

# Firms' Heterogeneity and Incomplete Pass-Through\*

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(PRELIMINARY AND INCOMPLETE)

## Abstract

A large body of empirical work documents the fact that prices of traded goods typically change by a smaller proportion than the real exchange rates between the trading countries (incomplete pass-through). Moreover, the wedge between exchange rates and relative prices appears to vary across countries (pricing-to-market). While these facts have received a lot of attention in the literature, we know very little on how the extent of pass-through and pricing-to-market vary across firms in a country. This paper presents a model of trade and international price-setting with heterogeneous firms, where firms' strategic behavior implies that pass-through is incomplete and depends on a firm's relative productivity (or size) compared to its competitors. Pricing-to-market behavior is also depending on firm's productivity and on countries' characteristics. I test the firm-level variation predicted by the model using a panel data set of cars prices in five European markets. Preliminary estimates support the predictions of the theory.

**Keywords:** Heterogeneous firms, incomplete pass-through, pricing to market.

**JEL Classification:** F11, L11, L13.

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# 1 Introduction

A large body of empirical work documents the fact that prices of traded goods typically change by a smaller proportion than the real exchange rates between the trading countries (incomplete pass-through). The wedge between export prices and domestic prices appears also to depend on the countries involved in the trade relationship, with exporters charging different prices to different export markets (pricing-to-market). While the basic fact of incomplete pass-through has received a lot of attention in the literature, there is little or no emphasis on how the extent of pass-through varies across firms in a country.

This paper presents a simple two-country model of trade and international price-setting where firms are heterogeneous and the world market for each good has the characteristics of an international oligopoly. National markets are segmented, and firms set their prices by taking into account the optimal response of their foreign competitors, whose cost structure is unobservable. For a wide range of parameterizations, this type of strategic behavior generates residual demands with an elasticity that is increasing in the price, and hence incomplete pass-through of cost changes into prices and pricing to market. The optimal price adjustments following changes in marginal cost depend on a firm's relative productivity compared to the average (or expected) productivity of its competitors: pass-through is a U-shaped function of firm's productivity. The intuition behind this result is as follows: the most productive firms don't fear external competition, and - with a probability approaching one - are the lowest price sellers, hence their pricing decisions are not characterized by any strategic consideration. Similarly, the least productive firms have tiny mark-ups, hence no room for absorbing cost increases through mark-up reductions, and pass most of their cost changes into changes in prices. Conversely, firms lying in the middle of the distribution take into consideration their competitors' optimal responses, and - following a cost shock - increase prices only partially, to avoid losing market share in favor of their competitors. The same reasoning implies similar firm-level variation in pricing to market behavior. Pass-through and pricing-to-market also depend on the aggregate characteristics of the countries involved. Pass-through is incomplete for transactions between identical countries, and is increasing in the relative average productivity of the importing country.

I test the firm-level variation predicted by the model using a panel data set of cars prices in five European markets. Preliminary estimates support the predictions of the model regarding realized trades: low productivity firms are more likely to be undercut by competitors, so the prices they charge are not observed in actual exchanges. If we exclude low productivity firms, the pass-through function predicted by the model is increasing and concave in productivity. I test this prediction with reduced form pass-through regressions including linear and quadratic interaction terms between firm size and exchange rate, and with quantile regressions. Both specifications confirm the model's findings. Similar pricing-to-market regressions show support for the result that larger firms tend to exhibit larger wedges between domestic and export prices.

Incomplete pass-through in the data may arise from two main margins: mark-up variability, meaning that firms absorb part of the cost increase through a reduction in mark-ups, and distribution margins, due to the fact that consumer prices are composed by a certain amount of non-tradeable distribution services, whose price is not affected by exchange rate fluctuations. Several papers have shown the empirical importance of distribution margins: see Burstein, Eichenbaum, and Rebelo (2005), Burstein, Neves, and Rebelo (2003), Campa and Goldberg (2006) among others. Nakamura (2007) uses micro-level data on the coffee industry to decompose price adjustments into the different components. The model presented in this paper abstracts from the distribution margin, and concentrates on mark-up variability, driven by non-linear optimal pricing strategies of firms. Adding a distribution margin to the model is certainly feasible, and will only reinforce the results of the theory.

Theoretical research on incomplete pass-through has achieved the result of mark-up variability through two main channels: exogenous price stickiness,<sup>1</sup> or imperfect competition with non-constant elasticity of demand. In this paper prices are fully flexible, hence the results on incomplete pass-through should be interpreted as long-run results, and not as the product of short term frictions. Imperfect competition models with variable elasticity of demand produce the result because changes in prices determine changes in the elasticity of demand: for appropriate parameterizations, firms may find optimal to adjust prices only partially in order not to lose market share in favor of their competitors. Variable elasticity of demand may be achieved

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<sup>1</sup>Gopinath and Rigobon (2008), among others, document the low frequency and small size of price adjustments.

by appropriate choices of preferences (like in Melitz and Ottaviano (2008) Gust, Leduc, and Vigfusson (2006)) or by specific assumptions on the nature of imperfect competition (as illustrated in Dornbusch (1987), and more recently implemented by Atkeson and Burstein (2008) among others). This paper contributes to this last strand of the literature. On the demand side, I assume consumers have CES preferences over a given set of goods, and that each good can be acquired by either a domestic or a foreign producer. The existence of an outside option (in this case, switching to another producer from a different country) generates a residual demand with non-constant elasticity. On the supply side, I assume that firms cannot observe their competitors' cost structure, and set optimal prices based on expectations on the prices charged by their competitors. Given that costs are unobservable, optimal prices also depend on the probability that buyers switch to another supplier.

This paper is closest in spirit to Feenstra, Gagnon, and Knetter (1996) and Alessandria (2004). In the former, CES preferences over a discrete number of products imply a U-shaped relationship between pass-through and the exporting country share in the destination market. My model generates a similar, firm-level prediction linking firm size (or productivity) and pass-through. In my framework firms are heterogeneous, and heterogeneity critically affects the extent of pass-through: I derive the conditions on the productivity distribution that are necessary to obtain incomplete pass-through, and illustrate how productivity dispersion affects price adjustments. As in Feenstra, Gagnon, and Knetter (1996), the empirical analysis in my paper concentrate on the cars market, but exploits more the detailed micro-structure of the data, following Goldberg and Verboven (2005).

The idea of incomplete price adjustments motivated by the possibility of consumers to switch to other producers is also present in Alessandria (2004). In his paper, agents have CES preferences and incomplete pass-through is driven by the possibility that consumers stop buying if the price charged is too high. Switching to another supplier involves costly search, hence optimal prices are set by keeping into account the consumers' threat of switching supplier. The result is a reservation price rule similar to the one assumed by Feenstra, Gagnon, and Knetter (1996), with optimal mark-ups depending on search and transport costs and on the number of firms competing in the same market. The model generates a pass-through function that is U-shaped in

the firm's market share. The mechanism is very similar to this paper for the presence of a threat of switching to another supplier. In my model the threat is instantaneous and has implications on prices via the non-observability of marginal costs. In Alessandria (2004), the threat takes effect over time due to the presence of search frictions.

The rest of the paper is organized as follows. In Section 2, I present a two-country model of trade with heterogeneous firms and strategic price-setting, and I characterize the optimal pricing strategy. In Section 3, I derive the conditions on the productivity distribution that assure incomplete pass-through and pricing-to-market, and discuss aggregation of individual price variation into changes in price indexes. Section 4 contains numerical examples illustrating the firm-level variation of pass-through and pricing-to-market and their dependence on the aggregate parameters of the model. In Section 5, I provide preliminary empirical evidence on the firm-level variation of price adjustments using data from the European cars industry. Section 6 concludes.

## 2 A Simple Model of Trade

In this section I introduce a simple model where firms' heterogeneity and imperfect competition generate incomplete pass-through of changes of marginal costs into prices.

