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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 fall on impact by around 11% and marginal costs by 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 codes: D22; F31; F41; F44; L11; L62; N14

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Non-technical Summary

The transmission of exchange-rate movements to prices, output and trade is a key question for central banks in open economies, and the historical record poses a puzzle. When countries abandoned fixed exchange rates, output and trade were mostly unaffected, yet the real exchange rate — the relative price of the same goods across countries — became as volatile as the currency itself. This finding, known as the Mussa puzzle, is usually read as evidence that prices are sticky in the buyer's currency. We propose and test a complementary explanation: exporters deliberately absorb currency movements in their margins and costs rather than passing them on to consumers.

We study the European car market between 1970 and 1999, when the currencies of France, Italy and the United Kingdom moved in and out of pegs through the Bretton Woods system and the Exchange Rate Mechanism (ERM I). The data include the price, sales and characteristics of roughly 350 car models sold in Belgium, France, Germany, Italy and the United Kingdom. First, we document how prices and sales of the same car model respond to exchange-rate movements under the two regimes across different destination markets. Second, we estimate a model of car demand and pricing to recover the price markup and marginal cost of each model, market and year. Third, we build a two-country macroeconomic model to test whether this product-level behaviour accounts for the aggregate facts.

Identical cars sell at different prices across countries: the gap averages 7%, but it is 4% under pegged regimes and 11% under floating ones. When the exchange rate moves, exporters barely change the price in the buyer's currency: only about a tenth of a currency movement passes through to local prices, so exporters absorb around 90% of the shock. Sales volumes do not respond.

The structural estimates show how the absorption is split between markups and costs. When a destination country leaves a peg and depreciates its currency, the markups exporters earn in their own currency fall by about 11% on impact and remain depressed for at least three years. Marginal costs also fall, by about 10%, but this adjustment fades after two years. Over time, the burden of the change in regime thus falls mainly on exporters' margins.

The mechanism we propose is based on pricing-to-market. An exporter whose price drifts above that of local competitors loses customers, so it prefers to keep its local price in line and let its margin and costs bear the exchange-rate shock. This is a real rigidity: it operates even when prices could be changed freely. Summed across products, it makes the real exchange rate track the nominal one while leaving quantities and trade essentially untouched. A two-country business-cycle model with pricing-to-market, operational hedging and segmented financial markets, calibrated to Germany, reproduces the near one-to-one comovement of nominal and real exchange rates and the muted response of output and net exports. Adding sticky prices and wages does not improve its fit.

Our results have implications for monetary policy. Exporters act as shock absorbers: most of an exchange-rate movement never reaches the prices consumers pay for imported goods and shows up instead in exporters' profitability. This weakens the direct exchange-rate channel to import-price inflation and cautions against reading the real effects of exchange rates as evidence of sticky prices alone. More broadly, the same behaviour governs how large exporters respond to other external shocks, such as tariffs or lasting shifts in monetary policy.

Introduction

Since Friedman (1953), a significant body of research in international macroeconomics and finance has evaluated how different exchange-rate regimes affect nominal and real economic variables. Seminal findings suggest 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 nominal policy (the exchange-rate regime) can influence a real variable (the real exchange rate), and it is regarded as one of the most convincing pieces of evidence for monetary non-neutrality (Nakamura and Steinsson 2018). It has also traditionally been interpreted as suggestive evidence of nominal rigidities (Mussa 1986; Monacelli 2004), yet Baxter and Stockman (1989) find that the breakdown left 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 comovement 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 Baxter and Stockman's (1989) neutrality result.

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 (LOP) 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 resulting 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 for at least two years after the break.

To assess the quantitative importance of these *real* patterns at the *micro* level for aggregate

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

outcomes, we embed the results from the structural estimation in a two-country real business cycle model. 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, to replicate the endogenous change in the volatility of exchange rates when transitioning from a pegged to a floating exchange-rate regime, imperfect international financial markets (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 previously observed 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. Overall, our results show that the model successfully replicates the Mussa puzzle and Baxter and Stockman's (1989) neutrality result 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 onto 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 — to 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 with relative aggregate consumption growth, provided exchange rates are sufficiently risky with respect to idiosyncratic states. Our paper differs from theirs 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 explains 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 exporters primarily absorb such shocks through

adjustments in markups.[3]

1.1 Assumptions

There are two countries — home (for concreteness, say Germany) and foreign (Italy, denoted by an asterisk) — each with its own nominal unit of account in which local prices are quoted (in this example, the home wage rate, W, is denominated in Deutsche Marks, while the foreign wage rate, W^*, is denominated in Italian lire). The nominal exchange rate $\mathcal{E}$ is defined as the price of a lira in Marks; thus, an increase in $\mathcal{E}$ corresponds to a nominal depreciation of the home currency.[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 lire and sold in Italy and $MC(j)$ is the marginal cost of production denominated in 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 γ^* governs Italy's degree of openness to international trade, $\mathcal{P}^*$ is an index of average prices in the foreign market, and $\mathcal{H}(\cdot) = \mathcal{G}'^{-1}(\cdot)$. In turn, $\mathcal{G}$ 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 $\mathcal{G}(\cdot)$:

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

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

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

Importantly, the Kimball (1995) aggregator collapses to a constant-elasticity-of-substitution 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 ω. 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 such 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 for the *micro* foundations both 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 to the exporters' optimal price.

