Firms' Heterogeneity, Incomplete Information, and Pass-Through

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Abstract

A large body of empirical work documents that prices of traded goods change by a smaller proportion than real exchange rates between the trading countries (incomplete pass-through). I present a Ricardian model of trade and international price-setting with heterogeneous firms, Bertrand competition and incomplete information. The model implies that: 1) firm-level pass-through is incomplete and a U-shaped function of firm market share; and 2) producers operating under incomplete information, like for example new entrants in a market, exhibit different pass-through rates than producers operating under complete information. Estimates from a panel data set of cars prices support the predictions of the model.

Keywords: Heterogeneous firms, incomplete information, incomplete pass-through.

JEL Classification: F12, F31, 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 basic fact of incomplete pass-through has received a lot of attention in the literature, and there is a recent and growing body of work on how the extent of pass-through varies across firms. This paper contributes to this literature by proposing a novel channel driving incomplete pass-through at the firm level and by testing its implications empirically. The key new ingredient is the lack of information about competitors in a market.

I present a simple model of trade and international price-setting where firms are heterogeneous and the market for each good has the characteristics of an international oligopoly with imperfect information. National markets are segmented, and firms set their prices by taking into account the optimal responses of their domestic and foreign competitors, whose exact cost structure is unobservable. I show that for a wide range of parameterizations, firms' strategic behavior generates residual demands with an elasticity that is increasing in the price charged, and hence incomplete pass-through of cost changes into prices. The optimal price adjustments following changes in marginal cost depend on a firm's relative size in the destination market compared to the average (or expected) size of its competitors: as a result, pass-through is a U-shaped function of firm's size. The intuition behind this result is as follows: the largest firms (who are also the most productive in the model) 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 smallest, 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 and shrink their mark-ups to avoid losing market share in favor of their competitors.

While the price setting problem with incomplete information broadly generates incomplete pass-

through, I show that its complete information counterpart generates limit pricing, *i.e.* either 0 or 100% pass-through. Hence producers experiencing incomplete information exhibit different pass-through rates compared to producers for whom information is complete. But when is incomplete information about competition most severe in reality? When firms enter a market with a new product, it is reasonable to think that the amount of information they have about their competitors is limited. Hence, in light of firm heterogeneity, we can interpret this prediction as saying that new entrants should pass-through a different portion of their marginal cost changes into prices compared to incumbent competitors.

With an eye to the empirical analysis that follows, I generalize the model to a setting where producers operating under different informational assumptions coexist. Under the assumption that the first and second lowest cost sellers of a good are from the same country, I show that in the model with cross-sectional heterogeneity in information, "new" producers (who have incomplete information about their competitors) tend to exhibit lower pass-through than "old" competitors (who have complete information about other old competitors but incomplete information about new competitors).

While the prediction of the model relating pass-through and market share can be generated also by alternative models,[1] the second prediction, related to information, is novel of my framework. Other settings may generate different pass-through rates among new entrants and incumbents, driven by their relative sizes. Models where the pricing functions are linear affine functions of marginal costs, like Melitz and Ottaviano (2008) or the distribution costs model used in Berman et al. (2012), for example, predict that new entrants, which are on average smaller firms than incumbents, should exhibit higher pass-through. This is contrary to the prediction of my model and to the empirical evidence that I present.

I test the predictions of the model using a panel data set of car prices in five European markets.[2]

[1] See Dornbusch (1987) for a description of the general environment giving rise to a U-shaped relationship between pass-through and market share.

[2] I use the data collected by Penny Goldberg and Frank Verboven, described in Goldberg and Verboven (2001).

The estimates consistently confirm the model's prediction linking the extent of pass-through and firm size. Moreover, the empirical analysis reveals a robust relationship between the extent of pass-through and the amount of information about competition in a market, proxied by the time since the introduction of a new product. New entrants, defined as firms that recently introduced a new product in a market, systematically exhibit lower pass-through than incumbents in the data.

It is instructive to put the predictions of the model into the context of the literature. Incomplete pass-through in the data may arise from two main margins: mark-up variability, whereby firms absorb part of the cost increases through reductions 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 prices are not affected by exchange rate fluctuations.[3] The model presented in this paper focuses on variable mark-ups and abstracts from other channels.

Theoretical research on incomplete pass-through has achieved the result of mark-up variability through two main channels: exogenous price stickiness,[4] 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 generate incomplete pass-through because changes in prices determine changes in the elasticity of demand: 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 by appropriate choices of preferences (like in Melitz and Ottaviano 2008 and in Gust et al. 2010) or by specific assumptions on the nature of imperfect competition, as illustrated in Dornbusch (1987) and more recently implemented by Atkeson and Burstein (2007, 2008). This paper contributes to this last strand of the literature. On the demand side, I assume that consumers have CES preferences over a given set of goods, and that they can

[3] Other channels driving incomplete pass-through in the data are imported intermediate inputs, which may link a firm's costs to exchange rates in complex ways, and non-constant returns to scale. Several papers have shown the empirical importance of distribution margins: see Burstein et al. (2003), Burstein et al. (2005), and Campa and Goldberg (2006) among others. Nakamura and Zerom (2010) use micro-level data on the coffee industry to decompose price adjustments into the different components.

[4] Gopinath and Rigobon (2008) document the low frequency and small size of price adjustments.

acquire each good from domestic or foreign producers. The existence of an outside option (in this case, switching to another producer) generates a residual demand with non-constant elasticity. On the supply side, I assume that firms cannot perfectly observe their competitors' cost structure, and set optimal prices based on their expectations about the prices charged by their competitors. Given that costs are unobservable, optimal prices depend on the probability that buyers switch to another supplier.

Models featuring incomplete pass-through at the firm level differ in terms of their implications for how the extent of pass-through varies across firms. We can broadly separate the literature in two groups. On one side, models with additive distribution costs (like Berman et al. 2012 and Chatterjee et al. 2013) imply that prices are linear affine functions of marginal costs, mark-ups are higher and pass-through is lower for larger and more productive firms.[5] In these models, pass-through incompleteness arises from the interaction of fixed costs and firm size, and there is no role for firms' strategic decisions. On the other side, there is a large class of models featuring some form of imperfect competition coupled with non-linear demand systems and strategic interactions in price setting. Dornbusch (1987) reviews this class of models and concludes that the exact shape of the pass-through function depends on the precise choice of market structure that one considers.[6] Particularly, models with Bertrand competition and incomplete information (like Fisher 1989 and this paper) and models with Cournot competition, product differentiation, and a nested CES system (like Atkeson and Burstein 2008, Amiti et al. 2014, and Auer and Schoenle 2015) imply that prices are concave functions of marginal costs, mark-ups are higher for larger and more productive firms, and firm-level pass-through is a U-shaped function of firm size.[7] In these models, pass-through incompleteness arises from strategic price adjustments whose extent depends on the amount of competition a firm faces in the export market, proxied by firm size or market share.

[5] Models with imperfect competition and linear demand systems, like the one in Melitz and Ottaviano (2008), share the same predictions.

[6] Yang (1997) illustrates the implications of a special case of the models described in Dornbusch (1987) for the relationship linking pass-through and market shares.