I consider a world of two countries, Domestic ( $d$ ) and Foreign ( $f$ ). Each country is populated by a large number of identical consumers, that have CES preferences over a set of differentiated goods:

$$U = q = \left[ \int q_i^{1-1/\eta} di \right]^{\eta/(\eta-1)}$$

where  $q_i$  is the quantity consumed of each good  $i$ , and  $\eta > 1$  denotes the elasticity of substitution across goods. Each good can be acquired from a domestic or from a foreign producer, and consumers buy it from the producer that charges the lowest price. A producer of good  $i$  in country  $j$  ( $j = d, f$ ) has a constant return to scale technology described by  $q_j^i = l_j^i / w_j z_j^i$ , where  $l_j^i$  is the quantity of labor hired to produce a quantity  $q_j^i$  of good  $i$ ,  $w_j$  is the labor cost in country  $j$ , and  $z_j^i$  denotes the firm's unit cost. Producers in each country are heterogeneous in

their costs: let  $G_j(\bar{z}_j)$  denote the mass of producers from country  $j$  that have unit cost  $z_j \leq \bar{z}_j$ . In this economy, the only feature differentiating goods are the cost parameters  $z_j^i$ , for  $j = d, f$ . Consequently, I drop the index  $i$  and denote each good by the couple of technology draws of its suppliers in the two countries. Let  $z = (z_d, z_f) \in \mathfrak{R}_+^2$  and  $q_j(z)$  the quantity purchased in country  $j$  of an input for which the domestic supplier has unit cost  $z_d$  and the foreign supplier has unit cost  $z_f$ . Finally, let  $p_{jk}(z_k)$  denote the price charged by a producer from country  $k$  with cost draw  $z_k$  for its sales in country  $j$  ( $j, k = d, f$ ). The timing is the following: (i) producers in both countries observe their own productivity and the aggregate parameters of the economy; (ii) based on his own productivity and on the expectations on prices charged his competitors, each producer declares a selling price; (iii) for each good, consumers decide whether to buy it domestically or abroad, based on the lowest price; (iv) producers whose realized demand is positive produce, sell and make profits.

A consumer in country  $j$  chooses the optimal quantity of each good  $q_j(z)$ , and whether to buy it domestically or abroad, based on the lowest price. The consumer's problem is summarized below:

$$\begin{aligned} \min_{q_j(z)} \quad & \int_{\mathfrak{R}_+^2} \min\{p_{jd}(z_d), p_{jf}(z_f)\} q_j(z) g(z) dz \\ \text{s.t.} \quad & \left[ \int_{\mathfrak{R}_+^2} q_j(z)^{1-1/\eta} g(z) dz \right]^{\eta/(\eta-1)} \geq q_j \end{aligned} \quad (1)$$

where  $g(z) = g_d(z_d) \cdot g_f(z_f)$  is the joint density of the cost distributions in the two countries.<sup>2</sup> Problem (1) has solution:

$$q_j(z) \equiv q_{jd}(z) = \left( \frac{p_{jd}(z_d)}{P_j} \right)^{-\eta} q_j \quad \text{if } p_{jd}(z_d) \leq p_{jf}(z_f) \quad (2)$$

$$q_j(z) \equiv q_{jf}(z) = \left( \frac{p_{jf}(z_f)}{P_j} \right)^{-\eta} q_j \quad \text{if } p_{jd}(z_d) \geq p_{jf}(z_f) \quad (3)$$

where  $q_{jd}(z)$  ( $q_{jf}(z)$ ) is the quantity of good  $z$  that a consumer in country  $j$  purchases from a

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<sup>2</sup>The cost distributions  $G_j(\cdot)$ ,  $j = d, f$ , are independent across countries.

producer in country  $d$  ( $f$ ). The term  $P_j$  is the consumer price index in country  $j$ :

$$P_j = \left[ P_{jd}^{1-\eta} + P_{jf}^{1-\eta} \right]^{1/(1-\eta)} \quad (4)$$

and:

$$P_{jd} = \left[ \int_0^\infty \int_0^{p_{jf}(z_f)} p_{jd}(z_d)^{1-\eta} g(z) dz \right]^{1/(1-\eta)} \quad (5)$$

$$P_{jf} = \left[ \int_0^\infty \int_{p_{jf}(z_f)}^\infty p_{jf}(z_f)^{1-\eta} g(z) dz \right]^{1/(1-\eta)}. \quad (6)$$

Markets are segmented. A producer from country  $k$  chooses the price to charge in country  $j$  to maximize its expected profits from sales in country  $j$ , taking into account the optimal pricing strategy of its direct competitor in the other country. Consumers buy from the producer charging the lowest price, so expected profits are given by profits in case of sale times the probability that the price charged is below the price charged for the same good by a producer in the other country. In formulating this problem, I assume that each producer in each country knows the aggregate parameters of the cost distributions, but cannot observe the individual unit cost of the foreign producer that produces its same good. The price setting mechanism has the properties of a potentially asymmetric first-price sealed-bid auction. Each supplier sets the price as a function of his own marginal cost in a way that, given that all the other suppliers set their price in the same way, no individual supplier could do better by choosing the price differently. The resulting equilibrium is a Bayes-Nash equilibrium, where each supplier chooses its optimal price based on his guess (correct in equilibrium) of the pricing rules followed by suppliers of the same good in other countries.

A producer from country  $k$  with unit cost  $z_k$  chooses the price to charge in country  $j$  to maximize:

$$\max_{p_{jk}(z_k)} [p_{jk}(z_k) - c_{jk}z_k] \left( \frac{p_{jk}(z_k)}{P_j} \right)^{-\eta} q_j [1 - F_{j,\sim k}(p_{jk}(z_k))] \quad (7)$$

where:

$$c_{jk} = \begin{cases} w_k & \text{if } k = j \\ etw_k & \text{if } k \neq j \end{cases},$$

$t$  is the iceberg cost of trade between the two countries, and  $e$  is the real exchange rate, expressed in units of domestic consumption per units of foreign consumption.  $F_{j,\sim k}(\cdot)$  is the c.d.f. of the prices charged in country  $j$  by suppliers NOT from country  $k$ . The term  $[1 - F_{j,\sim k}(p_{jk}(z_k))] = \text{prob}\{p_{jk}(z_k) \leq p_{j,\sim k}(z_{\sim k})\}$  is the mass of consumers in country  $j$  buying good  $z$  from suppliers from country  $k$ .<sup>3</sup>

The first order condition of problem (7) can be written as:

$$p_{jk}(z_k) = \left[ 1 - \frac{1}{\eta + H_{j,\sim k}[p_{jk}(z_k)]p_{jk}(z_k)} \right]^{-1} c_{jk}z_k \quad (8)$$

where  $H_{j,\sim k}[p_{jk}(z_k)]$  is the hazard rate:<sup>4</sup>

$$H_{j,\sim k}[p_{jk}(z_k)] = \frac{f_{j,\sim k}[p_{jk}(z_k)]}{[1 - F_{j,\sim k}[p_{jk}(z_k)]]}.$$

Given functional forms for the cost distributions  $G_d(\cdot)$ ,  $G_f(\cdot)$ , the model is solved up to the scale of production  $q$ .<sup>5</sup> To determine  $q_d$ ,  $q_f$ , I impose market clearing: total income ( $w_j L_j + \Pi_j$ , where  $L_j$  denotes labor force and  $\Pi_j$  denote aggregate profits in  $j$ ) must equate total expenditure ( $P_j q_j$ ) in each country, pinning down the equilibrium values of  $q_d$  and  $q_f$ .

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<sup>3</sup>With a large number of consumers, I can appeal to the law of large numbers to interpret the probability of buying from a producer as the actual share of buyers that decide to buy from that producer.

<sup>4</sup>Notice that - when the hazard rate is equal to zero - equation (8) reduces to the standard constant mark-up price of Armington models with CES preferences. The possibility of switching to another producer of the same good is the driving force behind the results of this paper.

<sup>5</sup>The algorithm to solve for the optimal pricing rules is described in the Appendix, and is available upon request to the author.

### 3 Incomplete Pass-Through of Cost Changes into Prices

In this section, I provide conditions under which the model produces the result that a shock to firms' costs is not reflected one-to-one into the prices charged.

The optimal adjustment in price following a change in marginal cost depends crucially on the elasticity of demand. In a standard CES model where varieties produced in different locations are different goods in the eyes of the buyers (where the Armington assumption holds), varieties of the same good produced in different countries are imperfect substitutes of each other, and the elasticity of demand is constant and equal to the elasticity of substitution across goods. This implies that any drop or increase in price generates a proportionate reaction on the demand side, that makes optimal for a firm to adjust one-to-one its price after a change in marginal cost. In the model outlined here, the same good produced in two different locations is exactly the same good, hence a supplier must choose its optimal price by keeping into account both the substitution effect across different goods and direct competition from producers of exactly the same, perfectly substitutable good produced abroad.<sup>6</sup> This feature introduces an additional component into the elasticity of demand, and the dependence of this component on prices is the driving force behind the incomplete pass-through result. More precisely, a supplier will find optimal to adjust its price less than proportionately after a change in marginal cost when the elasticity of demand is increasing in the price charged.<sup>7</sup> When this is true, the percentage reduction in demand caused by an increase in price is larger than the percentage increase in demand caused by a drop in price of similar size, inducing firms to be reluctant to adjust their

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<sup>6</sup>I assume there is only one supplier for each input in each country. This assumption can be relaxed by interpreting the production function of a supplier as the aggregate production function of a set of "lower-level" suppliers that produce the same input in a country. By assuming that the technology for producing an input is country-specific (*i.e.*, that  $z_j$  is constant across all producers of the same input in country  $j$ ) and that each lower-level producer has a decreasing returns to scale production function and pays a fixed cost to enter the market (along the lines of Rossi-Hansberg and Wright (2007)), it can be shown that the aggregation of lower-level producers generates a constant returns to scale technology that is isomorphic to the linear technology of each supplier in the model. This is achieved by appropriately redefining the technology draw  $z$  as a function of the fixed entry cost and of the parameter ruling decreasing returns for the lower-level producers.