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

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 1970–99, used by, among others, 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 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 model, 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 sometimes 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, production location and market-segment classification. The total number of observations is around 12,000, implying that on average approximately 80 models are sold in each market every year.

The dataset is augmented with data on production location (from Pemberton Associates), brand ownership and market segment for each model, and, to control for market-level conditions, macroeconomic variables.

Exchange-rate regime breaks. We adopt Petracchi's (2022) classification of exchange-rate regimes. The reference country is Germany, and the exchange-rate regime — pegged or

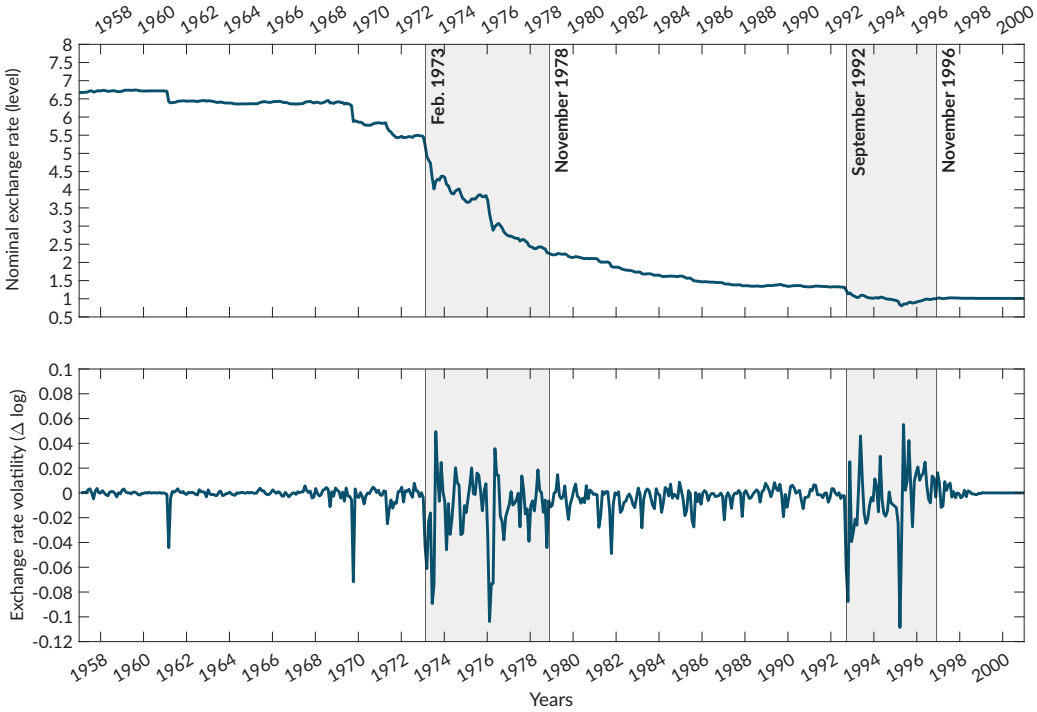
Table 1: Summary statistics for the European car market

	Belgium	France	Germany	Italy	U.K.	All
Average price (local currency)	563,258.9 (734,339.7)	102,117.4 (132,640.7)	29,441.0 (33,109.5)	26,502.3 (37,091.7)	11,060.1 (14,135.8)	-
Average price (ECU)	15,271.3 (19,933.8)	17,546.5 (21,753.0)	15,731.8 (18,689.9)	18,077.3 (21,750.1)	18,164.8 (21,192.7)	16,896.6 (20,694.8)
Foreign market share (%)	100.0 (0.0)	30.6 (9.8)	26.8 (5.5)	42.4 (13.0)	39.1 (11.7)	47.8 (28.3)
Horsepower (HP)	71.8 (45.3)	74.3 (47.9)	74.4 (47.1)	78.3 (52.0)	76.4 (47.9)	74.9 (48.0)
Weight (kg)	1,039.7 (270.0)	1,049.0 (273.2)	1,054.9 (275.0)	1,062.0 (282.9)	1,057.6 (270.2)	1,052.1 (274.1)
Annual sales by segment (1,000 units)						
Mini and Small	102.0 (16.5)	822.3 (92.6)	487.4 (177.3)	945.1 (188.5)	452.5 (120.3)	2,809.3 (449.2)
Medium and Large	189.8 (49.7)	748.4 (217.1)	1,280.8 (358.0)	576.8 (207.0)	903.1 (201.6)	3,699.0 (924.4)
Executive, Luxury, and Sport	68.3 (14.8)	205.7 (66.6)	693.9 (105.6)	136.9 (54.8)	222.2 (44.2)	1,327.1 (176.9)
All segments	360.2 (53.9)	1,776.4 (237.7)	2,462.2 (485.4)	1,658.8 (397.1)	1,577.8 (349.3)	7,835.4 (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 lire. Standard deviation in parentheses. Sample: 1970–99.