[7] Even if their model implies a U-shape, Amiti et al. (2014) argue that the relevant comparative statics exercise to assess the shape of the empirical pass-through function is performed by defining the mark-up elasticity while keeping the price index constant. With this modification, their model delivers a pass-through function that is decreasing in firm size.

The model in this paper is closest in spirit to Feenstra et al. (1996), Fisher (1989), and Alessandria (2004). In my model, like in Feenstra et al. (1996), following an exchange rate shock, a firm with a large market share in the destination market faces little competition from local firms that have not experienced a similar change in unit costs, and can pass through more fully the exchange rate change. However, while in Feenstra et al. (1996) market share is a country-level characteristic, firm heterogeneity in my model links market share and the extent of pass-through at the firm-level.

My model shares with the one in Fisher (1989) the concept of equilibrium considered: a Bayesian Nash equilibrium where there is strategic interdependence of the pricing rules set by firms. Bertrand competition under uncertainty implies that each firm chooses the optimal price based on the expectation it has of the prices charged by its competitors. I add to his analysis firms' heterogeneity and the fact that the choke price is endogenous and firm-specific.

The idea of incomplete price adjustments motivated by the possibility of consumers to switch to other producers is also present in Alessandria (2004).[8] 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.

To my knowledge, there is no other paper studying the relationship between pass-through and the extent of information about competition in a market, or examining possible differences in firm-level pass-through between new entrants and incumbents. As I already noted above, models with linear demand or with additive distribution costs predict that new entrants are on average smaller than incumbents and that pass-through is a decreasing function of firm size, so that new entrants should exhibit higher pass-through than incumbents, contrary to the predictions of my framework and to the empirical evidence that I report. Moreover, it has to be noted that the relationship

[8] In Alessandria (2004), 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 et al. (1996), with optimal mark-ups depending on search and transport costs and on the number of firms competing in the same market.

between pass-through and information that this model delivers holds also controlling for firm size, while in alternative models new entrants and incumbents of the same size display the same pass-through rates. Consistent with the model, the empirical relationship between information and pass-through is robust to controlling for market share.

Finally, this paper is closely related to a number of empirical contributions that have been testing the predictions of various models regarding the shape of the empirical pass-through function. Berman et al. (2012), Chatterjee et al. (2013), and Amiti et al. (2014) all find support for the prediction that the extent of pass-through is inversely related to the size of the firm, using large across-industries firm-level datasets from France, Brazil, and Belgium, respectively.

As in Feenstra et al. (1996), the empirical analysis in my paper provides evidence in support of the fact that, at least for certain industries, the relationship between pass-through and size (or market share) is U-shaped.[9] Like Feenstra et al. (1996), my empirical analysis concentrates on the cars market, but exploits more the detailed micro-structure of the data, following Goldberg and Verboven (2005). Moreover, I test and find support for the novel prediction of my model relating exchange rate pass-through and the amount of information about competition in the destination market.

The rest of the paper is organized as follows. In Section 2 I present the model. In Section 3 I derive the conditions for pass-through incompleteness and discuss the dependence of pass-through on firm market share and on the extent of information about competition in the destination market. Section 4 tests the predictions of the model using product-level data from the European car industry. Section 5 concludes.

[9] Auer and Schoenle (2015) also provide empirical evidence in support of a U-shaped firm-level pass-through function.

2 A Simple Model of Trade with Strategic Price Setting

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

2.1 The Environment

The economy is composed of many countries, indexed by $i, j, k \in \{1, ...N\}$. Consumers in each country have CES preferences over a continuum of differentiated goods:

$$U_i = Q_i = \left[\int q_i(x)^{1-1/\eta} dx\right]^{\eta/(\eta-1)}$$

for $i = 1, ...N$. $q_i(x)$ is the quantity consumed of good x in country i, Q_i denotes aggregate consumption in country i, and $\eta > 1$ denotes the elasticity of substitution across goods. Each good can be acquired from a producer located in any country, and consumers buy it from the producer that charges the lowest price.

Each country is populated by a continuum of heterogeneous producers. Each producer is specialized in the production of a single good x, and in each country j there are n_j potential producers of each good, with varying levels of efficiency.[10] Each producer of a good in each country has a constant return to scale technology that transforms labor into units of the good. Let $z_{mj}(x)$ be the number of units of labor that producer m of good x in country j needs to produce one unit of the good. Producers in each country are heterogeneous in their costs: $z_{mj}(x)$ is a random draw from a country-specific distribution $G_j(z)$. Finally, let $p_{imj}(x)$ denote the price charged for good x by producer m in country j for sales to country i.

The timing is the following: (i) producers in all countries observe their own productivity and the

[10] This assumption is analogous to the setup in Bernard et al. (2003). In a similar framework, de Blas and Russ (2015) endogenize the number of potential producers.

aggregate parameters of the economy; (ii) based on his own productivity and on the expectations on the prices charged by his domestic and foreign competitors, each producer declares a selling price; (iii) for each good, consumers decide to buy the good from the producer that charges the lowest price; (iv) producers whose realized demand is positive produce, sell and make profits.

For the time being, I describe the pricing problem under incomplete information. In Section 3.2 I will extend the model to incorporate producers operating under different informational assumptions.

2.2 Demand and Optimal Pricing under Incomplete Information

The demand side of the economy is standard. A consumer in country i chooses the optimal quantity of each good $q_i(x)$, and from which producer to buy it, to minimize total expenditure. The consumer's problem is:

$$\begin{aligned} \min_{q_i(x)} \quad & \int \min_{k\in\{1,...N\}} \left\{ \min_{m\in\{1,...n_k\}} \{p_{imk}(x)\} \right\} q_i(x)dx \\ s.t. \quad & \left[\int q_i(x)^{1-1/\eta} dx \right]^{\eta/(\eta-1)} \geq Q_i \end{aligned} \tag{1}$$

Problem (1) has solution:

$$q_i(x) = \left(\frac{p_i(x)}{P_i} \right)^{-\eta} Q_i \tag{2}$$

where $p_i(x)$ is the cheapest price at which good x is sold in country i: $p_i(x) = \min_{k\in\{1,...N\}} \left\{ \min_{m\in\{1,...n_k\}} \{p_{imk}(x)\} \right\}$ and P_i denotes the consumer price index in country i: $P_i = \left[\int p_i(x)^{1-\eta} dx \right]^{1/(1-\eta)}$.

Let's now move to the determination of the prices $p_{imj}(x)$, for $m = 1, ...n_j$ and $i, j = 1, ...N$. Markets are segmented. The set of goods consumed in each country is fixed, and in each country there is a fixed number of potential producers of each good.

A producer from country j maximizes its expected profits from sales to potential buyers in all countries, and may charge different prices to buyers in different countries. By assuming that no resale is possible, I study the pricing problem country by country.