<sup>7</sup>It is easy to prove that if the elasticity of demand is increasing in the price charged, the model exhibits incomplete pass-through. We have incomplete pass-through when:  $\frac{\partial \log p(z)}{\partial \log z} = \left[ 1 - \frac{p(z)}{|\varepsilon|^2} \cdot \frac{\partial |\varepsilon|}{\partial z} \right] < 1$ , or – equivalently – if:  $\frac{p(z)}{|\varepsilon|^2} \cdot \frac{\partial |\varepsilon|}{\partial z} > 0$ , which is always true if the elasticity of demand is increasing in  $p(z)$ .

prices proportionately to their costs.

A producer from country  $k$  with unit cost  $z_k$  faces demand in country  $j$  ( $j, k = d, f$ ) given by:

$$D_{jk} = \left( \frac{p_{jk}(z_k)}{P_j} \right)^{-\eta} q_j [1 - F_{j, \sim k}(p_{jk}(z_k))] \quad (9)$$

which implies an elasticity of demand equal to:

$$|\varepsilon_{jk}| = \frac{\partial \log D_{jk}}{\partial \log p_{jk}(z_k)} = \eta + \frac{f_{j, \sim k}[p_{jk}(z_k)]}{[1 - F_{j, \sim k}[p_{jk}(z_k)]]} p_{jk}(z_k). \quad (10)$$

Whether the elasticity of demand is increasing in the price charged only depends on the shape of the competitors' price distribution  $F_{j, \sim k}(\cdot)$ , and hence on the cost distributions  $G_d(\cdot)$ ,  $G_f(\cdot)$ . The following theorem states a necessary and sufficient condition for the elasticity of demand to be increasing in the price charged.

**Theorem 1.** *The elasticity of demand  $|\varepsilon_{jk}|$  is increasing in the price charged if and only if the competitors' cost distribution  $G_{\sim k}(\cdot)$  satisfies:*

$$g'(z) > -\frac{g(z)}{z} \left[ 1 + \frac{g(z)}{[1 - G(z)]} z \right] \quad \forall z. \quad (11)$$

**Proof:** The proof proceeds in two steps. I first use an auxiliary, simplified model to derive condition (11), and then show that condition (11) is also the necessary and sufficient condition for the full model.

Let us consider an auxiliary model where firms in one of the two countries (without loss of generality, say  $d$ ) set prices equal to their marginal costs, while firms in the other country ( $f$ ) set mark-up prices. The two countries are identical under every other characteristic, so wages are equalized (and normalized to one). Goods are freely tradeable ( $t = 1$ ). We prove that – for this auxiliary model – (11) is a necessary and sufficient condition for incomplete pass-through of changes of marginal costs into import prices. If  $p_{jd} = z_d$ , for  $j = d, f$ , the elasticity of import

demand reduces to:

$$|\varepsilon_{df}| = \eta + \frac{g_d(p_{df}(z_f))}{[1 - G_d(p_{df}(z_f))]} p_{df}(z_f). \quad (12)$$

Then condition (11) follows from differentiation of equation (12) with respect to  $p_{df}(z_f)$ .

Condition (11) holds with equality when the cost distribution  $G(\cdot)$  is a Pareto.<sup>8</sup> So to ensure that the elasticity of demand is increasing in the price charged we need the density  $g(\cdot)$  to exhibit a larger first derivative than a Pareto on its entire domain.

In the full model, where firms from both countries charge mark-up prices, there are also arbitrary wage differences and possibly non-zero trade costs. By differentiating (10) with respect to  $p_{jk}(z_k)$ , we obtain:

$$f'(p(z)) > -\frac{f(p(z))}{p(z)} \left[ 1 + \frac{f(p(z))}{[1 - F(p(z))]} p(z) \right] \quad \forall p(z). \quad (13)$$

When the cost distribution is Pareto over the support  $[a, +\infty)$ , we can solve analytically problem (7) for the optimal pricing rule, which (in this case) is linear in the marginal cost:

$$p_{jk}(z_k) = \frac{\vartheta + \eta}{\vartheta + \eta - 1} c_{jk} z_k. \quad (14)$$

In the Pareto case, optimal prices are also Pareto-distributed over the support  $[amc_{jk}, \infty)$ , where  $m$  is the constant mark-up in (14):  $m = \frac{\vartheta + \eta}{\vartheta + \eta - 1}$ . Moreover, the elasticity of demand (10) is constant ( $|\varepsilon_{jk}| = \eta + \vartheta$ ) and condition (13) holds with equality. Hence also for the full model the Pareto distribution is the cutoff separating the set of distributions implying incomplete pass-through from the others. Conditions (13) and (11) are characterized by the same cutoff, hence condition (11) is sufficient to characterize the set of distributions implying incomplete pass-through also for the full model. (*q.e.d*)

By applying Theorem 1, it is possible to derive the implications of any cost distribution for the shape of the elasticity of demand. The Pareto distribution is the cutoff between two sets of distributions that imply different results for the responsiveness of prices to changes in marginal costs. The relevant set for this exercise is the one composed by those distributions

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<sup>8</sup> $G(z) = 1 - \left(\frac{z}{a}\right)^{-\vartheta}$  for  $z \geq a$ ,  $a > 0$ , and  $\vartheta > 0$ .

such that the slope of the density function is larger than in the Pareto case for each value of  $z$ . For example, the exponential law, the Fréchet and the Weibull distributions satisfy condition (11). Finally, the condition in Theorem 1 is closely related to the log-concavity of the survival function  $[1 - G(\cdot)]$ :

**Corollary 1.** *If the survival function  $[1 - G(z)]$  is log-concave  $\forall z$ , then (11) holds and the elasticity of demand is increasing in the price charged.*

**Proof:** The survival function  $[1 - G(\cdot)]$  is log-concave if and only if the following inequality holds:

$$g'(z) > -\frac{g(z)^2}{[1 - G(z)]} \quad \forall z$$

which implies that inequality (11) also holds. (*q.e.d.*)

Log-concavity is sufficient but not necessary to drive the result; Theorem 1 is a weaker requirement (for example, the Weibull distribution exhibits a log-concave survival function only for certain values of its parameters, but satisfies Theorem 1 for the entire range of them).

### 3.1 Incomplete Pass-Through and Productivity

Optimal prices in this economy can be expressed as:

$$p_{jk}(z_k) = \frac{|\varepsilon_{jk}|}{|\varepsilon_{jk}| - 1} c_{jk} z_k \quad \text{for } j, k = d, f \quad (15)$$

where the elasticity of demand  $|\varepsilon_{jk}|$  is given by (10). Pass-through is given by:

$$PT_{jk}(z_k) = \frac{\partial \log(p_{jk}(z_k))}{\partial z_k} = 1 - \frac{p_{jk}(z_k)}{|\varepsilon_{jk}|^2} \cdot \frac{\partial |\varepsilon_{jk}|}{\partial z_k}. \quad (16)$$

Notice that the elasticity of demand, optimal prices and pass-through are functions of the firm's cost  $z_k$ . Consider first extremely productive firms, for which the unit cost  $z_k$  approaches zero. For those firms, the term  $[1 - F_{j, \sim k}(p_{jk}(z_k))] = \text{prob}\{p_{jk}(z_k) \leq p_{j, \sim k}(z_k)\}$  approaches one, and the demand approaches the one in a standard model with monopolistic competition and CES

preferences. Hence the elasticity of demand is constant:  $|\varepsilon_{jk}| \rightarrow \eta$ , prices are characterized by the CES constant mark-up, and pass-through is complete. Consider now extremely unproductive firms, for which the unit cost  $z_k$  tends to infinity. For those firms, the term  $[1 - F_{j,\sim k}(p_{jk}(z_k))] = \text{prob}\{p_{jk}(z_k) \leq p_{j,\sim k}(z_k)\}$  approaches zero, the elasticity of demand tends to infinity, and prices tend to perfectly competitive ones. Also with prices equal to marginal cost, pass-through is complete. Finally, for firms such that  $z_k \in (0, +\infty)$ ,  $[1 - F_{j,\sim k}(p_{jk}(z_k))] = \text{prob}\{p_{jk}(z_k) \leq p_{j,\sim k}(z_k)\} \in (0, 1)$ ,  $|\varepsilon_{jk}| \in (\eta, +\infty)$  and is increasing in  $z_k$  (and in  $p_{jk}(z_k)$ ), so passthrough is strictly between 0 and 1. This result is analogous to the one in Feenstra, Gagnon, and Knetter (1996), extended to consider a continuum of goods, heterogeneous firms, and endogenous market shares. The numerical analysis in Section 4 will provide a more precise characterization of the shape of the pass-through function.

