses.

Table A.2: Relative prices and quantities by car segment

| | A. $\Delta$ Ln prices ($\Delta\tilde{p}^{m}_{jt}$) | | | B. $\Delta$ Ln sales | | |
|---|---|---|---|---|---|---|
| | All sample | Pegged regimes | Floating regimes | All sample | Pegged regimes | Floating regimes |
| Mini and Small | -0.083 | -0.259 | -0.105 | 0.212 | 1.768 | 0.920 |
| | (0.091) | (0.209) | (0.147) | (0.397) | (1.359) | (0.822) |
| Medium and Large | -0.092 | -0.535 | -0.120 | 0.586 | 1.458 | 0.766 |
| | (0.087) | (0.169) | (0.187) | (0.380) | (0.968) | (0.755) |
| Executive, Luxury, and Sport | -0.105 | -0.217 | -0.109 | -1.103 | -1.621 | -0.291 |
| | (0.081) | (0.192) | (0.170) | (0.344) | (0.848) | (0.634) |
| All | -0.096 | -0.330 | -0.111 | -0.197 | 0.229 | 0.435 |
| | (0.048) | (0.111) | (0.097) | (0.220) | (0.521) | (0.426) |
| Obs. | 6,003 | 4,451 | 1,552 | 5,495 | 4,130 | 1,365 |
| N. clusters | 340 | 247 | 209 | 337 | 246 | 202 |

*Notes*: Figures report conditional marginal effects of the change in the nominal exchange rate on relative prices in local currency ($\Delta\tilde{p}_{jmt}$, Panel A) or sales (Panel B) by car segment and exchange rate regime. "All" reports effects pooled across regimes (or segments in the bottom row). Fixed effects are model-year - regime and model-market pair - regime fixed effects. Robust standard errors in parentheses, clustered by destination market and car company.

# B Demand Probabilities, Share Inversion, and Demand Derivatives

This appendix gives the details behind the demand derivatives used in the supply-side inversion.

For consumer $i$, define

$$V_{ijmt} = \delta_{jmt} - \frac{\alpha}{y_{imt}} p_{jmt}.$$

Products are grouped into segments $g$, and each segment is divided into domestic and foreign subgroups $h$. Let $\mathcal{J}_{hg,mt}$ denote the set of products in subgroup $h$ of segment $g$ in market-year $(m,t)$. For product $j \in \mathcal{J}_{hg,mt}$, the individual choice probability is

$$s_{ijmt} = s_{ijmt|hg} s_{ihgmt|g} s_{igmt},$$

where

$$s_{ijmt|hg} = \frac{\exp\left(V_{ijmt}/(1-\sigma^S_g)\right)}{\sum_{\ell \in \mathcal{J}_{hg,mt}} \exp\left(V_{i\ell mt}/(1-\sigma^S_g)\right)},$$

$$s_{ihgmt|g} = \frac{\exp\left(I_{ihgmt}/(1-\sigma^G_g)\right)}{\sum_{r \in \{D,F\}} \exp\left(I_{irgmt}/(1-\sigma^G_g)\right)},$$

and

$$s_{igmt} = \frac{\exp(I_{igmt})}{1 + \sum_{g'} \exp(I_{ig'mt})}.$$

The inclusive values are

$$I_{ihgmt} = (1-\sigma_g^S)\log \sum_{\ell \in \mathcal{J}_{hg,mt}} \exp\left(V_{i\ell mt}/(1-\sigma_g^S)\right),$$

and

$$I_{igmt} = (1-\sigma_g^G)\log \sum_{r \in \{D,F\}} \exp\left(I_{irgmt}/(1-\sigma_g^G)\right).$$

For any candidate value of the nonlinear parameters, mean utilities are recovered using the modified BLP contraction

$$\delta_{jmt}^{r+1} = \delta_{jmt}^{r} + (1-\bar{\sigma})\left[\log s_{jmt}^{obs} - \log s_{jmt}(\delta_{mt}^{r};\theta)\right],$$

where

$$\bar{\sigma} = \max_g \{\sigma_g^S, \sigma_g^G\}.$$

The market-share derivative is computed by averaging individual-level derivatives over the empirical income distribution:

$$D_{kj,mt} = L_{mt}\frac{\partial s_{kmt}}{\partial p_{jmt}} = \frac{L_{mt}}{N_{mt}}\sum_{i=1}^{N_{mt}} \frac{\partial s_{ikmt}}{\partial p_{jmt}}.$$