In choosing the optimal price to charge in country i, a producer of good x from country j must consider both direct competition from the producers of the same good (in country j and abroad) and indirect competition from the producers of other, imperfectly substitutable goods in all countries. 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 its other producers. 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 costs of the other producers of his same good. The price setting mechanism has the properties of a potentially asymmetric first-price sealed-bid auction.[11] The assumption of incomplete information seems natural in the international context, where it may be too costly to monitor a foreign competitor's cost structure. Consequently, each producer sets the price as a function of his own marginal cost in a way that, given that all the other producers set their price in the same way, no individual producer could do better by choosing the price differently. The resulting equilibrium is a Bayesian Nash equilibrium, where each producer chooses its optimal price based on his guess (correct in equilibrium) of the pricing rules followed by the other producers of the same good.[12]

Producer m of good x from country j (who has unit cost $z_{mj}(x)$) chooses the price to charge in country i to maximize:

$$\max_{p_{imj}(x)} \left[p_{imj}(x) - c_{ij} z_{mj}(x)\right] \left(\frac{p_{imj}(x)}{P_i}\right)^{-\eta} Q_i \cdot \prod_{l \neq m} \left[1 - F_{ij}(p_{imj}(x))\right] \cdot \prod_{k \neq j} \prod_{l=1}^{n_k} \left[1 - F_{ik}(p_{imj}(x))\right]. \quad (3)$$

The term $c_{ij} z_{mj}(x)$ denotes the marginal cost of the producer, where c_{ij} is a combination of origin-

[11] In their survey of the auctions literature, McAfee and McMillan (1987) report that *"sealed-bid tenders are [...] used by firms procuring inputs from other firms"*. Asymmetric auctions seem a natural tool to study pricing in international markets, *"when both domestic and foreign firms submit bids and, for reasons of comparative advantage, there are systematic cost differences between domestic and foreign firms"*. Garetto (2013) uses a similar price setting mechanism to model optimal pricing of intermediate goods when the buyers have the possibility of integrating production. Dvir (2012) studies the final good producers optimal procurement problem in a setting with the same informational assumptions.

[12] The equilibrium concept is the same as in Fisher (1989). I add to his framework firm heterogeneity and endogenous choke prices.

destination parameters:

$$c_{ij} = \begin{cases} w_j & \text{if } i = j \\ e_{ij} t_{ij} w_j & \text{if } i \neq j \end{cases},$$

$t_{ij} > 1$ is the iceberg cost of trade between the two countries, and e_{ij} is the real exchange rate, expressed in units of consumption in i per units of consumption in j. $F_{ij}(\cdot)$ is the c.d.f. of the prices charged in country i by producers from country j. The term $\prod_{l \neq m} [1 - F_{ij}(p_{imj}(x))]$ is the probability that the price $p_{imj}(x)$ is the lowest among the prices set for good x by producers from j selling to i. Similarly, the term $\prod_{k \neq j} \prod_{l=1}^{n_k} [1 - F_{ik}(p_{imj}(x))]$ is the probability that the price $p_{imj}(x)$ is the lowest among the prices set for good x by producers from countries other than j selling to i. The product of these two terms is the probability that $p_{imj}(x) = p_i(x)$, *i.e.* that $p_{imj}(x)$ is the lowest price at which consumers in country i can buy good x.

The first order condition of problem (3) can be written as:

$$p_{imj}(x) = \left[1 - \frac{1}{\eta + \left[(n_j - 1) H_{ij}[p_{imj}(x)] + \sum_{k \neq j} n_k H_{ik}[p_{imj}(x)] \right] \cdot p_{imj}(x)} \right]^{-1} c_{ij} z_{mj}(x) \qquad (4)$$

where $H_{ik}[p_{imj}(x)]$ is the hazard rate:

$$H_{ik}[p_{imj}(x)] = \frac{f_{ik}(p_{imj}(x))}{[1 - F_{ik}(p_{imj}(x))]}, \text{ for } k = 1, ...N \qquad (5)$$

and $f_{ik}(\cdot)$ is the density associated with $F_{ik}(\cdot)$.

Let $|\varepsilon_{imj}(x)|$ denote the elasticity of residual demand perceived by producer m of good x in country j for its sales to country i:

$$|\varepsilon_{imj}(x)| \equiv \eta + \left[(n_j - 1) H_{ij}[p_{imj}(x)] + \sum_{k \neq j} n_k H_{ik}[p_{imj}(x)] \right] \cdot p_{imj}(x). \qquad (6)$$

The expression of the elasticity of demand summarizes the two forces that affect optimal price setting in equation (4): a supplier must choose its optimal price by keeping into account both the possibility of substitution across different goods (η) and direct competition from the producers of exactly the same, perfectly substitutable good in each country. This second force is summarized by the sum of the hazard rates $H_{ik}[p_{imj}(x)]$. Each hazard rate describes the probability that – after an infinitesimal increase in the price charged by producer m from country j – a consumer in country i switches to buying the same good x from another producer, either in country j (the term $(n_j - 1)H_{ij}[p_{imj}(x)]$) or in any other country (the term $\sum_{k \neq j} n_k H_{ik}[p_{imj}(x)]$), conditional on having bought from producer m from country j before the price increase. Notice that when all the hazard rates are equal to zero, $|\varepsilon_{imj}(x)| = \eta$ and equation (4) reduces to the standard constant mark-up pricing rule induced by imperfect competition and CES preferences.[13]

Given functional forms for the cost distributions $G_i(\cdot)$, the model is solved up to the scale of production Q_i and the equilibrium wages w_i, for $i = 1, ...N$. Full employment and market clearing conditions allow to close the model.

The next section characterizes the optimal changes in prices following shocks to marginal costs.

3 Incomplete Pass-Through of Cost Changes into Prices

This section starts by providing conditions under which a shock to firms' costs is not reflected one-to-one into the price charged (incomplete pass-through). Then I move to illustrate two relationships. The first one, between pass-through and firm size, has received a significant amount of attention in the literature, and is generated by my model, among others. The second one, between pass-through and the extent of information about a seller's competitors, is to my knowledge novel of this framework.

[13] The result of endogenous mark-ups holds for any functional specification of the cost distributions $G_j(\cdot)$ except for the Pareto, for which the elasticity of demand is constant and hence mark-ups are constant too. I consider this particular case of limited empirical relevance, since there is extensive evidence in the literature about the fact that the empirical productivity distribution – not the cost distribution – can be well approximated by a Pareto.

The optimal price adjustment following a change in marginal cost depends crucially on the elasticity of demand. As equation (4) shows, the fact that each supplier in the model must keep into account his competitors' strategies induces a variable component into the elasticity of demand, and the dependence of this component on prices determines the extent of pass-through. More precisely, a supplier finds 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.[14] 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 prices proportionately to their costs.

In the model outlined in the previous section, the elasticity of demand that producer m of good x from country j faces when selling in country i is described by equation (6). Whether the elasticity of demand is increasing in the price charged only depends on the shape of the price distributions $F_{ik}(\cdot)$, and hence on the cost distributions $G_i(\cdot)$. The following theorem states a sufficient condition for the elasticity of demand to be increasing in the price charged.

Theorem 1. *The elasticity of demand $|\varepsilon_{imj}(x)|$ is increasing in the price charged if the cost distributions $G_i(\cdot)$ satisfy:*

$$g_i'(z) > -\frac{g_i(z)}{z}\left[1 + \frac{g_i(z)}{[1-G_i(z)]}z\right] \quad \forall z, \forall i = 1, ...N. \tag{7}$$

Proof: See Appendix A.

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

[14] 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: $\frac{\partial \log p}{\partial \log z} = \left[1 - \frac{p}{|\varepsilon|^2} \cdot \frac{\partial |\varepsilon|}{\partial z}\right] < 1$, or – equivalently – if: $\frac{p}{|\varepsilon|^2} \cdot \frac{\partial |\varepsilon|}{\partial z} > 0$, which is always true if the elasticity of demand is increasing in p.