### 3.2 Aggregation

In this section I discuss how to aggregate individual prices to investigate the extent of incomplete pass-through of aggregate shocks into aggregate prices.

On this matter, it is important to observe that we cannot use ideal price indexes to measure the effect of aggregate shocks on aggregate prices. By construction, the CES ideal price indexes take into account the equilibrium expenditure shares in each of the goods, so a variation in the individual prices is accompanied by the corresponding equilibrium variation in demand. Moreover in this model a change in price may induce a change in the acquisition option: consumers may switch to imports after an increase in the domestic price, and this switch is taken into account by the ideal price index. In order to isolate the change in aggregate prices while keeping quantities and acquisition choices constant, I adopt an aggregation method that mimics the construction of the CPI index.<sup>9</sup> I refer to these new price aggregates as the “actual” price

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<sup>9</sup>The CPI index contains two levels of aggregation. At the lower level, individual prices are collected into item-area indexes through a geometric average:

$$\pi_t^i = \Pi_{j=1}^{N_i} \left( \frac{p_{jt}^i}{p_{jt-1}^i} \right)^{\frac{1}{N_i}}$$

where  $p_{jt}^i$  is the price of good  $j$  at time  $t$  in the item-area  $i$  and  $N_i$  is the number of collected prices in item-area

indexes.

The actual price index for inputs produced in country  $k$  and sold in country  $j$  ( $j, k = d, f$ ) is:

$$\tilde{P}_{jk} = \frac{1}{S_{jk}} \int_{B_{jk}} p_{jk}(z_k) s_{jk}(z_k) g(z) dz \quad (17)$$

where the integral is defined over the set  $B_{jk}$ , which is the set of goods that a final good producer in country  $j$  buys from a supplier in country  $k$  :

$$B_{jk} = \{(z_d, z_f) : p_{jk}(z_k) = \min\{p_{jd}(z_d), p_{jf}(z_f)\}\} \text{ for } j, k = d, f. \quad (18)$$

The term  $s_{jk}(z_k)$  is the expenditure share in country  $j$  of a good bought from a country  $k$  supplier with draw  $z_k$ :

$$s_{jk}(z_k) = \frac{p_{jk}(z_k) q_{jk}(z)}{\underbrace{\int_{B_{jk}} p_{jk}(z_k) q_{jk}(z) g(z) dz}_{s_{jk}(z_k)|K}} \underbrace{[1 - F_{j, \sim k}(p_{jk}(z_k))]}_{prob\{K\}}. \quad (19)$$

The expenditure share  $s_{jk}(z_k)$  is given by the expenditure share conditional on buying from country  $k$  ( $s_{jk}(z_k)|K$ ) times the probability of buying from  $k$  ( $prob\{K\}$ ). The term  $S_{jk}$  in equation (17) is the total expenditure share in country  $j$  on goods bought from country  $k$ :

$$S_{jk} = \frac{P_{jk} q_{jk}}{P_j q_j} = \frac{\int_{B_{jk}} p_{jk}(z_k) q_{jk}(z) g(z) dz}{P_j q_j}. \quad (20)$$

Consequently, the actual CPI index for country  $j$  is given by:

$$CPI_j = S_{jd} \tilde{P}_{jd} + S_{jf} \tilde{P}_{jf}. \quad (21)$$

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*i.* At the upper level, item-area indexes are aggregated into the CPI index by:

$$\Delta CPI_{b,t} = \sum_i s_b^i \pi_t^i$$

where  $s_b^i = E_b^i / (\sum_i E_b^i)$  is the expenditure share in item-area  $i$  in the base year  $b$ . In my calculations, I abstract from the lower level aggregation and implicitly assume  $N_i = 1 \forall i$ , so that the item-area index is just equal to the individual price variation.

Changes in actual price indexes are computed aggregating individual price changes, but assuming that the price changes do not affect the expenditure shares and the acquisition option. I denote with  $\hat{P}_{jk}$  the percentage variation in the actual price index  $\tilde{P}_{jk}$ :

$$\hat{P}_{jk} = \frac{1}{S_{jk}} \int_{B_{jk}} \hat{p}_{jk}(z_k) s_{jk}(z_k) g(z) dz \quad (22)$$

where  $\hat{p}_{jk}(z_k)$  is the percentage variation in the individual price  $p_{jk}(z_k)$ .

## 4 Numerical Examples

In this section I use some numerical examples to quantify the extent of pass-through predicted by the model and its variation across firms. I start by considering a scenario in which the two countries are identical in every characteristic, compute pass-through on import prices following an exchange rate depreciation, and show how aggregate and firm-level pass-through vary with the aggregate parameters of the model. In a symmetric world with trade costs, the concavity of the pricing functions imply that firms do pricing-to-market. I quantify the differences between domestic and export prices that the model implies, and their variation across firms.

### 4.1 Parameterization and Baseline Example

I start by considering two identical countries, and compute changes in import prices following a depreciation of the domestic currency. The two countries have the same technology ( $G_d = G_f = G$ ), the same wage level ( $w_d = w_f$ ), and start with a one-to-one exchange rate. I assume costs are distributed according to a Weibull law with shape parameter  $\vartheta$  and location parameter  $T$ :  $G(z) = 1 - e^{-Tz^\vartheta}$ , for  $T, \vartheta > 0$ . For these preliminary calculations, I set  $\eta$  to a standard value of 2. The shape parameter of the cost distribution is set to  $\vartheta = 4$ , and the location parameter is set to  $T = 1$ .

I compute prices of imported goods and the associated mark-ups across the entire firms' cost distribution. I am interested in quantifying how prices and mark-ups react after a change in

the exchange rate. Since the one described here is a purely real, partial equilibrium economy, exchange rate shocks are isomorphic to exogenous productivity shocks, or to any exogenous shock changing the relative distribution of marginal costs in the two countries. I denote with  $e$  the real exchange rate between the two countries, expressed in units of domestic consumption per units of foreign consumption. I consider a 1% depreciation of the domestic currency ( $e' = 1.01$ ), and compute its effect on import prices. The model implies that – in response to the depreciation – foreign firms increase their export prices less than proportionally (here, less than 1%). On aggregate, the model implies an increase in the import price index of 0.69%.<sup>10</sup> This sluggish price adjustment is covered by a reduction in mark-ups. The extent of the adjustment following the depreciation varies across firms, depending on their productivity level. Figure 1 shows the firms’ cost distribution, optimal prices and mark-ups, and the extent of pass-through as functions of the unit cost  $z$ .

The most productive firms are the ones with the highest mark-ups (up to 100% in this example) and they completely pass the depreciation into a price increase (pass-through tends to one for  $z \rightarrow 0$ ): since these firms are “infinitely” productive, the probability that buyers switch option (*i.e.*, that they start buying from domestic producers instead) after they increase their price is almost zero. On the other hand, very unproductive firms have almost zero profits and very little margin to shrink their mark-ups, so they have to pass through completely the cost increase into a price increase (pass-through is one for  $z$  “high”). Pass-through is strictly less than one for firms that lie in the middle of the cost distribution: these firms can strategically reduce mark-ups and not adjust fully their price in order to induce the buyers to keep buying from them and not to switch to domestic producers after the depreciation. I explore the empirical implications of this prediction in Section 5.

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<sup>10</sup>The baseline example generates a level of pass-through that is comparable with empirical studies: Campa and Goldberg (2005) report an average long-run exchange rate pass-through coefficient of 64% among OECD countries. Gagnon and Knetter (1995) center the range of pass-through estimates found in various studies around 60% .