Let $g_j$ and $h_j$ denote the segment and subgroup of product $j$, and write

$$a_{ijmt} = s_{ijmt|h_j g_j}, \qquad b_{ih_j g_j mt} = s_{ih_j g_j mt|g_j}, \qquad c_{ig_j mt} = s_{ig_j mt}.$$

For products $j$ and $k$ in the same market-year, the individual derivative is

$$\frac{\partial s_{ikmt}}{\partial p_{jmt}} = -\frac{\alpha}{y_{imt}} s_{ikmt} A_{ikj,mt},$$

where

$$\begin{aligned} A_{ikj,mt} = {} & \mathbf{1}\{g_k = g_j,\ h_k = h_j\}\frac{\mathbf{1}\{k=j\} - a_{ijmt}}{1-\sigma_{g_j}^S} \\ & + \mathbf{1}\{g_k = g_j\}\frac{\mathbf{1}\{h_k = h_j\} - b_{ih_j g_j mt}}{1-\sigma_{g_j}^G} a_{ijmt} \\ & + \left[\mathbf{1}\{g_k = g_j\} - c_{ig_j mt}\right] b_{ih_j g_j mt} a_{ijmt}. \end{aligned}$$

This expression accounts for substitution within the same segment-origin subgroup, across subgroups within the same segment, and across segments through the outside-option-inclusive upper nest.

# C General Equilibrium Model

## C.1 Home Country

**Households.** The solution to the consumption-savings problem of the representative household can be obtained by formulating a Lagrangian. Combining the first-order conditions of the Lagrangian and the accumulation rule for the capital stock results in the Euler equation, the labour supply equation, and the capital pricing equation:

$$C_t^{-\sigma} = \beta R_t \mathbb{E}_t \left[ \frac{C_{t+1}^{-\sigma}}{P_{t+1}} \right] P_t,$$

$$C_t^{\sigma} L_t^{\varphi} = \frac{W_t}{P_t}, \text{ and}$$

$$\left(1 + \kappa \frac{\Delta K_{t+1}}{K_t}\right) C_t^{-\sigma} = \beta \mathbb{E}_t \left\{ \left(C_{t+1}^{-\sigma}\right) \left[ \frac{R_{t+1}^K}{P_{t+1}} - \delta + \left(1 + \kappa \frac{\Delta K_{t+2}}{K_{t+1}}\right) + \frac{\left(\kappa \frac{\Delta K_{t+2}}{K_{t+1}}\right)^2}{2\kappa} \right] \right\}.$$

**Domestic firms.** The solution to the cost minimisation of the representative domestic firm results in the following demands for labour, capital, and intermediate inputs:

$$W_t L_{Dt} = (1-\phi)(1-\vartheta) MC_{Dt} Y_{Ht},$$

$$R_t^K K_{Dt} = (1-\phi)\vartheta MC_{Dt} Y_{Ht}, \text{ and}$$

$$P_t X_{Dt} = \phi MC_{Dt} Y_{Ht}.$$

**Exporters.** The solution to the cost minimisation of the representative exporter results in the following demands for labour, capital, intermediate inputs, and directly imported inputs:

$$\begin{aligned} W_t L_{Et} &= (1-\phi^e)(1-\phi)(1-\vartheta) MC_{Et} Y_{Ht}^*, \\ R_t^K K_{Et} &= (1-\phi^e)(1-\phi)\vartheta MC_{Et} Y_{Ht}^*, \\ P_t X_{Et} &= (1-\phi^e)\phi MC_{Et} Y_{Ht}^*, \text{ and} \\ \mathcal{E}_t P_{Ft}^* E_{Ft}^* &= \phi^e MC_{Et} Y_{Ht}^*. \end{aligned} \tag{9}$$