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 such that the slope of the density function is larger than in the Pareto case for each value of z. For example, the exponential, Fréchet and Weibull distributions satisfy condition (7). Finally, this condition is closely related to the log-concavity of the survival functions $[1 - G_i(\cdot)]$:[15]

Corollary 1. *If the survival functions* $[1 - G_i(z)]$ *are log-concave* $\forall$ z *and* $\forall i = 1, ...N$*, then condition (7) holds and the elasticity of demand is increasing in the price charged.*

Proof: See Appendix A.

3.1 Incomplete Pass-Through and Firm Size

Theorem 1 establishes a condition that disciplines the relationship between the firms' productivity distribution and the extent of pass-through in the model. However, firms' heterogeneity also implies that the elasticity of demand is firm-specific, and so is the extent of pass-through. I characterize here the dependence of pass-through on firm sales and market share in the destination market.

Optimal prices in this economy can be expressed as:

$$p_{imj}(x) = \frac{|\varepsilon_{imj}(x)|}{|\varepsilon_{imj}(x)| - 1} c_{ij} z_{mj}(x) \quad \text{for } i, j = 1, ...N \quad \text{and} \quad m = 1, ...n \tag{8}$$

where the elasticity of demand $|\varepsilon_{imj}(x)|$ is given by equation (6). Pass-through of marginal costs into prices is given by:

$$PT_{imj}(x) = \frac{\partial \log(p_{imj}(x))}{\partial \log z_{mj}(x)} = 1 - \frac{p_{imj}(x)}{|\varepsilon_{imj}(x)|^2} \cdot \frac{\partial |\varepsilon_{imj}(x)|}{\partial z_{mj}(x)}. \tag{9}$$

Since both the elasticity of demand and the optimal price are functions of the firm's marginal

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

cost $z_{mj}(x)$, so is pass-through. Similarly, firm sales and market share in each country are also (decreasing) functions of $z_{mj}(x)$.

Consider first extremely productive firms, for which the unit cost $z_{mj}(x)$ approaches zero. Those firms have large sales and market shares in each country they sell to. For those firms, the probability to charge the lowest price for good x in country i, $prob\{p_{imj}(x) = p_i(x)\}$, approaches one, and demand approaches the one in a standard model with monopolistic competition and CES preferences. Hence the elasticity of demand tends to a constant: $|\varepsilon_{imj}(x)| \to \eta$, prices are characterized by the CES constant mark-up, and pass-through is complete. Consider now extremely unproductive firms, for which the unit cost $z_{mj}(x)$ tends to infinity. Those firms have the smallest sales and market shares in each country they sell to. For those firms, $prob\{p_{imj}(x) = p_i(x)\}$ approaches zero, the elasticity of demand tends to infinity, and prices tend to the perfectly competitive ones. With prices equal to marginal costs, pass-through is also complete. Finally, for firms such that $z_{mj}(x)$ is at an intermediate range, $prob\{p_{imj}(x) = p_i(x)\} \in (0,1)$, $|\varepsilon_{imj}(x)| \in (\eta, +\infty)$ and – from Theorem 1 – is increasing in $z_{mj}(x)$ (and in $p_{imj}(x)$), so pass-through is strictly between 0 and 1. As a result, pass-through is a U-shaped function of firm sales and market share in a country. This result is analogous to the one in Feenstra et al. (1996), extended to consider a continuum of goods, heterogeneous firms, and endogenous firm market shares. More generally, all models belonging to the class analyzed by Dornbusch (1987) share this prediction.[16] Notice that this analysis applies to any change in the unit cost of the firms: productivity shocks, changes in wages or transportation costs, and exchange rate shocks, which will be the focus of the empirical analysis.

3.2 Information and Pass-through

I showed earlier how firms' heterogeneity, imperfect competition, and incomplete information give rise to incomplete pass-through of changes of marginal costs into prices. In order to assess the role of incomplete information for pass-through, I extend the model to incorporate cross-sectional

[16] This class includes the models in Atkeson and Burstein (2008), Amiti et al. (2014), and Auer and Chaney (2009), among others.

heterogeneity in the information that a producer has about his competitors.

I start by noticing that under complete information, *i.e.* if each producer can observe his competitors' costs, the solution of the model is identical to the Bertrand game in Bernard et al. (2003) and Atkeson and Burstein (2007): the producer who has the lowest cost of supplying good x to country i charges a price equal to the minimum between the monopolistically competitive price and the marginal cost of the second lowest cost producer. All other producers of good x remain latent. Under this scenario, the optimal pricing rule is piecewise linear. Under the assumption that the first and second lowest cost sellers of good x to country i are located in the same country, the pricing rule exhibits 100% pass-through of changes of marginal costs into prices. It is important to stress that this result hinges heavily on the assumption that the first cheapest and second cheapest suppliers of good x to country i are from the same country. As pointed out by Atkeson and Burstein (2007), the extent of pass-through with Bertrand competition under complete information depends on whether the lowest cost producer and his best latent competitor are located in the same country or not: if they are, shocks to exchange rates affect their marginal costs equally, implying complete pass-through via the linearity of the pricing function. Conversely, if the best latent competitor is located in a different country than the lowest cost producer, pass-through is zero as long as the optimal pricing strategy is limit pricing, and complete as long as monopoly pricing prevails. Atkeson and Burstein (2007) remark that the first scenario is likely to be realized when national comparative advantage is strong with respect to international trade costs.

The assumption of complete information is a very extreme one, but is a useful benchmark to consider. More realistically, for the purpose of this section and of the empirical analysis that follows, I assume that there are two types of agents in the economy, "uninformed" and "informed". One can think about informed producers as experienced, or "old" producers, who have been selling their product for some time already and know the ins and outs of the market. Similarly, we can interpret uninformed producers as new entrants in a market.

I assume that producers are arbitrarily partitioned in these two groups: in each country j

there are n_j^o informed old producers and $n_j - n_j^o$ uninformed new producers. I assume that a new producer has incomplete information, *i.e.* he does not observe the unit costs of any of his competitors, and that other competitors (both old and new) cannot observe the unit cost of the new producer. Consistently, an old producer has complete information about other old producers, but has incomplete information about new producers.[17]

In this setting, in equilibrium, the lowest cost old producer charges a price that is bounded above by the marginal cost of the second lowest-cost old producer. Conditional on this upper bound on his price, the lowest cost old producer plays the incomplete information game described in Section 2 with the new producers. I characterize the solution of the game below, and argue that the solution of the problem implies lower (higher) pass-through rates for new (old) producers. Notice that this analysis nests the two extreme models I discussed earlier: when $n_j^o = 0 \ \ \forall j$, all producers are new and the model is the one analyzed in Section 2. When $n_j^o = n \ \ \forall j$, all producers are old and the model reduces to Bertrand competition.