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 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 *Pegged Exchange-Rate Regime*
France	November 20, 1978 *Introduction of the Exchange Rate Mechanism*
Italy	February 13, 1973 *Exit from the Snake*
	November 20, 1978 *Introduction of the Exchange Rate Mechanism*
	September 17, 1992 *Exit from the Exchange Rate Mechanism*
	November 25, 1996 *Re-accession into the Exchange Rate Mechanism*
United Kingdom	June 23, 1972 *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 by examining the extent of deviations from the 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 $Q_{jmt} = \frac{P^m_{jt}}{P^{DE}_{jt}}\mathcal{E}_{mt}$, where P^m_{jt} is the price of car model j in market m at time t, P^{DE}_{jt} is the price of the same car model in Germany, and $\mathcal{E}_{mt}$ is the nominal exchange rate between market m and Germany. If the LOP held exactly, Q_{jmt} would equal 1 for all car models, markets, and time periods. Instead, 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 LOP.

Table 3: Real exchange rates at the product level

	Exchange-rate Regime		
Car segment	All	Pegged	Floating
Mini and Small	1.007	0.960	1.080
	(0.007)	(0.009)	(0.014)
Medium and Large	1.054	1.003	1.143
	(0.008)	(0.010)	(0.015)
Executive, Luxury, and Sport	1.105	1.078	1.151
	(0.010)	(0.012)	(0.016)
All	1.067	1.044	1.106
	(0.009)	(0.012)	(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 ($Q_{jmt} = P^m_{jt}/P^{DE}_{jt}\mathcal{E}_{mt}$), by exchange rate regime and car segment. 'All' reports the unconditional means. Pegged and floating regimes are defined between country m and Germany. Standard errors 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 when products are introduced. Appendix Table A.1, 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 time of 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}) — comove 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 $\Delta\tilde{p}_{jmt} \equiv \ln(P^m_{jt}/P^{DE}_{jt}) - \ln(P^m_{jt-1}/P^{DE}_{jt-1})$, $\Delta\varepsilon_{mt} \equiv \ln(\mathcal{E}_{mt}) - \ln(\mathcal{E}_{mt-1})$, γ_{mot} are year-regime fixed effects, and δ_{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 negative one across almost all 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. This incomplete pass-through is even more pronounced under floating exchange-rate regimes, in which the estimated coefficient is -0.114 (not statistically significant), compared to -0.381 under pegged regimes. This pattern suggests exporters engage even more actively in pricing-to-market

[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.

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 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, and Sport	-0.095	-0.241	-0.123	0.024	-1.523	0.230
	(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 LOP are persistent and economically significant. Second, these deviations are systematically larger under floating exchange-rate regimes, particularly for higher-end vehicle segments. Third, when faced with exchange-rate shocks, exporters do not adjust prices — indeed, they exhibit even stronger pricing-to-market behaviour under floating regimes — and they leave quantities essentially unchanged.

[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 $\times$ regime fixed effects).

These patterns motivate our structural analysis in the following sections, in which 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 Brenkers and Verboven's (2006) flexible two-level nested-logit specification, estimated using Berry et al.'s (1995) share-inversion and GMM logic. On the supply side, we use a direct multiproduct Bertrand-pricing benchmark. Unlike the full vertical model in Brenkers and Verboven, 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 ξ_j absorb time-invariant unobserved model attributes while market-year fixed effects ξ_{mt} absorb market-level variation in the value of purchasing a new car relative to the outside option. The residual η_{jmt} captures remaining unobserved product-market-year demand shocks.

The error term ν_{ijmt} follows Brenkers and Verboven's (2006) two-level nested-logit structure. 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 sharing the same subgroup parameter, as in Brenkers and Verboven. 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:

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

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 by 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 η_{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

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

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), we 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

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

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 breaks between pegged and floating exchange-rate regimes. 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 $\varsigma_e \in \{-1, 1\}$ 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 estimation windows for each event.

For each structural outcome

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

where μ_{jmt}^{prod} and c_{jmt} are markup and marginal cost in terms of the 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 ϕ_{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