## C.2 Equilibrium Definition and Model Solution

**Equilibrium in the Nonlinear Model.** Given the exogenous shocks $\{a_t,\ a_t^*, \zeta_t\}$, the policy specifications for the sequence of gross nominal interest rates $\{R_t,\ R_t^*\}$, and the targeted nominal exchange rate $\{\bar{\mathcal{E}}\}$, an equilibrium in the nonlinear model is a collection of stochastic processes for $\{Y_t,\ Y_t^*,\ Y_{Ht},\ Y_{Ft},\ Y_{Ht}^*,\ Y_{Ft}^*,\ C_t,\ C_t^*,\ L_t,\ L_t^*,\ K_t,\ K_t^*,\ X_t,\ X_t^*,\ P_t,\ P_t^*,\ \mathcal{P}_t,\ \mathcal{P}_t^*,\ P_{Ht},\ P_{Ft},\ P_{Ht}^*,\ P_{Ft}^*,\ W_t,\ W_t^*,\ R_t^K,\ R_t^{K^*},\ \mathcal{F}_t,\ \mathcal{F}_t^*,\ B_t,\ B_t^*,\ \mathcal{E}_t\}$ that solves the price indexes (4) and (5); the optimal pricing equations (6) and (7); the Euler equation; the labour supply equation; the asset pricing equation; the domestic firm demands for labour, capital, and intermediate inputs; the exporter demands for labour, capital, intermediate inputs, and directly imported inputs; their respective counterparts in the foreign country; the market clearing conditions for labour, capital, and goods in the home country; the market clearing conditions for labour, capital, and goods in the foreign country; and the market clearing conditions in the international financial markets.

# D Additional Results

## D.1 Event Study Sample

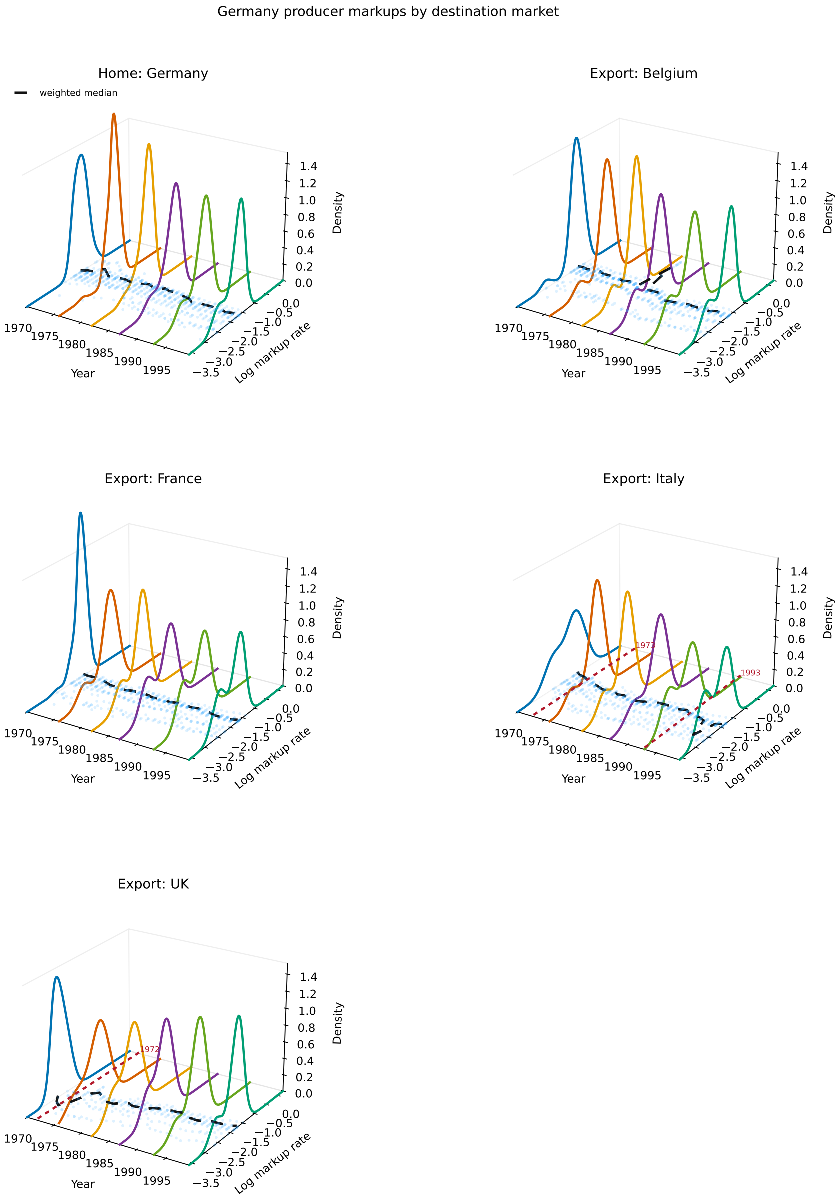
Table A.3: Directed structural event sample