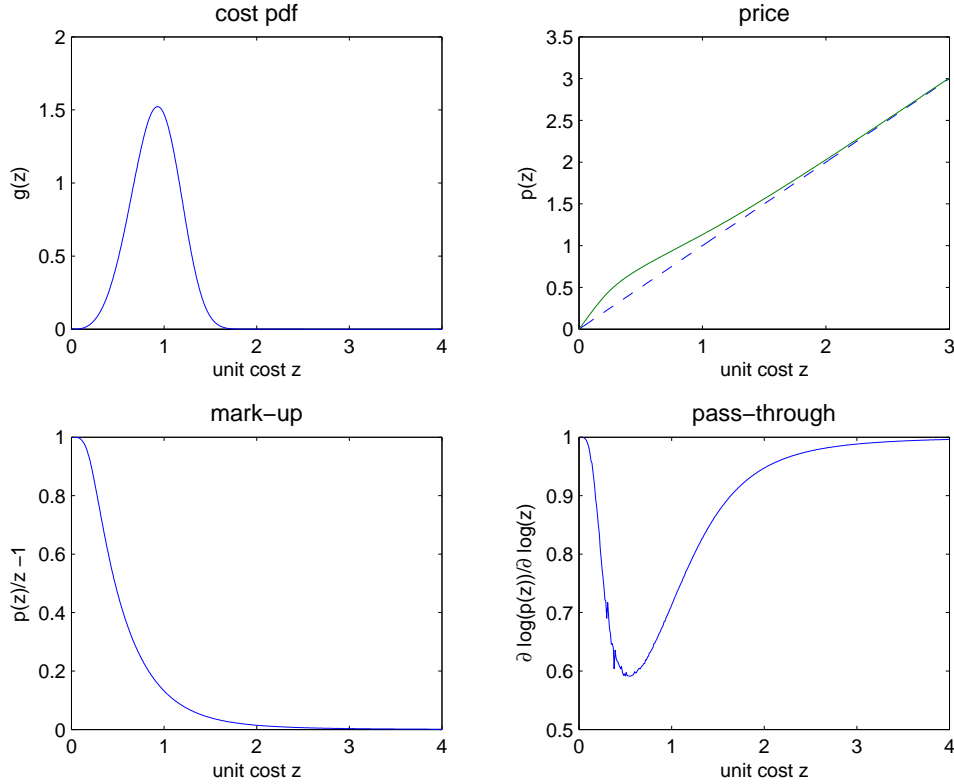


Figure 1: Mark-ups and pass-through as functions of unit costs (baseline example).

## 4.2 Average Cost and Cost Dispersion

Mark-ups variability and price responses to shocks are affected by heterogeneity in the productivity distributions of the two countries. The parameters of the cost distributions,  $T$  and  $\vartheta$ , describe productivity advantages of firms in one country with respect to the other. In the baseline example,  $T_d/T_f = \vartheta_d/\vartheta_f = 1$ . As  $T_d/T_f$  increases, domestic suppliers are on average more productive than foreign suppliers. This implies that profit margins on import prices (foreign exports) are going to be lower, as foreign firms are selling in a more competitive domestic market. As a consequence, import prices are closer to the marginal costs of the exporting firms, and pass-through is going to be higher. The left panel of Figure 2 shows this effect: an increase of  $T_d/T_f$  from 0.1 to 10 implies an increase in aggregate pass-through from about 55% to 70%.

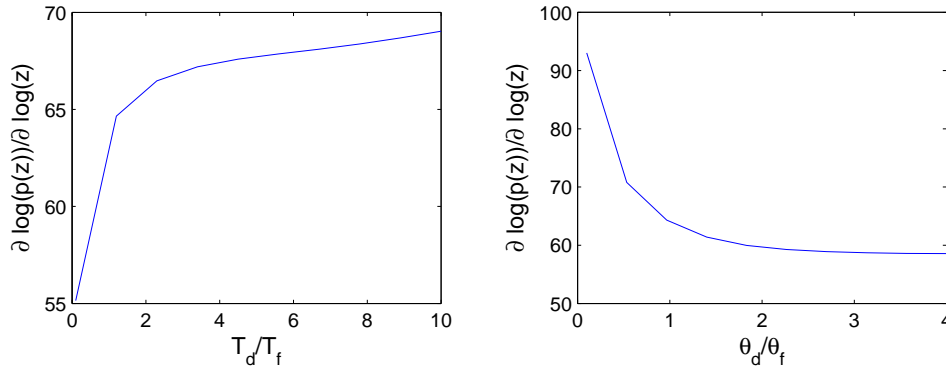


Figure 2: Pass-through as a function of aggregate productivity parameters.

The effect of the shape parameter  $\vartheta$  is larger in magnitude. When  $\vartheta_d/\vartheta_f$  increases, the variance of the costs of domestic suppliers becomes smaller with respect to the one of foreign suppliers. As a consequence, pass-through on aggregate import prices drops. The right panel of Figure 2 shows that an increase of  $\vartheta_d/\vartheta_f$  from 0.1 to 4 implies a drop in aggregate pass-through from about 90% to 60%. Figure 3 shows this comparative statics at the firm level: the upper panels display the cdf and pdf of the cost distributions of domestic firms, while the lower panels display the implied mark-ups and pass-through on imports, for  $\vartheta_d/\vartheta_f$  increasing from 1 to 4. When  $\vartheta_d > \vartheta_f$ , the cost distribution of domestic firms second-order stochastically dominates the one of foreign firms. As  $\vartheta_d/\vartheta_f$  increases, the cost distribution of domestic firms becomes less disperse, and so do the distributions of mark-ups and pass-through.

### 4.3 Pricing to Market

Firms' prices and profit margins are correlated with each firm's productivity relative to its competitors. In a world of identical countries with costless trade and a one-to-one exchange rate, the competition that a firm faces in its domestic market and in the foreign market is exactly the same. Trade barriers and exchange rate differentials create a wedge between the two markets: trade barriers, for example, make imports more costly than domestic purchases and create a disadvantage for foreign firms selling in the domestic market. In a model with constant mark-ups, this would have no effect on the pricing strategies of foreign firms, while it

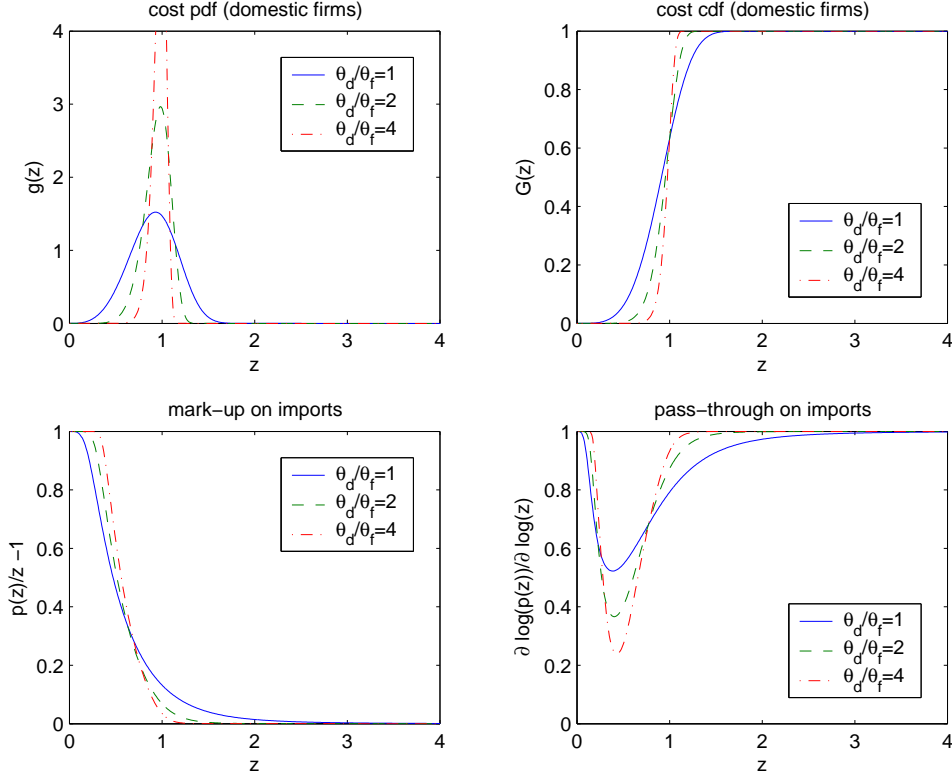


Figure 3: Pass-through as a function of unit cost and cost variance of competitors.

does have an effect in this model. Trade costs induce foreign firms to shrink their profit margins on exports: in order to be competitive in the domestic market, they partially absorb the trade costs through a reduction in mark-ups instead than through a full increase in price. Trade cost differentials across countries also generate price and mark-up differentials across different export destinations. Consider the baseline example, with the domestic country  $d$  importing from two other countries,  $A$  and  $B$ . The three countries are identical, except for the trade barriers that separate them  $t_{dA} > t_{dB} > 1$ . The standard CES model would predict import prices to be higher than domestic prices, and the ratio between the two to be constant and equal to the trade barrier:  $p_{export}/p_{domestic} = t$ . Conversely, in a world with heterogeneous firms and endogenous mark-ups, the wedge between domestic and export prices varies with the firm's productivity. The left panel of Figure 4 plots the ratio  $p_{export}/p_{domestic}$  as function of  $z$  for the baseline example with two exporting countries (in the example, I set  $t_{dA} = 1.5$  and  $t_{dB} = 1.3$ ). In both cases, firms that