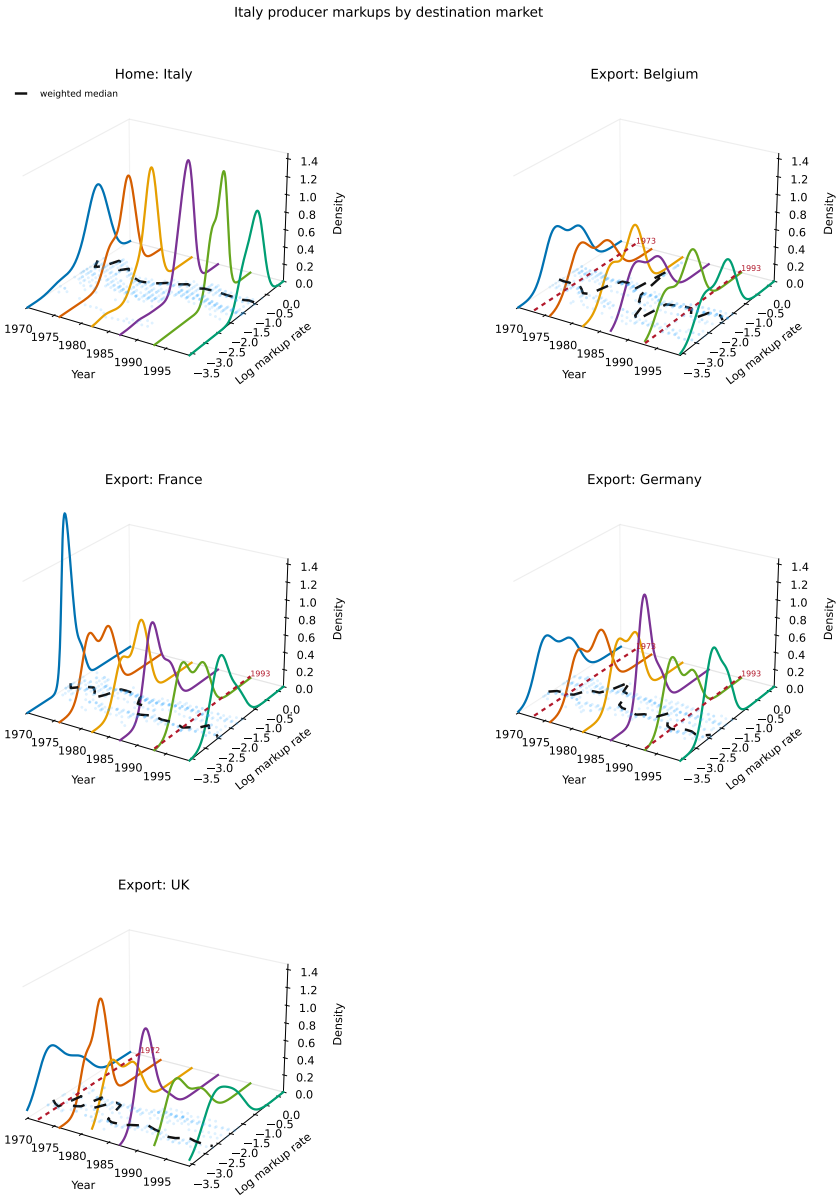
We start by showing, as an example, the distribution of markup rates for Italian producers selling in different markets over time in Figure 2.[11] The markup distribution in the home market provides a useful benchmark for interpreting the export-market panels. Looking at domestic sales, the median markup 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. 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. 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.

Figure 3 shows a decline in producer-currency markups at the break. The impact coefficient is -0.113, so markups fall by about 11% 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.

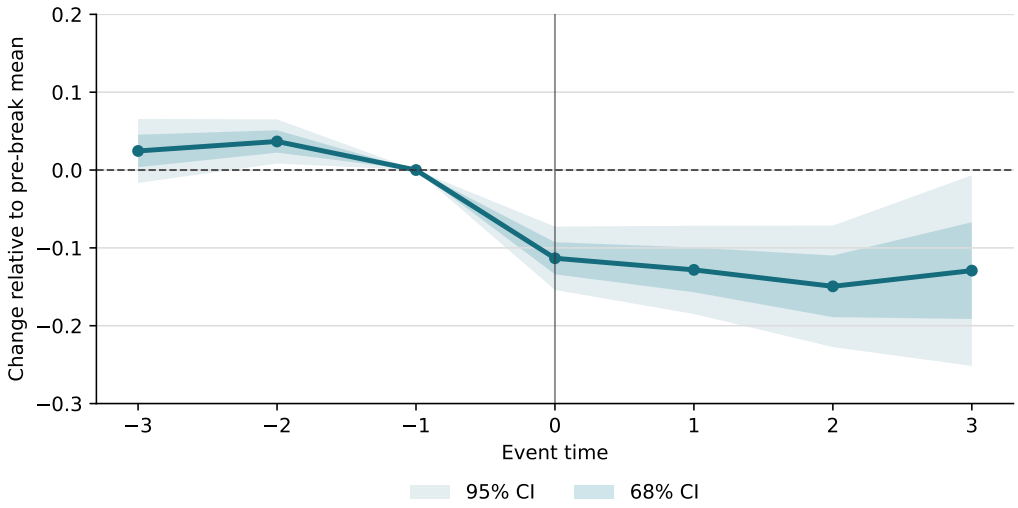
[11] The estimated coefficients of the model are reported in Appendix D.3.

Figure 2: Markup distribution of cars produced in Italy



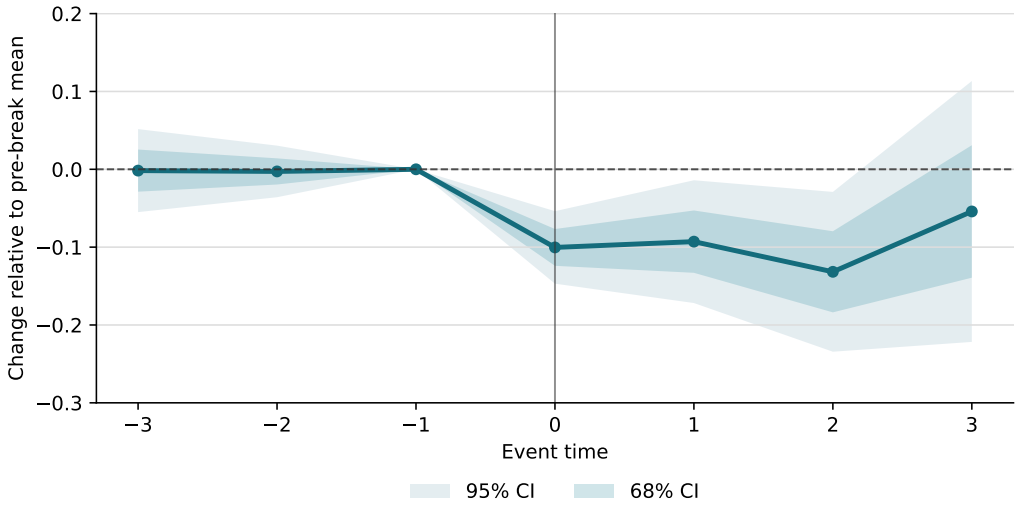
Notes: The figure reports the conditional distribution of log markup rates for Italian producers. Each coloured curve is the quantity-weighted kernel density of log markup rates in a selected calendar year. Blue points show the underlying product-year observations projected onto the year-markup plane.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

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% 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 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]

Analysing the two figures together, we 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.