| Origin → destination | Year | $\Delta \log E$ | Window | Obs. | Products |
|---|---|---|---|---|---|
| Germany → U.K. | 1972 | 0.080 | No $r = -3$ | 45 | 16 |
| Italy → U.K. | 1972 | 0.058 | No $r = -3$ | 35 | 14 |
| U.K. → Belgium | 1972 | -0.087 | No $r = -3$ | 41 | 14 |
| U.K. → Germany | 1972 | -0.080 | No $r = -3$ | 19 | 7 |
| U.K. → Italy | 1972 | -0.058 | No $r = -3$ | 12 | 5 |
| Germany → Italy | 1973 | 0.208 | Full | 127 | 37 |
| Italy → Belgium | 1973 | -0.136 | Full | 98 | 22 |
| Italy → Germany | 1973 | -0.208 | Full | 87 | 22 |
| France → Italy | 1992 | 0.151 | Full | 100 | 24 |
| Germany → Italy | 1992 | 0.160 | Full | 128 | 27 |
| Italy → Belgium | 1992 | -0.144 | Full | 98 | 22 |
| Italy → France | 1992 | -0.151 | Full | 85 | 19 |
| Italy → Germany | 1992 | -0.160 | Full | 84 | 19 |

*Notes:* "Window" indicates whether the event has support for the full $[-3, 3]$ annual window. The sign action is applied to the event-study outcome before stacking directed events.

## D.2 Markup Distribution Germany

Figure A.1: Markup distribution of cars produced in Germany



*Notes*: The figure reports the conditional distribution of log markup rates for German producers. Each coloured curve is the quantity-weighted kernel density of log markup rates in a selected calendar year. Blue points show the underlying product-year observations projected onto the year-markup plane. The black dashed line traces the quantity-weighted median log markup rate by year.

## D.3 Structural Model Estimates

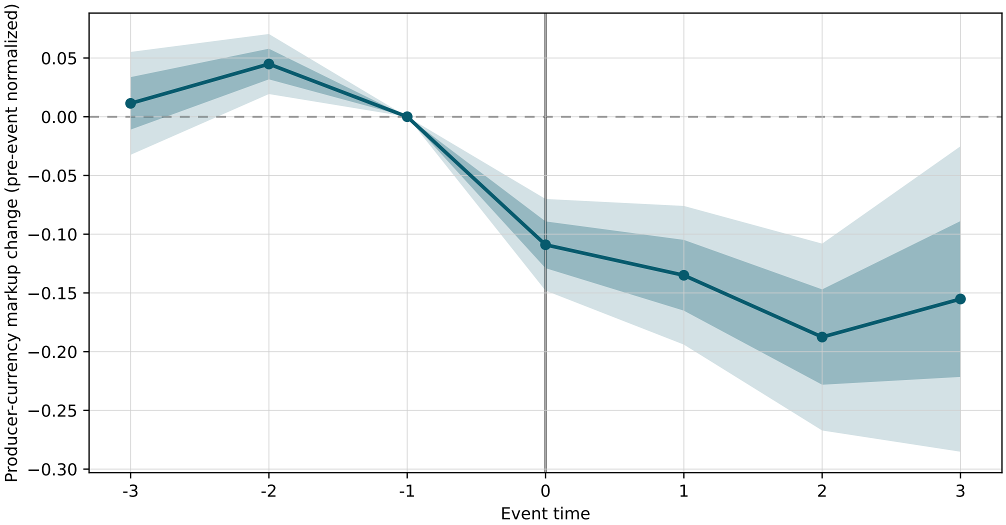
Table A.4: Demand model estimates

| Parameter | Estimate |
|---|---|
| *Parameters for Car Characteristics* | |
| Horsepower | 0.015 |
| Fuel inefficiency | -0.030 |
| Width | 0.036 |
| Height | 0.013 |
| Foreign | -0.835 |
| -Price | 6.231 |
| *Subgroup nesting* $\sigma_{hg}$ | |
| Subcompact | 0.870 |
| Compact | 0.576 |
| Intermediate | 0.530 |
| Standard | 0.591 |
| Luxury | 0.171 |
| *Segment nesting* $\sigma_g$ | |
| Subcompact | 0.302 |
| Compact | 0.387 |
| Intermediate | 0.328 |
| Standard | 0.416 |
| Luxury | -0.057 |