Let $z_i^o(x)$ denote the unit cost of the old producer who has the lowest cost of selling good x in market i:

$$z_i^o(x) \equiv \left\{ z_{mj}(x) : c_{ij} z_{mj}(x) = \min_{k \in \{1,...N\}} \left\{ \min_{l \in \{1,...n_k^o\}} c_{ik} z_{lk}(x) \right\} \right\}. \tag{10}$$

I denoted with $G_k(\cdot)$ the c.d.f. of the unit costs $z_{lk}(x)$, for $k = 1, ...N$. Let $G_{ik}(\cdot)$ denote the c.d.f. of the marginal costs $c_{ik} z_{lk}(x)$ (the firm's unit cost augmented by wages, exchange rates and bilateral trade costs). Let $G_i^o(\cdot)$ denote the c.d.f. of the marginal cost of the best old producer of good x selling to i:[18]

$$G_i^o(z) = 1 - \prod_{k \in \{1,...N\}} \left[1 - G_{ik}(c_{ik} z_{lk}) \right]^{n_k^o}. \tag{11}$$

[17] These informational assumptions are equivalent to the ones in Che and Kim (2004), who study the equilibrium in first-price auctions with two groups of bidders with different information sets. Che and Kim (2004) notice that *"...it is presumably easier for a bidder to estimate the preferences and technological abilities of the old firms than those of the new ones"*.

[18] With an eye to the parametric example that follows, notice that if $G_k(z)$ is a Weibull distribution, also $G_i^o(z)$ is a Weibull distribution.

Suppose that both the lowest cost and the second lowest cost old sellers of good x to country i are from country j. Let z_i^{o2} denote the unit cost of the second lowest cost old seller. Then the price charged by the lowest cost old seller is $\tilde{p}_{ij}^o(x) = \min\{p_{ij}^o(x), c_{ij} z_i^{o2}\}$, where $p_{ij}^o(x)$ is the solution of the following problem:

$$\max_{p_{ij}^o(x)} \left[p_{ij}^o(x) - c_{ij} z_i^o(x)\right] \cdot \left[\frac{p_{ij}^o(x)}{P_i}\right]^{-\eta} Q_i \cdot \left[1 - F_{ij}(p_{ij}^o(x))\right]^{n-n_j^o} \cdot \prod_{k \neq j} \left[1 - F_{ik}(p_{ij}^o(x))\right]^{n-n_k^o} \quad (12)$$

where $\left[1 - F_{ij}(p_{ij}^o(x))\right]^{n-n_j^o}$ is the probability that $p_{ij}^o(x)$ is lower than all the prices charged by new producers from j, while $\prod_{k \neq j} \left[1 - F_{ik}(p_{ij}^o(x))\right]^{n-n_k^o}$ is the probability that $p_{ij}^o(x)$ is lower than all the prices charged by new producers from other countries.

The solution of this problem takes the form:

$$p_{ij}^o(x) = \left[1 - \frac{1}{\eta + \sum_{k=1}^{N} (n - n_k^o) H_{ik}[p_{ij}^o(x)] \cdot p_{ij}^o(x)}\right] c_{ij} z_i^o(x) \quad (13)$$

where $H_{ik}(\cdot)$ is the hazard rate function defined in equation (5).

Let's now consider the pricing problem of a new producer. Assume (without loss of generality) that seller m from country j that is selling good x to country i is a new producer. He chooses the price to charge ($p_{imj}^n(x)$) that solves the following problem:

$$\max_{p_{imj}^n(x)} \quad \left[p_{imj}^n(x) - c_{ij} z_{mj}(x)\right] \cdot \left[\frac{p_{imj}^n(x)}{P_i}\right]^{-\eta} Q_i \cdot \left[1 - F_i^o(p_{imj}^n(x))\right] \cdot \left[1 - F_{ij}(p_{imj}^n(x))\right]^{n-n_j^o-1} \cdot ... \\ \prod_{k \neq j} \left[1 - F_{ik}(p_{ij}^o(x))\right]^{n-n_k^o} \quad (14)$$

where $F_i^o(\cdot)$ is the c.d.f. of the price charged by the best old seller of x to i, and $\left[1 - F_i^o(p_{imj}^n(x))\right]$ is the probability that $p_{imj}^n(x)$ is lower than the price charged by the best old seller of x to i.

The solution of this problem takes the form:

$$p^n_{imj}(x) = \left[1 - \frac{1}{\eta + \left[H^o_i[p^n_{imj}(x)] + (n - n^o_j - 1)H_{ij}[p^n_{imj}(x)] + \sum_{k\neq j}(n - n^o_k)H_{ik}[p^n_{imj}(x)]\right] \cdot p^n_{imj}(x)}\right] c_{ij} z_{mj}(x) \tag{15}$$

where $H^o_i(\cdot)$ is the analogous hazard rate constructed using the c.d.f. of the price charged by the best old seller of x to i.

I proceed now to argue that the two pricing functions in equations (13) and (15) exhibit systematically different pass-through rates. As I have shown above, the rate of pass-through is lower the more responsive is the elasticity of demand to price changes. The lowest cost old producer of good x in country i has elasticity of demand given by:

$$\varepsilon^o_i = \eta + \sum_{k=1}^{N}(n - n^o_k)\frac{f_{ik}(p)}{1 - F_{ik}(p)} \cdot p, \tag{16}$$

while a new producer of good x from country j selling in country i has elasticity of demand given by:

$$\varepsilon^n_{imj} = \eta + \left[\frac{f^o_i(p)}{1 - F^o_i(p)} + (n - n^o_j - 1)\frac{f_{ij}(p)}{1 - F_{ij}(p)} + \sum_{k\neq j}(n - n^o_k)\frac{f_{ik}(p)}{1 - F_{ik}(p)}\right] \cdot p. \tag{17}$$

These two elasticities only differ in terms of one of the hazard rates, so we can re-write them as:

$$\varepsilon^o_i = \Theta + \frac{f_{ij}(p)}{1 - F_{ij}(p)} \cdot p \tag{18}$$

$$\varepsilon^n_{imj} = \Theta + \frac{f^o_i(p)}{1 - F^o_i(p)} \cdot p \tag{19}$$

where $\Theta \equiv \eta + \left[\sum_{k\neq j}(n - n^o_k)\frac{f_{ik}(p)}{1-F_{ik}(p)} + (n - n^o_j - 1)\frac{f_{ij}(p)}{1-F_{ij}(p)}\right] \cdot p$. Hence the comparison of the two elasticities boils down to the comparison between $\frac{f_{ij}(p)}{1-F_{ij}(p)}$ and $\frac{f^o_i(p)}{1-F^o_i(p)}$. It makes sense intuitively that the elasticity of demand of a new producer is more responsive to price changes than the elasticity of demand of an old producer: given that the old producer is the lowest cost producer

among the old ones, it is more likely that a buyer switches to the old producer after a price change from a new producer than a buyer switching to a new producer after a price change from an old producer.