As a timing falsification, we re-estimate the event study around alternative years in which no exchange-rate regime break occurred. We select a feasible pseudo-event year for every directed country pair and otherwise preserve the baseline specification. We then compare the estimates around the actual regime breaks with the distribution obtained around these alternative dates. Neither producer-currency markups nor marginal costs exhibit an impact decline as large as at the actual regime breaks. Appendix D.4 reports the results.

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.

[12] We run the same specification using the instruments proposed by Gandhi and Houde (2026) and report results in Appendix D.5. The patterns of both markups and marginal costs remain qualitatively the same.

5 General Equilibrium Model

As noted, our model builds on an international real business cycle framework with productivity shocks and 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 (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 the 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 follows 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 their discounted expected utility over final consumption C_t and labour L_t, given the discount factor β, the coefficient of relative risk aversion σ, and the inverse Frisch elasticity of

labour supply φ:

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

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 Π_{Dt} and Π_{Et} the profits of domestic firms and exporters. We assume the household trades only home-currency bonds and owns only domestic firms and exporters.

The within-period consumption expenditure $P_t C_t$, split 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 home and foreign variety i. Final consumption C_t is implicitly defined by the Kimball (1995) aggregator:

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

The parameter γ governs the degree of openness to international trade, and the function $\mathcal{G}(\cdot)$, defined as in Aruoba et al. (2024), 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:

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

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

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

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

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

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

Gross investment Z_t, like final consumption C_t, is a Kimball (1995) bundle of domestic and foreign varieties, with demand schedules analogous to those above. The capital stock accumulates according to the following law of motion with quadratic adjustment costs, where depreciation is δ and capital adjustment cost is κ:

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

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.

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,

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

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:

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

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

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

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

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 ρ represents interest rate smoothing in the monetary-policy rule, and the parameters ω_π and ω_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

International financial markets are segmented since home- and foreign-country 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-optimisation 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 $\Gamma_t =$

$\xi\,[\mathbb{V}\text{ar}_t(\mathcal{E}_{t+1})]^{\iota}$, with $\xi \geq 0$ and $\iota \geq 0$, captures the financiers' risk-bearing capacity. For simplicity, we assume the 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 production by the domestic firms to be allocated to the home market, while production by exporters must be allocated to the foreign market. This ensures that demand in both markets is satisfied:

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

$$Y^*_{Ht} = C^*_{Ht} + X^*_{Ht} + Z^*_{Ht} = \gamma\mathcal{H}\left(\frac{P^*_{Ht}}{\mathcal{P}^*_t}\right)[C^*_t + X^*_t + Z^*_t],$$

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 NX_t denotes net exports in units of the home currency.

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

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 $\bar{\mu} = 1$. Henceforth, 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

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

Table 5: Model parameters

Non-Calibrated Parameter	Variable	Value	Source
Household discount factor	β	0.99	
Relative risk aversion	σ	2	
Inverse Frisch elasticity	φ	1	
Intermediate input share	ϕ	0.617	Diehl (2001)
Capital share	ϑ	0.38	Goldberg and Verboven (2001)
Import intensity of exporter	ϕ^e	0.37	Goldberg and Verboven (2001)
Openness to trade	γ	0.157	
Elasticity of substitution	$\frac{\omega}{\omega-1}$	1.5	
Interest rate smoothing	ρ	0.95	
Inflation rate targeting	ω_π	2.15	
Persistence of the shocks	ρ_a, ρ_{a^*}, ρ_ζ	0.97	
Std. dev. of financial shocks	$\chi_1\sigma_\zeta$	1	
Coefficient of net foreign assets	χ_2	0.001	
Calvo probability for price reset	λ_p	0.75	
Calvo probability for wage reset	λ_w	0.85	

Calibrated Parameter	Variable		Targeted Moment
Capital adjustment cost	κ	$\rightarrow$	$std(\Delta z_t)/std(\Delta y_t) = 2.5$
Std. dev. of productivity shocks	σ_a, σ_{a^*}	$\rightarrow$	$corr(\Delta q_t, \Delta c_t - \Delta c_t^*) = -0.4$
Correlation of productivity shocks	ρ_{a,a^*}	$\rightarrow$	$corr(\Delta y_t, \Delta y_t^*) = 0.35$

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; κ, σ_a, and ρ_{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 $corr(\Delta y_t, \Delta y_t^*) = 0.35$.

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 (τ) as a function of observable variables: the percentage changes in the exporter's markups (μ_t) and marginal costs (mc_{Et}), bilateral nominal exchange-rate appreciation/depreciation (ε_t), and inflation in the destination market (p^*_t).