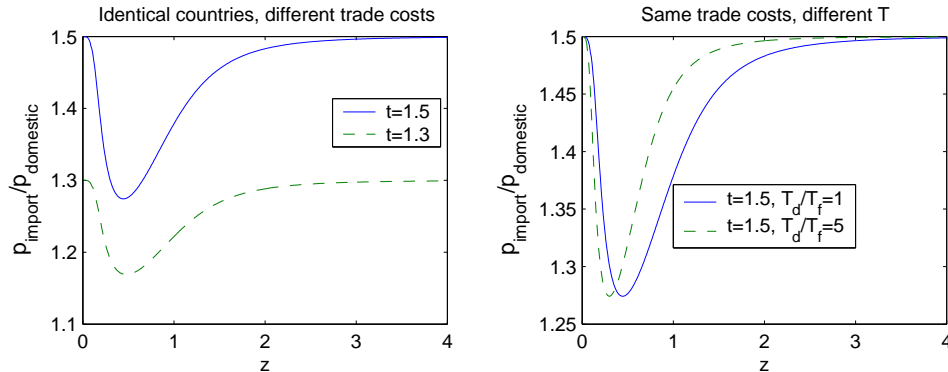


Figure 4: Extent of pricing to market (difference between export and domestic prices) .

lie in the middle of the cost distribution (the ones for which pass-through is more incomplete) do pricing to market, and are able to absorb up to half of the trade cost through a reduction in mark-up. The width of the price wedge (or the extent of the incomplete price adjustment) is directly related to the magnitude of the trade barrier.

The wedge between domestic and export prices also depends on country characteristics. The right panel of Figure 4 shows the ratio of import over domestic prices for two identical countries and for two countries with different average productivities. When the domestic country is more productive than the foreign country, pass-through on import prices is higher. The picture shows that also the price wedge is smaller in this case, where only a small portion of (relatively productive) firms find profitable to do pricing-to-market (the area above the curve is smaller for  $T_d/T_f = 5$  than for  $T_d/T_f = 1$ ). Hence the model predicts that firms should do less pricing-to-market when exporting to relatively more productive (richer) countries.

## 5 Empirical Evidence: Incomplete Pass-Through and Pricing-to-Market in the Cars Industry

The model predicts that firms lying in different portions of the cost distribution should have different extents of pass-through incompleteness and pricing-to-market. The intuition behind

this result is associated with the shape of the residual demand function that a firm faces, *i.e.* the demand for the good once taken into account the optimal pricing response of the firm's competitors. Convexity of the residual demand curve (9) determines its elasticity to price changes, and hence the optimal mark-ups and price adjustments. For firms that are among the most productive in the distribution, the term  $[1 - F_{j,\sim k}(p_{jk}(z_k))]$  approaches one, as the probability of charging a price lower than their competitors is very high. For those firms, residual demand approximates the constant elasticity one, and optimal prices approach the CES constant mark-up ones, which are linear in marginal costs and hence exhibit complete pass-through. For firms that are among the least productive in the distribution, the term  $[1 - F_{j,\sim k}(p_{jk}(z_k))]$  approaches zero, as the probability of charging a price lower than their competitors is very low. For those firms, the elasticity of demand approaches infinity, and the optimal pricing strategy is marginal cost pricing. For firms that lie in the middle of the distribution, the convexity of demand lies between these two extremes.

In the model, firms differ in their unit costs  $z$ , or in their labor productivity  $1/z$ . Low-cost firms are more productive, and sell larger quantities at lower prices. Due to CES preferences, the quantity sold by a firm is proportional to the term  $p(z)^{-\eta}$ , which is positively correlated with productivity  $1/z$ . Hence the model predicts a relationship between the extent of pass-through (and pricing-to-market) as a function of firm's size (= quantity sold). Figure 5 shows this relationship in the baseline example. The figure plots pass-through ( $\partial \log(p)/\partial \log(z)$ ) as a function of log-quantity sold. For large (and productive) firms, the relationship appears to be increasing and concave, indicating that large and more productive firms tend to pass-through a larger portion of their cost shocks into prices. The amount of pass-through increases at a decreasing rate with the firm's size. This behavior is reversed for small (and unproductive) firms. Nonetheless, these firms are more likely to be undercut by the prices charged by their competitors in other countries, so that the prices they charged are less likely to be observed in actual exchanges. For this reason, the empirical evidence that follows focuses on testing the increasing and concave shape of the pass-through function for relatively large firms. In the remaining of the section, I use data from the European car market to estimate the shape of the pass-through function as a function of size.

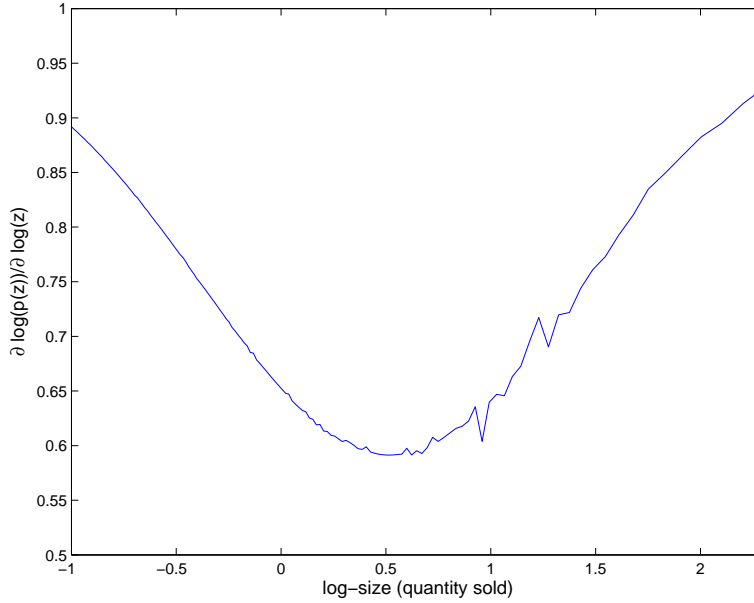


Figure 5: Pass-through as a function of size.

## 5.1 Data

I use a panel data set of car prices assembled by Penny Goldberg and Frank Verboven.<sup>11</sup> The data set contains detailed product-level information for car sales in 5 European markets (Belgium, France, Germany, Italy and the UK) over the period 1970-2000. For each product, or car model, the data record selling price and quantity sold in each of the destination markets, and a list of car characteristics. Moreover, the data include information on both the country of incorporation of the firm and the country where the model was effectively produced. There are 14 origin countries: the 5 destination markets plus Spain, Netherlands, Sweden, Japan, Korea, Czech Republic, Yugoslavia, Poland, and Hungary. I concentrate the attention to prices of imported cars in the five markets, keeping track of the origin and destination countries of each sale. I define the origin country as the country where production effectively took place (independently on the country of incorporation of the firm). This is the relevant definition to consider shocks to the exchange rates as shocks that actually distort the relative cost of production between two

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<sup>11</sup>For a more detailed description of the data, see Goldberg and Verboven (2001), Goldberg and Verboven (2005).

countries.

## 5.2 Exchange Rate Pass-through: Specification and Results

Pass-through in the model is a function of both aggregate and firm-level characteristics. At the firm level, as the results of previous sections show, the extent of pass-through depends on a firm’s “location” in the productivity distribution. Since in the model productivity is positively correlated with size, I use quantity sold of a product as a measure of size.<sup>12</sup> At the aggregate level, pass-through also depends on the productivity/technology of the destination country, represented by the parameters  $T$ ,  $\vartheta$ . As a proxy for it, I use real GDP per capita in the destination country (import demand shifter).

In the model, each firm only produces one good, and is identified with it. In the cars industry, however, most firms sell more than one product, or model, so I need to take a stand on what is the relevant level of observation. Anecdotal evidence seems to suggest that a firm may be more or less competitive in a foreign market for some products with respect to others.<sup>13</sup> For this reason, I identify a firm in the model with a firm-product pair in the data, and run the regressions at the product level.<sup>14</sup>

Based on these considerations, I run the following reduced-form pass-through regression:

$$\begin{aligned} \ln(p_{icdt}) = & \alpha + \beta_1 \ln(q_{icdt}) + \beta_2 \ln(gdp_{dt}) + \gamma_0 \ln(e_{cdt}) + \dots \\ & \dots + \gamma_1 \ln(q_{icdt}) \times \ln(e_{cdt}) + \gamma_2 [\ln(q_{icdt})]^2 \times \ln(e_{cdt}) + \delta_{cd} + \epsilon_{icdt} \end{aligned} \quad (23)$$

where  $p_{icdt}$  denotes the price of product  $i$ , produced in country  $c$  and sold in country  $d$ , in year  $t$  and in local currency (importer’s currency),  $q_{icdt}$  is the quantity sold in country  $d$  of the same product,  $e_{cdt}$  is the exchange rate (importer’s currency  $d$  per unit of exporter’s currency  $c$ ) in

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<sup>12</sup>With measures of employment and cost of intermediates, one could construct measures of firm productivity such as output per worker or value added per worker. Unfortunately, the dataset does not include this information.