I illustrate this mechanism explicitly via a parametric example. Suppose the price distributions are Weibull:[19] $F_{ij}(p) = 1 - e^{-T_{ij}p^{\vartheta}}$, $\forall i, j \in \{1, ...N\}$, and $F_i^o(p) = 1 - e^{-T_i^o p^{\vartheta}}$ for the lowest cost old supplier to country i. Under this assumption, the elasticities of demand of an old and new supplier are, respectively: $\varepsilon_i^o = \Theta + \vartheta T_{ij} p^{\vartheta}$ and $\varepsilon_{imj}^n = \Theta + \vartheta T_i^o p^{\vartheta}$. Since old and new suppliers from the same country draw their costs from the same distribution, equation (11) implies that the cost distribution of the lowest cost old seller of good x to country i has a lower mean than the cost distribution of a new supplier from j, hence $T_i^o > T_{ij}$,[20] and the elasticity of demand of a new supplier is more responsive to price changes than the elasticity of demand of an old supplier: $\frac{\partial \varepsilon_{imj}^n}{\partial p} > \frac{\partial \varepsilon_i^o}{\partial p}$ implying a lower pass-through rate for new producers compared to old producers in a market. This prediction holds also when the lowest cost old producer applies limit pricing: under the assumption that the second lowest cost old producer is from his same country, pass-through is complete in that event.

In summary, the prediction arising from this exercise is that prices charged by new, uninformed producers should exhibit lower pass-through than prices charged by old, informed producers.

To my knowledge this prediction is novel of this framework, and I show in the next section that it finds broad support in the data. I proxy the extent of information about a firm's competitors with the time a firm has been selling a product in a given market, effectively testing the hypothesis that exchange rate pass-through should be lower for new entrants than for incumbents.

Notice that, under this interpretation, the prediction of my model contrasts with what is predicted by frameworks with endogenous entry, like Melitz and Ottaviano (2008) or the additive distribution costs framework used by Berman et al. (2012) among others. In these models, new entrants are typically small firms compared to the average incumbents, and since prices are linear

[19] This parametric assumption satisfies Theorem 1.

[20] The location parameter of the Weibull distribution is inversely related to its mean.

affine functions of marginal costs, pass-through is decreasing in firm size so new entrants should exhibit higher pass-through than incumbents, against what the empirical evidence shows.

4 Empirical Evidence: Exchange Rate Pass-Through in the Cars Industry

In this section I use data from the European car industry to test the two predictions of the model that I highlighted in the previous section. First, pass-through is a U-shaped function of firm market share, and second, new entrants in a market, likely operating under incomplete information, exhibit lower pass-through than experienced producers who have been selling in the market for a while.

4.1 Data

I use a panel data set of car prices assembled by Pinelopi Goldberg and Frank Verboven.[21] I argue that the car industry is a good laboratory to test the predictions of my model. The small number of competitors in the car industry makes imperfect competition and strategic complementarity in pricing very plausible assumptions.

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, before the introduction of the euro. For each product, or car model, the data record both the selling price and the quantity sold in each destination market and a list of car characteristics, which allow me to disentangle price changes that are not due to quality changes. Moreover, the data include information on both the country of incorporation of the producing firm and the country where the model was effectively produced. 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

[21] For a more detailed description of the data, see Goldberg and Verboven (2001, 2005).

between two countries. Based on this definition, 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 on prices of imported cars in the five destination markets, keeping track of the origin and destination countries of each sale.

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, 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.[22] 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.[23,24]

In order to test the first prediction, on the relationship between exchange rate pass-through and firm size, I use market share in the destination market as measure of size.[25] In order to test the second prediction, on the relationship between exchange rate pass-through and the extent of information about competitors, I augmented the existing dataset with additional variables that keep track of the time when a product is first introduced in a market. More precisely, I define a dummy variable D^n_{idt} that takes value one if firm-product pair i is operating under incomplete information in a destination market d in year t. I assume that information is incomplete if product i has been sold in market d for at most n years (where $n = 1, 2, 3$ in the empirical analysis that follows). The variable D^n_{idt} is the empirical counterpart to the partition of producers into informed and uninformed in the model. Appendix B provides details about the construction of the variable proxying for incomplete information.

[22] See TheEconomist (2008)'s survey on cars in the emerging markets.

[23] The dataset allows to identify car 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.

[24] Berman et al. (2012) also run pass-through regressions using firm-product pairs. Chatterjee et al. (2013) extend the framework in Berman et al. (2012) to consider multiproduct firms, and study within-firm, across-products price adjustments following exchange rates appreciations.

[25] The results are robust to using quantity sold as a measure of size. 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.

4.2 Exchange Rate Pass-through and Firm Size: Specification and Results

To test the shape of the relationship between firm-level exchange rate pass-through and firm size, I run the following reduced-form pass-through regression:

$$\begin{aligned} ln(p_{icdt}) &= \alpha + \beta_1 ln(q_{icdt}) + \beta_2 ln(gdp_{dt}) + \gamma_0 ln(e_{cdt}) + \gamma_1 ln(q_{icdt}) \times ln(e_{cdt}) + ... \\ &\quad ... + \gamma_2 [ln(q_{icdt})]^2 \times ln(e_{cdt}) + \delta_t + \delta_{cd} + \delta_{firm} + \delta_i + \delta_{char} + \varepsilon_{icdt}. \end{aligned} \tag{20}$$

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 market share 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} is the GDP per capita of the destination country in year t (import demand shifter), δ_t are year fixed effects (to interpret the results as a pure within estimation), δ_{cd} are country-pair fixed effects, δ_{firm} are firm fixed effects, δ_i are product fixed effects, and δ_{char} are fixed effects related to cars characteristics.[26] ε_{icdt} is an orthogonal error term. The role of the fixed effects in the regressions is to control as much as possible for supply-side determinants of prices, so that the estimation of equation (20) can be interpreted as the estimation of a demand function.

Regression (20) delivers the following empirical counterpart to the pass-through function generated by the model:

$$\frac{\partial ln(p_{icdt})}{\partial ln(e_{cdt})} = \hat{\gamma}_0 + \hat{\gamma}_1 ln(q_{icdt}) + \hat{\gamma}_2 [ln(q_{icdt})]^2, \tag{21}$$

where the inclusion of a linear and a quadratic interaction term follows Feenstra et al. (1996) and is meant to capture the nonlinearities in the relationship between pass-through and size that the model predicts.

Table 1 displays the results. Column I reports the results of the regression without interaction

[26] I use car class (or segment) as the characteristic defining these fixed effects. In the data, cars are grouped in five classes: subcompact, compact, standard, intermediate, and luxury. Previous studies (most notably Feenstra et al. 1996) treated cars as a homogeneous product category. The presence of car characteristics in the dataset I use allows me to compare cars that belong to the same market segment. Moreover, controlling for car characteristics ensures that changes in prices of individual products do not reflect changes in product quality.

	(I)	(II)	(III)	(IV)
Log-market share	-.049	-.056	-.019	-.010
	(.003)***	(.004)***	(.002)***	(.002)***
Log-GDP per capita	-1.060	-1.068	-1.013	-1.008
	(.027)***	(.027)***	(.013)***	(.009)***
Log-exchange rate	.051	.109	.067	.106
	(.010)***	(.021)***	(.010)***	(.008)***
Interaction market share-exchange rate		.025	.0006	.011
		(.006)***	(.003)	(.002)***
Interaction market share squared-exchange rate		.002	.0002	.0009
		(.0005)***	(.0003)	(.0002)***
Firm and car class fixed effects	No	No	Yes	No
Product fixed effects	No	No	No	Yes
R^2	.981	.981	.996	.998
No. of obs	8978	8978	8978	8978

Table 1: Pass-through regressions with size-exchange rate interactions (standard errors in parentheses). All specifications include country-pair and year fixed effects.

terms. The coefficient on size is negative, indicating that larger firms tend to charge lower prices, in line with the predictions of the model.[27] The coefficient on GDP per capita is negative, indicating that firms charge lower prices in richer, more productive countries. As expected, the pass-through coefficient $\hat{\gamma}_0$ is positive and smaller than one. All three coefficients are significant at the 1% level.