We estimate τ 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-input share to $\phi = 0.617$ 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 period; we modify the capital-adjustment-cost parameter κ to match the relative volatility of investment and output, $std(\Delta z_t)/std(\Delta y_t) = 2.5$; and we set $\phi^e = 0.37$ 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 (ζ_t). We assume ζ_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 (ρ_{a,a^*}). We always choose the relative volatility of the shocks, σ_a/σ_ζ, 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, ρ_{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; we choose values for κ, σ_a, and ρ_{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 real exchange rate (Δq_t) comoves strongly with the nominal exchange rate (Δe_t), replicating the Mussa (1986) puzzle. 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 puzzle as evidence of nominal rigidities (for example, Monacelli 2004).

Table 6: Model results for Germany

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

Notes: The table reports a set of 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 κ, σ_a, and ρ_{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 maintains the observed muted reaction of macro variables to exchange rates because exporters actively hedge against exchange-rate fluctuations. The second and third rows of Table 6 report the ratios of the standard deviation of the nominal exchange rate (Δe_t) to the standard deviations of output and consumption (Δy_t and Δc_t), in log differences. These moments highlight the ability of our model to generate higher volatility of the nominal exchange rate compared to output and consumption — without introducing nominal price and wage rigidities — as observed in the data. The fourth row shows the ratio between the standard deviation of net exports (Δnx_t) and the real exchange rate (Δq_t). Again, the model produces higher volatility of the real exchange rate than 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 maintain the observed 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 adjustment patterns of prices, quantities, markups, and marginal costs in response to switches between pegged and floating exchange-rate regimes and by viewing 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. The estimation reveals 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 in 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 they validate the quantitative importance of the estimated degree of pricing-to-market.

Taken together, our results support the presence of a mechanism explaining the strong comovement 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 1970–99. While the setting is thus specific to one industry and period, the car market provides 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 long-term monetary policy.

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Appendix

A Motivating Evidence — Additional Results

Table A.1: Real exchange rates at the product level in the 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, and Sport	1.140	1.115	1.181
	(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 errors in parentheses.

Table A.2: 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	-0.083	-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 $\times$ regime and model-market pair $\times$ 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

$$a_{ijmt} = s_{ijmt|h_jg_j}, \qquad b_{ih_jg_jmt} = s_{ih_jg_jmt|g_j}, \qquad c_{ig_jmt} = s_{ig_jmt}.$$

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

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

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

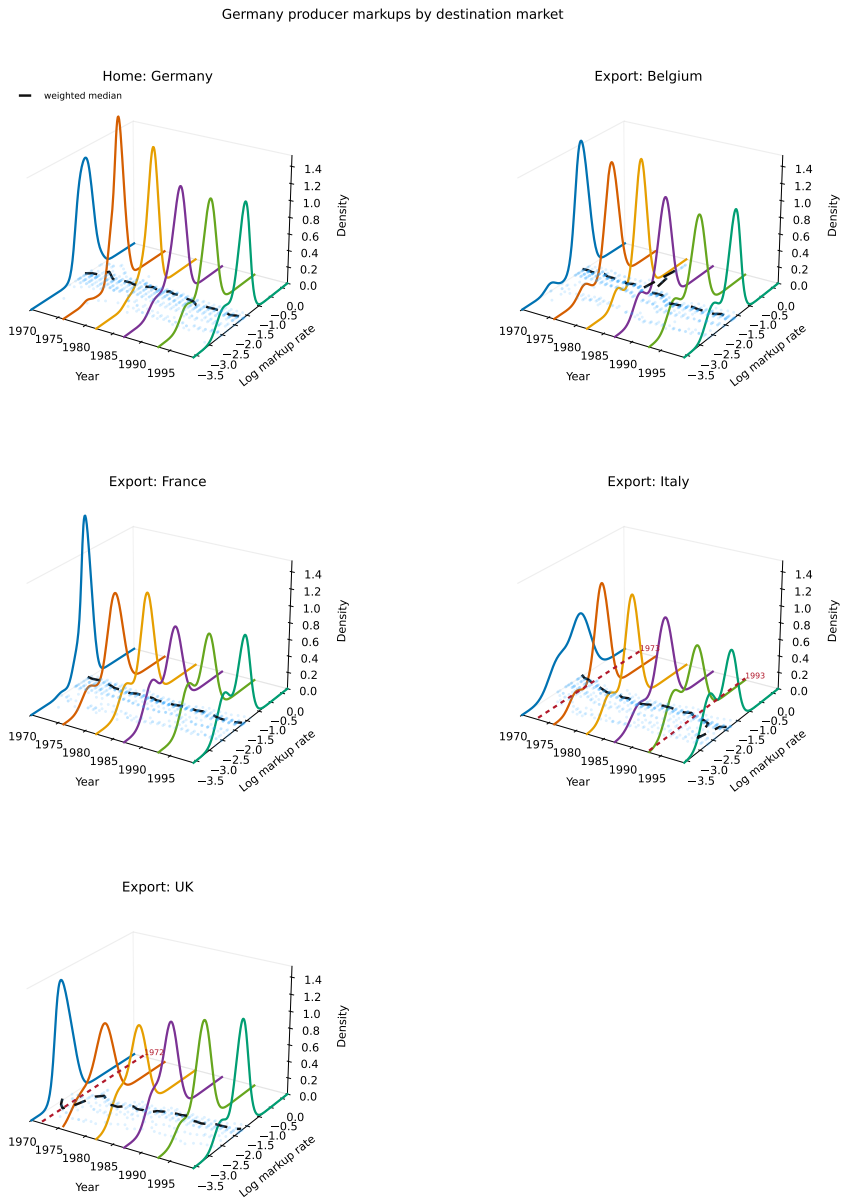
Table A.3: Directed structural event sample