<sup>13</sup>See Economist (2008)’s survey on cars in the emerging markets.

<sup>14</sup>The dataset controls for cars models that have changed name over time but retained more or less constant characteristics. I treat different denominations of the same model over the years as the same product in the analysis.

year  $t$ ,  $gdp_{dt}$  is the GDP per capita of the destination country in year  $t$ ,  $\delta_{cd}$ , are country-pair fixed effects, and  $\epsilon_{icdt}$  is an orthogonal error term.

Regression (23) generates the following empirical counterpart to the pass-through function shown in the model:

$$\frac{\partial \ln(p_{icdt})}{\partial \ln(q_{icdt})} = \hat{\gamma}_0 + \hat{\gamma}_1 \ln(q_{icdt}) + \hat{\gamma}_2 [\ln(q_{icdt})]^2, \quad (24)$$

where the model predicts  $\hat{\gamma}_1 > 0$  and  $\hat{\gamma}_2 < 0$ . Table 1 displays the results.

	(I)	(II)	(III)
Log-size	-0.0622*** (0.0062)	-0.0543*** (0.0062)	0.06*** (0.0057)
Log-exchange rate	0.429*** (0.0198)	0.1049* (0.0584)	0.252*** (0.0467)
Log-GDP per capita	0.1513*** (0.0442)	0.1769*** (0.0441)	-0.011 (0.0352)
Interaction size-exchange rate		0.0631*** (0.0133)	0.0023** (0.0106)
Interaction size squared-exchange rate		-0.0028*** (0.0008)	-0.0006 (0.0006)
Fixed effects	No	No	Yes
$R^2$	0.9244	0.9255	0.9536
No of obs.	8978	8978	8978

Table 1: Pass-through regressions with size-exchange rate interactions (standard errors in parentheses).

Column (I) reports the results of the regression without the interaction terms. All coefficients are significant at the 1% level. The coefficient on size is negative, indicating that larger (and more productive) firms tend to charge lower prices, in line with the predictions of the model. As expected, the pass-through coefficient  $\hat{\beta}_2$  is positive and smaller than one, while the coefficient on GDP per capita is positive, indicating that firm charge higher prices in richer, more produc-

tive countries.<sup>15</sup> Except for one, all country-pair fixed effects are highly significant, indicating variation in price adjustments across countries.<sup>16</sup> Column (II) reports the results of the regression adding linear and quadratic interaction terms. The common coefficients are significant and similar in size to the previous specification. As predicted by the model,  $\hat{\gamma}_1$  is positive and  $\hat{\gamma}_2$  is negative, indicating an increasing and concave shape of pass-through as a function of size. Both interaction coefficient are significant at the 1% level. All country-pair fixed effects are also significant. Column (III) shows the results of the same regression adding car class and firm fixed effects, to control for the effects of car characteristics on prices.<sup>17</sup> The coefficient on size is positive in this specification, indicating that - controlling for car characteristics, larger firms charge higher prices. The coefficient on GDP per capita is negative and non-significant. The sign of the other coefficients is preserved, and especially of the interaction coefficients  $\hat{\gamma}_1$  and  $\hat{\gamma}_2$ , that also in this specification are positive and negative, respectively (even though  $\hat{\gamma}_2$  loses significance). All country-pair and most of the class and firm fixed effects are significant.

For robustness, I also run the pass-through regression by size quartiles. The results are contained in Appendix B, and confirm the results of regression (23): the pass-through coefficients are ordered according to the firms' size quartiles.

### 5.3 Pricing to Market: Specification and Results

Firms' differential responses to exchange rate shocks also depend on the specific countries involved. Following Knetter (1989), Knetter (1993), and Goldberg and Knetter (1997), I quantify the differences in pricing to market across firms by running the following pricing-to-market regressions:

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<sup>15</sup>The model does not have a clear implication for the sign of the coefficient  $\hat{\beta}_3$ . A market with a higher GDP per capita may be characterized by more productive domestic firms, which would push down the prices in that market, but may be also associated with higher demand due to the higher income. This second effect, which does not appear in the model due to CES preferences, goes in the direction of pushing up the prices, and seems the dominant one in the data.

<sup>16</sup>The only non-significant country-pair fixed effect is the one associated to exports from Yugoslavia to France, for which there are only eleven observations for only one product.

<sup>17</sup>The empirical analysis in Feenstra, Gagnon, and Knetter (1996) treats cars as homogeneous goods, due to the unavailability of car characteristics consistently defined across countries. The data assembled by Goldberg and Verboven overcome this problem, allowing to control for car characteristics to disentangle effective mark-up changes from quality differences across different models.

$$\begin{aligned}
\ln(p_{icdt}) &= \alpha + \beta_{1c}\ln(q_{icdt}) + \beta_{2c}\ln(gdp_{dt}) + \beta_{3c}\ln(gdp_{ct}) + \gamma_{0c}\ln(e_{cdt}) + \dots \\
&\dots + \gamma_{1c}\ln(q_{icdt}) \times \ln(e_{cdt}) + \gamma_{2c}[\ln(q_{icdt})]^2 \times \ln(e_{cdt}) + \dots \\
&\dots + \gamma_{3c}\ln(gdp_{dt}/gdp_{ct}) \times \ln(e_{cdt}) + \delta_d + \epsilon_{icdt}, \quad \forall c.
\end{aligned} \tag{25}$$

The regression is run separately for each origin country  $c$ . The dependent variable  $p_{icdt}$  is the price of product  $i$ , produced in country  $c$  and sold in country  $d$ , in year  $t$  and in local currency (importer's currency),  $q_{icdt}$  denotes the quantity sold in country  $d$  of the same product,  $e_{cdt}$  is the exchange rate (importer's currency  $d$  per unit of exporter's currency  $c$ ) in year  $t$ ,  $gdp_{dt}$  ( $gdp_{ct}$ ) is the real GDP per capita of the destination (origin) country in year  $t$ , and  $\delta_d$  are destination-country fixed effects. I include in the regression linear and quadratic size-exchange rate interaction terms, to test for variation in pricing-to-market across firms of different size, and an interaction term between the exchange rate and relative GDP per capita in the two countries, to test the prediction of the model according to which pass-through should be increasing in the relative productivity (or GDP per capita) of the importing country with respect to the exporting one (see Section 4).

The data includes 14 origin countries, but I run the regression only for the ones for which we have a significant amount of data: France, Germany, Italy, the U.K. and Japan.<sup>18</sup> Tables 2, 3 and 4 display the results for Germany, Italy, and Japan.

Column (I) reports the results of the regression with size interaction terms, but without using the information on the origin country. The coefficients on size and destination country GDP per capita tend to be significant, but differ in sign across countries. Also the intercept of the pass-through function ( $\hat{\gamma}_0$ ) exhibits significant variation across the three tables: while German exports exhibit more than complete pass-through, the intercept is negative for Italian exports, and smaller but close to one for the Japanese. The signs of the interaction terms though are the same in the three countries, and aligned with the predictions of the model:  $\hat{\gamma}_1 > 0$ ,  $\hat{\gamma}_2 < 0$ , and both coefficients are significant at the 1% level in the three countries. The destination country

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<sup>18</sup>The dataset counts more than 1000 observations for each of these origin countries.

	(I)	(II)	(III)
Log-size	-0.1704*** (0.0098)	-0.1719*** (0.0107)	-0.0583*** (0.0065)
Log-exchange rate	2.326*** (0.0769)	2.5323*** (0.0929)	2.6516*** (0.0529)
Log-GDP per capita (destination country)	1.1986*** (0.0543)	1.3188*** (0.822)	1.2524*** (0.0466)
Log-GDP per capita (origin country)		-0.211*** (0.0727)	-0.2634*** (0.0429)
Interaction size-exchange rate	0.0568*** (0.0166)	0.0552*** (0.0169)	-0.0165* (0.0097)
Interaction size squared-exchange rate	-0.0033*** (0.0009)	-0.0031 (0.0009)	0.001* (0.0005)
Interaction rel. GDP-exchange rate		0.0248** (0.0102)	0.0167*** (0.0057)
Fixed effects	No	No	Yes
$R^2$	0.9816	0.9822	0.9945
No of obs.	1829	1779	1779

Table 2: Pricing-to-market regressions, exports from Germany (standard errors in parentheses).

fixed effects are all highly significant.