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. The estimates of $\hat{\gamma}_1$ and $\hat{\gamma}_2$ are positive and significant at the 1% level, consistent with the prediction of the model that pass-through is a U-shaped function of firm size in the destination market. Figure 1 plots the empirical pass-through function (21) that is implied by the estimates reported in column II, together with the distribution of firm market shares that is observed in the data.

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. The signs of all the coefficients are preserved,

[27] The results are robust to the use of lagged market share as a measure of size.

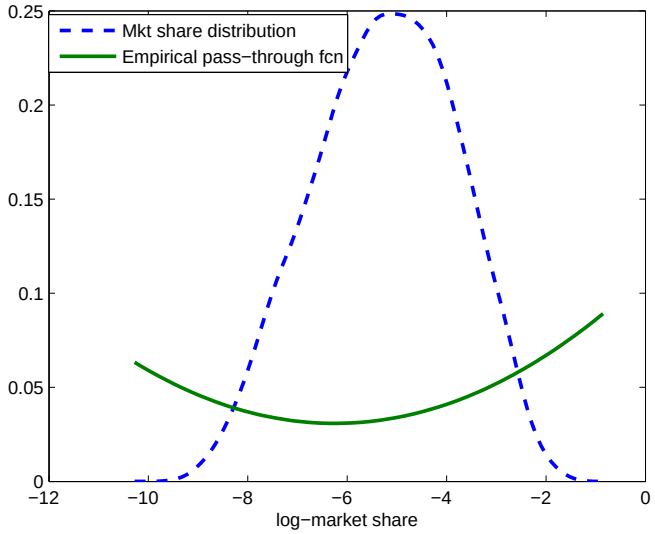

Figure 1: Plot of the empirical pass-through function.

but the interaction terms lose significance. Column IV shows the results of the same regression without firm and car class fixed effects but with product fixed effects. The signs of the coefficients are unchanged with respect to the previous specifications, and the linear and quadratic interaction terms are significant at the 1% level.[28] The results of these different specifications strongly support the prediction of the model about the U-shape of the firm-level pass-through function.

4.3 Exchange Rate Pass-through and Information: Specification and Results

To test the relationship between producer-level exchange rate pass-through and the extent of information about competition in the destination market, I run the following regression:

$$\begin{aligned} ln(p_{icdt}) &= \alpha + \beta_1 ln(q_{icdt}) + \beta_2 ln(gdp_{dt}) + \beta_3 D^n_{idt} + \beta_4 D^p_{fdt} + ... \\ &.... + \gamma_0 ln(e_{cdt}) + \gamma_1 ln(e_{cdt}) \times D^n_{idt} + \gamma_2 ln(e_{cdt}) \times D^p_{fdt} + ... \\ &... + \delta_t + \delta_{cd} + \delta_{firm} + \delta_i + \delta_{char} + \varepsilon_{icdt}. \end{aligned} \tag{22}$$

[28] An even more restrictive specification of regression (20) would include product-year fixed effects. Unfortunately, the small number of data points in some of the groups that these fixed effects produce prevents me from running this specification.

where $D^n_{idt} = 1$ if product i has been sold in destination market d for less than n years. D^n_{idt} proxies for the presence of incomplete information about a firm's competitors: if a producer only recently started to sell product i in market d, it is reasonable to think that the amount of information he has about the competition is limited. The model predicts that producers operating under incomplete information exhibit lower pass-through, hence we expect $\hat{\gamma}_1 < 0$.

One could also think that the relevant competition to consider when entering a market is related to the type of product (here, car) sold. For example, if firm f was already selling cars in the same class as car product i, one could think that entering the market with a new product may be associated with less severe lack of information. The dummy variable D^p_{fdt}, which takes the value of 1 if firm f is already selling products in the same class as product i in market d, captures this effect. Hence we expect $\hat{\gamma}_2 > 0$.

Table 2 shows the results using D^2_{idt} as proxy for incomplete information: this is equivalent to say that firms have incomplete information about their competitors in the first two years in which they sell a new product in a market.[29]

The most basic effect of information on pass-through is reported in column I, where no other controls are included. As expected, the coefficient on the interaction between the incomplete information dummy and the exchange rate is negative and significant at the 1% level. Under this specification, incomplete information decreases average exchange rate pass-through from 43.3% to 38.8%. Controlling for firm-product market share and GDP per capita in the destination market (column II) barely changes the result. In column III I add to the regression the dummy D^p_{fdt}, indicating that incomplete information is less severe if a firms enters a market where it is already selling similar products. As expected, the coefficient on the interaction between D^p_{fdt} and the exchange rate is positive, indicating that experience in selling similar products mitigates the effect of information incompleteness and increases pass-through. Columns IV and V add country-pair

[29] I chose incomplete information to be relevant for $n = 2$ years to take into account the fact that, for products introduced at the end of the year, the lack of information about competitors is likely to last more than a few months. For robustness, I run regression (22) also using D^1_{idt} and D^3_{idt} as proxies for incomplete information. The results are analogous to the ones reported.

	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)
Log-market share		-.079	-.094	-.074	-.060	-.067	-.071
		(.020)***	(.020)***	(.007)***	(.005)***	(.008)***	(.005)***
Log-GDP per capita		.581	.619	.267	-.904	.271	-.913
		(.141)***	(.139)***	(.051)***	(.044)***	(.051)***	(.044)***
Log-exchange rate	.433	.427	.364	.157	.026	.313	140
	(.006)***	(.007)***	(.009)***	(.019)***	(.012)**	(.043)***	(.028)***
D^2_{idt}	-.273	-.361	-.381	-.407	.054	-.401	.053
	(.061)***	(.062)***	(.062)***	(.020)***	(.014)***	(.019)***	(.014)***
Interaction D^2_{idt}-exchange rate	-.045	-.050	-.042	-.020	.004	-.017	.003
	(.014)***	(.014)***	(.014)***	(.004)***	(.003)	(.004)***	(.003)
D^p_{fdt}			.128	-.099	-.094	-.096	-.094
			(.050)**	(.018)***	(.012)***	(.018)***	(.012)***
Interaction D^p_{fdt}-exchange rate			.119	.0008	.013	.003	.013
			(.011)***	(.004)	(.003)***	(.004)	(.003)***
Interaction mkt share-exchange rate						.043	.044
						(.013)***	(.008)***
Interaction mkt share^2-exchange rate						.003	.004
						(.001)***	(.0007)***
Country-pair fixed effects	No	No	No	Yes	Yes	Yes	Yes
Year fixed effects	No	No	No	No	Yes	No	Yes
R^2	.491	.486	.496	.952	.98	.952	.98
No. of obs	5899	5533	5533	5533	5533	5533	5533

Table 2: Pass-through regressions with proxies for incomplete information and size-exchange rate interactions (standard errors in parentheses).

and year fixed effects.[30] Finally, columns VI and VII jointly test the two predictions of the model, on the dependence of pass-through on both market share and the extent of information. Both results are robust to this more inclusive specification.