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 convention 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

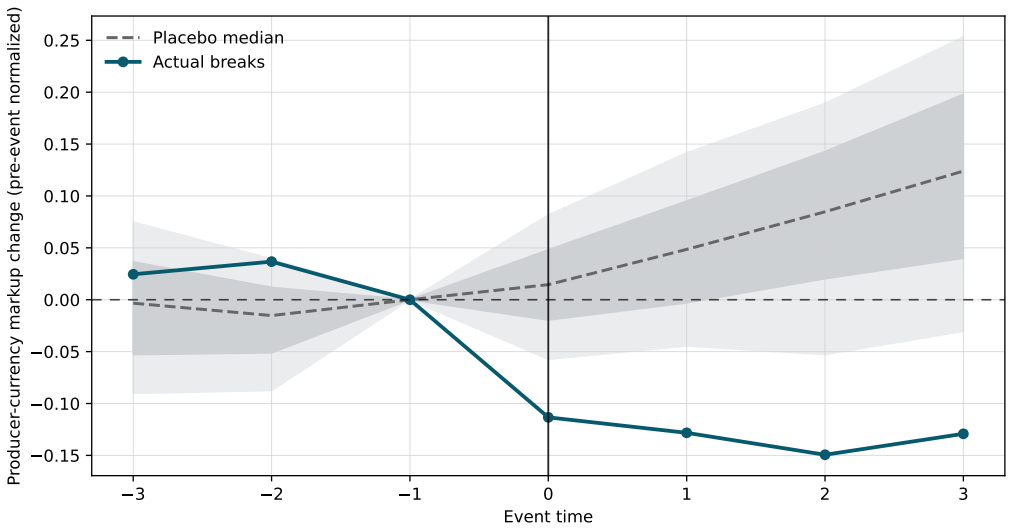
Parameter	Estimate
Parameters for Car Characteristics	
Horsepower	0.015
Fuel inefficiency	-0.030
Width	0.036
Height	0.013
Foreign	-0.835
-Price	6.231
Subgroup nesting σ_{hg}	
Subcompact	0.870
Compact	0.576
Intermediate	0.530
Standard	0.591
Luxury	0.171
Segment nesting σ_g	
Subcompact	0.302
Compact	0.387
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 Timing Placebos

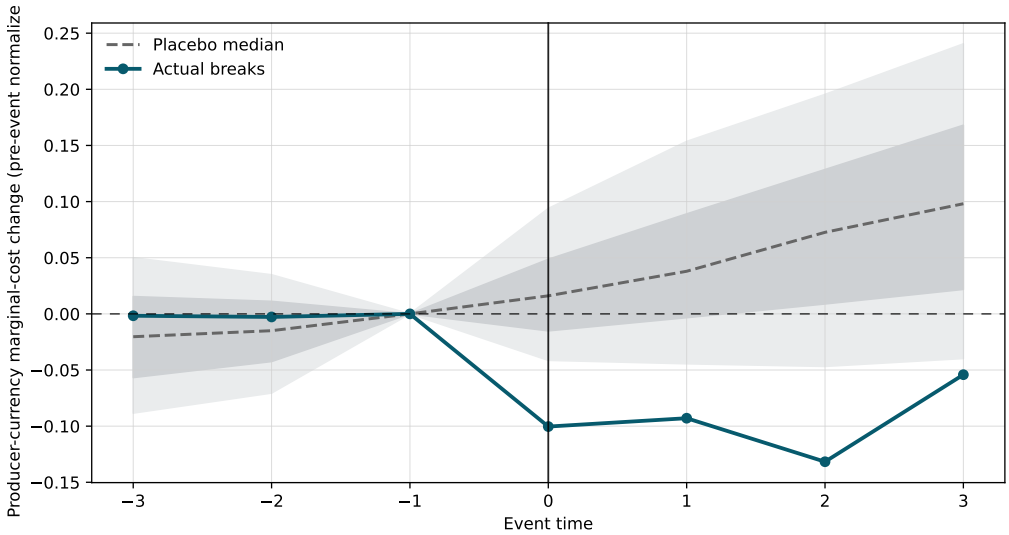
We conduct a timing-placebo exercise using the same 13 directed country-pair events, depreciation/appreciation signs, quantity weights, product-by-event fixed effects, pair-specific pre-event normalisation, and $[-3, +3]$ event window as in the baseline specification. For each pair, we randomly draw a pseudo-event year more than six years from its actual regime break and reproduce the pair's observed event-time support. Across 500 assignments, the actual impact estimates for producer-currency markups and marginal costs, -0.113 and -0.100, lie below every placebo estimate; the corresponding 95% placebo ranges are $[-0.057, 0.082]$ and $[-0.041, 0.094]$. These results indicate that the estimated declines are concentrated around the observed regime-break dates.