Column (II) adds information on the origin country GDP per capita for Germany and Italy (not for Japan, for which this information is not contained in the data). The sign and magnitude of the coefficients is preserved. Moreover, the coefficient on the interaction term between relative GDP per capita and exchange rate is positive and significant, confirming the prediction of the model that pass-through is increasing in the relative productivity of the importing country.

Column (III) adds car class and firm fixed effects. The results of the previous specifications are preserved for Italy and Japan, while the interaction terms change sign for German exports. Destination country and car class fixed effects are all significant; not so much for firm fixed

	(I)	(II)	(III)
Log-size	-0.0729* (0.0398)	0.074* (0.0401)	0.0727*** (0.0247)
Log-exchange rate	-1.8954*** (0.1159)	-4.1514*** (0.4338)	-3.6879*** (0.2664)
Log-GDP per capita (destination country)	-1.4336*** (0.0961)	-3.5821*** (0.425)	-3.0964*** (0.2604)
Log-GDP per capita (origin country)		2.2998*** (0.4458)	1.7287*** (0.2733)
Interaction size-exchange rate	0.0621*** (0.0236)	0.0708*** (0.0238)	0.1092*** (0.0148)
Interaction size squared-exchange rate	-0.0029*** (0.0012)	-0.0034 (0.00012)	-0.0057*** (0.0008)
Interaction rel. GDP-exchange rate		0.046* (0.0258)	0.0385*** (0.0157)
Fixed effects	No	No	Yes
$R^2$	0.9255	0.9274	0.973
No of obs.	1308	1253	1253

Table 3: Pricing-to-market regressions, exports from Italy (standard errors in parentheses).

effects.

The results for France and the U.K. do not support the predictions of the theory. The interaction coefficients display all the opposite signs with respect to what the model predicts. This seems to suggest that while the data aggregated across countries support the predictions of the model, more country-specific variables must be taken into account to explain firm-level variation in pricing-to-market.

#### 5.4 Testing condition (11)

To be added.

	(I)	(III)
Log-size	-0.0677*** (0.0139)	-0.0304*** (0.0086)
Log-exchange rate	0.9725*** (0.0935)	1.2372*** (0.0543)
Log-GDP per capita (destination country)	0.6777*** (0.0521)	0.6699*** (0.0308)
Interaction size-exchange rate	0.0815*** (0.0935)	0.0325*** (0.0118)
Interaction size squared-exchange rate	-0.0045*** (0.0012)	-0.0018*** (0.0009)
Fixed effects	No	Yes
$R^2$	0.9708	0.9905
No of obs.	1873	1873

Table 4: Pricing-to-market regressions, exports from Japan (standard errors in parentheses).

## 6 Conclusions

I presented a simple two-country model of trade and international price-setting where firms are heterogeneous and the world market of each good has the characteristics of an international oligopoly with unobservable firm-level costs. I show that for a wide range of productivity parameterizations, firms' strategic price setting endogenously generates residual demands with an elasticity that is increasing in the price, and hence incomplete pass-through of cost changes into prices and pricing to market. Moreover, the extent of pass-through and pricing to market depends on a firm's relative productivity compared to its competitors: pass-through is a U-shaped function of a firm's productivity. The firm-level variation predicted by the model is tested using a panel data set of cars prices in five European markets. Preliminary estimates seem to support the predictions of the model.

This paper contributes to the literature on incomplete pass-through and pricing to market

by putting more structure on the determinants and the implications of strategic behavior in price setting. While the basic fact of incomplete pass-through has received a lot of attention in the literature, to my knowledge, there has been little or no emphasis on how the extent of pass-through varies across firms in a country. The empirical results supporting the theory are still preliminary, nonetheless they outline a promising avenue to better understand pricing behavior across firms.

## Appendix

### A Algorithm to Solve for the Pricing Rule

The pricing rule  $p_{jk}(z_k)$ , for  $j, k = d, f$ , is the solution of the following system of first order conditions:<sup>19</sup>

$$p_{jk}(z_k)(1 - \eta) + \eta c_{jk} z_k - p_{jk}(z_k)[p_{jk}(z_k) - c_{jk} z_k] \left[ \frac{f_{j, \sim k}(p_{jk}(z_k))}{1 - F_{j, \sim k}(p_{jk}(z_k))} \right] = 0. \quad (\text{A.1})$$

Notice that system A.1 can be solved in pairs, *i.e.*, the two equations for  $j = d$  are independent from the two equations for  $j = f$ . For each  $j$ , I solve numerically the system with the following algorithm:

1. Given an initial vector of productivities  $z_k$  for each country  $k$ , guess an initial pricing rule  $p_{jk}^0(z_k)$  for each origin country  $k$  to destination country  $j$ .
2. Compute  $F_{jk}^0(p_{jk}^0(z_k))$ .
3. Given  $F_{jk}^0(\cdot)$ , find the pricing rules  $p_{jk}^1(z_k)$  (one for each origin country  $k$ ) that solve (A.1).
4. If  $p_{jk}^1(z_k) - p_{jk}^0(z_k) < \varepsilon, \forall k$ , STOP.  
If  $\exists k$  such that  $p_{jk}^1(z_k) - p_{jk}^0(z_k) \geq \varepsilon$ , compute  $F_{jk}^1(p_{jk}^1(z_k))$ , and continue iterating until convergence.

If a solution exist, it must lie between the marginal cost and the monopolistic competition pricing rule. I use the marginal cost to initialize the algorithm.

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<sup>19</sup>The system A.1 is derived from problem 7.

## B Regressions by Size Quartiles

As a robustness check, I run the following pass-through regressions, where I allow the pass-through coefficient to be different across quartiles of firms ordered by size:

$$\begin{aligned} \ln(p_{icdt}) = & \alpha + \beta_1 \ln(q_{icdt}) + \beta_2 \ln(gdp_{dt}) + \gamma_1 \mathbb{I}_{\{quart_q=1\}} \times \ln(e_{cdt}) + \gamma_2 \mathbb{I}_{\{quart_q=2\}} \times \ln(e_{cdt}) + \dots \\ & \dots + \gamma_3 \mathbb{I}_{\{quart_q=3\}} \times \ln(e_{cdt}) + \gamma_4 \mathbb{I}_{\{quart_q=4\}} \times \ln(e_{cdt}) + \delta_{cd} + \epsilon_{icdt} \end{aligned} \quad (\text{A.2})$$

where  $\mathbb{I}_{\{quart_q=i\}}$  is the indicator function denoting all the observations for which the quantity sold  $q_{icdt}$  belongs to its  $i$ -th quartile.

The model predicts that firms selling larger quantities should exhibit more pass-through:  $\hat{\gamma}_1 < \hat{\gamma}_2 < \hat{\gamma}_3 < \hat{\gamma}_4$ .

The following results confirm the predictions of the model for the first 3 quartiles:  $\hat{\gamma}_1 < \hat{\gamma}_2 < \hat{\gamma}_3$ , and the coefficients are significantly different from each other. We cannot reject the hypothesis that  $\hat{\gamma}_3 = \hat{\gamma}_4$ , indicating that the difference between the coefficients becomes insignificant for the highest quartiles.<sup>20</sup>

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<sup>20</sup>Smaller and insignificant differences for higher quartiles are consistent with the concavity of the pass-through function.

	(I)	(II)	(III)
Log-size	-0.2178*** (0.0126)	-0.0529*** (0.0062)	0.0773*** (0.0063)
Log-GDP per capita	0.9078*** (0.0869)	0.1795*** (0.044)	0.0426 (0.0373)
Log-exchange rate ( $quart_q = 1$ )	0.3101*** (0.0075)	0.3998*** (0.0198)	0.3413*** (0.0158)
Log-exchange rate ( $quart_q = 2$ )	0.4596*** (0.008)	0.4399*** (0.0198)	0.3735*** (0.0157)
Log-exchange rate ( $quart_q = 3$ )	0.5128*** (0.0086)	0.4594*** (0.02)	0.3979*** (0.016)
Log-exchange rate ( $quart_q = 4$ )	0.6033*** (0.0113)	0.4511*** (0.0202)	0.3949*** (0.0163)
Country-pair fixed effects	No	Yes	Yes
Car class and firm fixed effects	No	No	Yes
<hr/>			
<i>Prob &gt; F:</i>			
$H_0 : \hat{\gamma}_1 = \hat{\gamma}_2$	0	0	0
$H_0 : \hat{\gamma}_2 = \hat{\gamma}_3$	0	0.0001	0
$H_0 : \hat{\gamma}_3 = \hat{\gamma}_4$	0	0.1762	0.5779
<hr/>			
$R^2$	0.5687	0.9256	0.9573
No of obs.	8978	8978	8978

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