To conclude, the results displayed in Table 2 show that the relationship between market size, information and exchange rate pass-through that is predicted by the model finds support in the data.

[30]The results lose significance with the addition of more restrictive sets of fixed effects.

5 Conclusions

I presented a simple Ricardian 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 imperfect information. I have shown that – for a wide range of parameterizations – firms' strategic price setting endogenously generates residual demands with an elasticity that is increasing in the price charged, and hence incomplete pass-through of cost changes into prices.

In this framework, strategic behavior in price setting has two important implications. First, the extent of pass-through and pricing-to-market depends on a firm's relative size compared to its competitors. The model predicts a U-shaped relationship, where very small and very large firms pass-through a larger portion of an exchange rate appreciation into their export prices, while firms in the middle of the size distribution pass-through less. Second, producers operating under incomplete information, like new entrants in a market, tend to exhibit different pass-through rates compared to experienced producers, operating under complete information. Under reasonable assumptions, the model predicts that new entrants exhibit lower pass-through than incumbents, who are likely more informed about their competition. I tested the predictions of the model using a panel data set of cars prices in five European markets. The estimates broadly support the predictions of the theory.

I believe that this paper contributes to the literature on incomplete pass-through in two ways. First, the model deepens our understanding of the possible channels that drive this phenomenon, by providing a novel structural framework where trade flows and market shares are endogenous and depend on firms' strategic considerations in an environment with possible incomplete information. Second, by supporting the predictions of the structural model, the empirical analysis improves our understanding of the relationship between firm size, information, and pass-through.

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Appendix

A Proofs

This section contains the proofs of Theorem 1 and Corollary 1.

Theorem 1. *The elasticity of demand* $|\varepsilon_{imj}(x)|$ *is increasing in the price charged if the cost distributions* $G_i(\cdot)$ *satisfy:*

$$g_i'(z) > -\frac{g_i(z)}{z}\left[1 + \frac{g_i(z)}{[1-G_i(z)]}z\right] \quad \forall z, \quad \forall i = 1, ...N. \tag{A.1}$$

Proof: I prove the theorem in the cleaner setting where there is only one producer of each good in each country. The proof is straightforward to extend to the case of n_j producers in each country j ($j = 1, ...N$).

The proof proceeds in two steps. I first use an auxiliary, simplified model to derive condition (A.1), and then show that condition (A.1) is also the sufficient condition for the full model.

Let us consider an auxiliary model where the competitors of the supplier of good x from country j set prices equal to their marginal costs, while the supplier of good x from country j sets mark-up prices. Countries are identical under every characteristic, so wages are equalized and normalized to one. Goods are freely tradeable ($t_{ij} = 1$) and there is a one-to-one exchange rate. I prove that – for this auxiliary model – (A.1) is a sufficient condition for incomplete pass-through of changes of marginal costs into prices.

If all prices other than $p_{ij}(x)$ are equal to marginal costs, the elasticity of demand that the supplier of good x in country j faces ($|\varepsilon_{ij}(x)|$) reduces to:

$$|\varepsilon_{ij}| = \eta + \sum_{k \neq j} \frac{g_k(p_{ij}(x))}{[1 - G_k(p_{ij}(x))]} p_{ij}(x). \tag{A.2}$$

Then condition (A.1) follows from differentiation of (A.2) with respect to $p_{ij}(x)$.

Condition (A.1) holds with equality when the cost distributions $G_i(\cdot)$ are Pareto.[31] So to ensure that the elasticity of demand is increasing in the price charged we need that each density $g_i(\cdot)$ exhibits a larger first derivative than a Pareto on its entire domain.

Now that I established the result for the auxiliary model, I move to consider the full model, where all firms charge mark-up prices, there may be also arbitrary wage differences and possibly non-zero trade costs. By differentiating (6) with respect to $p_{ij}(x)$, we obtain:

$$f'_{ik}(p_{ij}(x)) > -\frac{f_{ik}(p_{ij}(x))}{p_{ij}(x)} \left[1 + \frac{f_{ik}(p_{ij}(x))}{[1 - F_{ik}(p_{ij}(x))]} p_{ij}(x)\right] \quad \forall p_{ij}(x) \text{ and } \forall k = 1, ...N. \tag{A.3}$$

When the cost distributions $G_i(\cdot)$ are Pareto with shape parameter ϑ and location parameter a_i, one can solve analytically for the optimal pricing rule, which in this case is linear in the marginal cost:

$$p_{ij}(x) = \frac{\vartheta + \eta}{\vartheta + \eta - 1} c_{ij} z_j(x). \tag{A.4}$$

[31] $G(z) = 1 - \left(\frac{z}{a}\right)^{-\vartheta}$ for $z \geq a$, $a > 0$, and $\vartheta > 0$.

When unit costs are Pareto-distributed, optimal prices are also Pareto-distributed over the support $[a_i\bar{m}c_{ij}, \infty)$, where $\bar{m}$ is the constant mark-up in (A.4): $\bar{m} = \frac{\vartheta+\eta}{\vartheta+\eta-1}$. Moreover, the elasticity of demand is constant ($|\varepsilon_{ij}(x)| = \eta+\vartheta$) and condition (A.3) 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 (A.1) and (A.3) are characterized by the same cutoff, hence (A.1) is sufficient to characterize the set of distributions implying incomplete pass-through also for the full model. (*q.e.d*)

Corollary 1. *If the survival functions* $[1 - G_i(z)]$ *are log-concave* $\forall$ z *and* $\forall$ $i = 1...N$, *then condition (A.1) holds and the elasticity of demand is increasing in the price charged.*

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

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

which implies that inequality (A.1) also holds. (*q.e.d.*)

B On the Construction of the Incomplete Information Dummy

The dataset covers the years 1970-1999. During this time, old products continue to be sold, new products are introduced, and old products are replaced with new versions. To keep these possibilities into account, the construction of the incomplete information dummy D^n_{idt} follows these steps:

1. In the original dataset there are two variables that describe products: *co* identifies a product code, while *zcode* identifies as one product different versions of the same product that are replacements of one another. I believe that replacing an old version of a car model does not entail incomplete information, as the set of competitors is essentially the same. For this reason, I define car products using the variable *zcode* and do not consider a replacement as the introduction of a new product.

2. For products that are introduced before 1970, the dataset may not include information for the years in which they were first introduced in each destination market. To identify these products, for each *zcode*, I searched when the first version of the product was launched in its home market and added this information to the dataset. If the year of launch is at or after 1970, the dataset contains enough information to define the incomplete information dummy for the product, as described below. In the baseline regressions I drop those observations for which the year of launch is before 1970. For robustness, I also run the regressions leaving them in the dataset and setting the dummy equal to zero (which is equivalent to assuming that there is complete information for products launched before 1970).

3. If the year of launch is at or after 1970, for each *zcode*, destination market, and year, define a dummy D^1_{idt} which assumes value one if year t is the first year in which product i is sold in market d, and zero otherwise.

4. If the year of launch is at or after 1970, for each *zcode*, destination market, and year, define a dummy D^2_{idt} which assumes value one if year t is the second year in which product i is sold in market d, and zero otherwise. Similarly define D^3_{idt}, D^4_{idt}, D^5_{idt}.