Figure A.2: Producer-currency markup adjustment at actual and placebo event dates



Notes: The solid line reports the event-study estimates around the actual exchange-rate regime breaks. The dashed line reports the median estimate obtained from the random timing assignments. In each assignment, a feasible non-break year is selected for every directed origin-destination pair, and the event study is re-estimated while preserving the baseline event signs, quantity weights, product-by-event fixed effects, pre-event normalisation, and pair-specific event-time support. Pseudo-event years are required to lie more than six years from the corresponding actual break. The darker and lighter shaded areas report the 68% and 95% ranges of the placebo estimates, respectively. 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 event. Negative estimates correspond to markup declines in the direction associated with a destination-currency depreciation relative to the producer currency. Event time -1 is the omitted period.

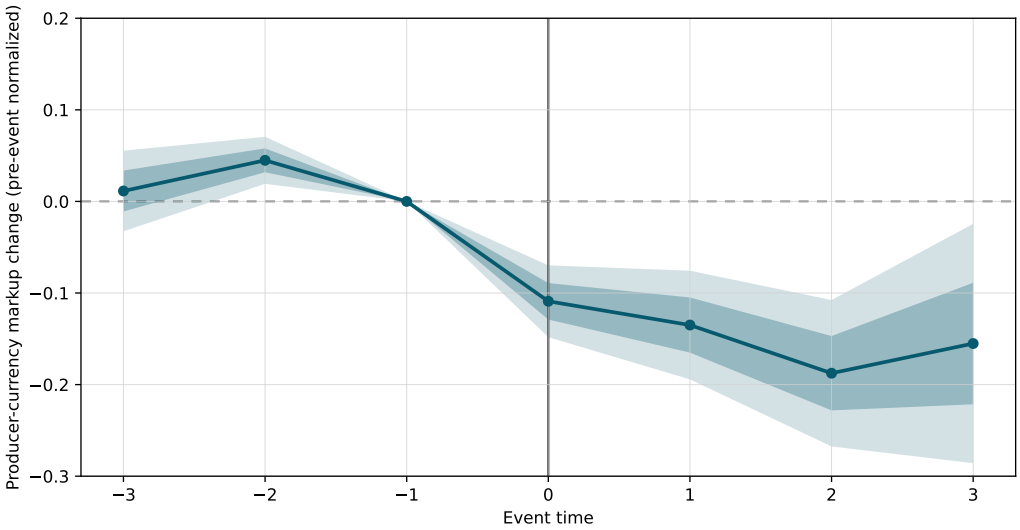
Figure A.3: Producer-currency marginal-cost adjustment at actual and placebo event dates



Notes: The solid line reports the event-study estimates around the actual exchange-rate regime breaks. The dashed line reports the median estimate obtained from the random timing assignments. In each assignment, a feasible non-break year is selected for every directed origin-destination pair, and the event study is re-estimated while preserving the baseline event signs, quantity weights, product-by-event fixed effects, pre-event normalisation, and pair-specific event-time support. Pseudo-event years are required to lie more than six years from the corresponding actual break. The darker and lighter shaded areas report the 68% and 95% ranges of the placebo estimates, respectively. The outcome is the signed change in FOC-implied producer-currency marginal costs, normalised by the absolute sales-weighted event-pair mean in the year before the event. Negative estimates correspond to marginal-cost declines in the direction associated with a destination-currency depreciation relative to the producer currency. Event time -1 is the omitted period.

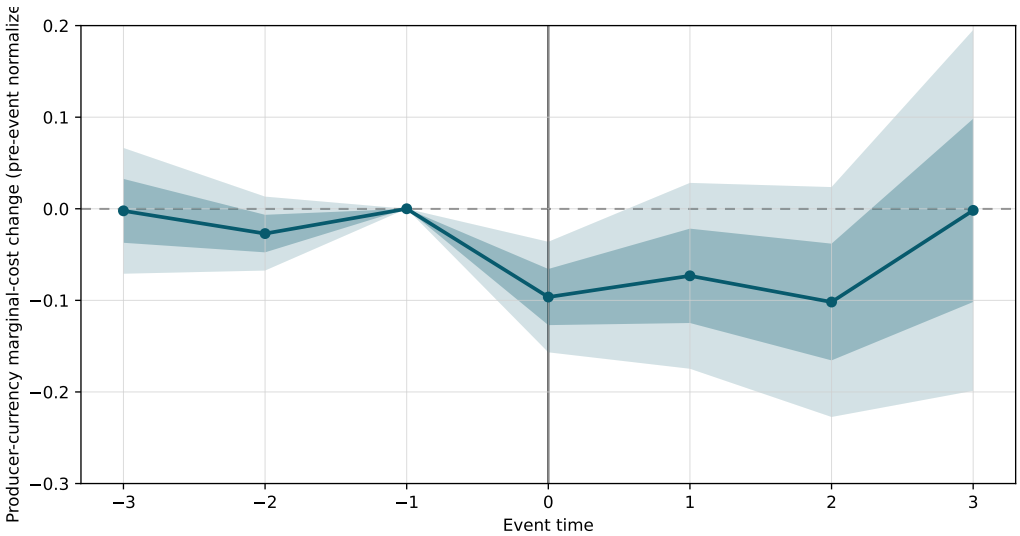
D.5 Gandhi and Houde (2026) Instruments

Figure A.4: 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.5: 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.

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