*Notes:* The table reports the flexible income-bucket nested-logit demand estimates used in the structural analysis. The mean-utility equation includes product and market-year fixed effects. The price coefficient enters household utility as $\alpha_i = \alpha / y_i$, where $y_i$ is income. Subgroup and segment nesting parameters vary by segment. The estimation sample contains 11,549 product-market observations in 150 market-year cells.

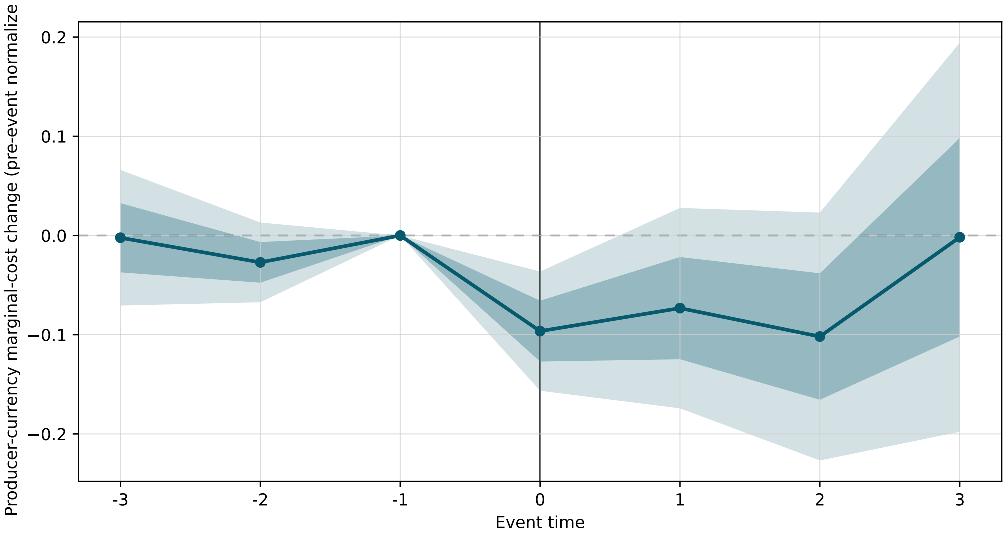
## D.4 Gandhi and Houde (2026) Instruments

Figure A.2: Producer-currency markup adjustment around exchange-rate regime breaks



*Notes*: The figure reports event-study estimates for directed origin-destination event pairs around pegged-to-floating episodes. The outcome is the signed change in FOC-implied producer-currency markups, normalised by the absolute sales-weighted event-pair mean in the year before the break. Structural markups are recovered from a demand system estimated using Gandhi–Houde-style differentiation instruments, following Gandhi and Houde (2026). Negative coefficients correspond to markup declines in the direction associated with destination-currency depreciation relative to the producer currency. Observations are weighted by unit sales. The specification includes product-by-event fixed effects. Standard errors are clustered at the product-by-event level. The light shaded band is the 95% confidence interval; the darker band is the 68% confidence interval.

Figure A.3: Producer-currency marginal-cost adjustment around exchange-rate regime breaks



*Notes*: The figure reports event-study estimates for directed origin-destination event pairs around pegged-to-floating episodes. The outcome is the signed change in recovered producer-currency marginal costs, normalised by the absolute sales-weighted event-pair mean in the year before the break. Marginal costs are recovered jointly with markups from the same structural demand estimates based on Gandhi–Houde-style differentiation instruments (Gandhi and Houde, 2026). Negative coefficients correspond to marginal-cost declines in the direction associated with destination-currency depreciation relative to the producer currency. Observations are weighted by unit sales. The specification includes product-by-event fixed effects. Standard errors are clustered at the product-by-event level. The light shaded band is the 95% confidence interval; the darker band is the 68% confidence interval.