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Quality pricing-to-market☆

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ABSTRACT

This paper analyzes firm's pricing-to-market decisions in vertically differentiated industries. We first present a model featuring firms that sell goods of heterogeneous quality levels to consumers who are heterogeneous in their income and thus their marginal willingness to pay for quality increments. We derive closed-form solutions for the unique pricing game under costly international trade. The comparative statics highlight how firms' pricing-to-market decisions are shaped by the interaction of consumer income and good quality. We derive two testable predictions. First, the relative price of high qualities compared to low qualities increases with the income of the destination market. Second, the rate of cost pass-through into consumer prices falls with quality if destination market income is sufficiently high. We present evidence in support of these two predictions based on a dataset of prices, sales, and product attributes in the European car industry.

1. Introduction

Empirical evidence shows that vertical product differentiation is a key determinant of export selection and international trade flows.[1]

This paper argues that good quality is also a key determinant of firms' pricing-to-market (PTM) decisions. In particular, we theoretically and empirically document how PTM is shaped by the interaction of good quality and consumers' valuation for quality. First, we show that the higher a good's quality, the higher is its price in richer markets relative to poorer markets. Second, we show that the degree to which prices react to exchange rate movements crucially depends on the interaction of good quality and destination market income: the rate of pass-through tends to be lower for higher qualities, an effect that is stronger for richer destination markets.

The first part of our analysis theoretically explores how goods of different quality are priced depending on the income distribution of the destination market. We develop a model that draws on recent theories featuring non-homothetic preferences with fixed mark-ups (i.e., see Fajgelbaum et al., 2011) and derive variable mark-ups by drawing on the literature on vertical competition in the field of industrial organization (i.e., see Mussa and Rosen, 1978).

The industry is populated by a large number of firms, each producing a good of unique quality. These firms are selling to consumers with non-homothetic preferences, who differ in their income and thus in their marginal willingness to pay for quality increments. Strictly positive mark-ups arise, since each firm holds a blueprint of a certain quality, giving it market power over a segment of consumers. The firm's market power in a given market is endogenous,

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[1] At the aggregate level, richer nations tend to systematically export and import higher unit value goods (Schott, 2004; Hummels and Klenow, 2005; Hummels and Skiba, 2004; Hallak, 2006), and also structural estimates of product quality show that vertical product differentiation is of first-order importance for our understanding of international trade flows (see Khandelwal, 2010 or Hallak and Schott, 2011). Within countries, product quality drives the selection of goods and firms into exporting (see Hummels and Skiba, 2004; Baldwin and Harrigan, 2011; Johnson, 2012; Kugler and Verhoogen, 2012; Crozet et al., 2012; Manova and Zhang, 2012).

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which generates variable markups. Equilibrium prices thus depend not only on production costs but also on the distribution of quality supply, the distribution of consumers' income, and the interaction of these supply and demand factors.

The model generates two main predictions regarding the interaction of supply and demand. First, prices of low-quality goods are relatively high in poor markets and prices of high-quality goods are relatively high in rich markets. Intuitively, for a given distribution of quality supply, prices are high wherever demand is high. For example, in richer markets where more consumers are willing to pay for higher qualities, high-quality firms face low elasticities and thus charge more for their products.[2]

The second prediction concerns the pass-through of exchange rate shocks into consumer prices. Our theory predicts that the rate of pass-through tends to be decreasing in quality. The demand elasticities of top-quality firms are especially variable due to the interplay of two different effects. On the one hand, the top-quality firm is surrounded by fewer competitors, which raises its market power and thus its markup. On the other hand, the top firm risks loosing its entire market if it charges a price above the richest consumer's willingness to pay for quality. In that case, its market power drops sharply. The combination of both effects implies that the market power of high-quality firms is extremely variable and their markups react stronger to exchange rate changes than markups of low-quality firms. Hence, exchange rate pass-through into consumer prices tends to be relatively low for high-quality goods.

In the second part of our paper, we empirically test these two predictions using a dataset of prices and product attributes in the European car industry. First, we document that higher-quality goods are relatively more expensive in markets with higher income. Second, we show that the rate of cost pass-through into consumer prices falls with quality if destination market income is suffciently high.

The economic magnitudes of the effects we uncover are non-negligible. To exemplify, consider a car at the 10*th* percentile of car quality and one at the 90*th* percentile of car quality. We find that the low-quality car is 1.7% *more* expensive when exported to a low-income market than when exported to a high-income market. In contrast, the high-quality car is 4.6% *less* expensive when exported to a low-income market than when exported to a high-income market. In this example, the interaction of car quality and market income can thus account for relative price differences in the order of magnitude of 6–7%, which is very significant compared to the margins in this industry. Regarding exchange rate pass-through (ERPT), for a car with average quality, the estimated one year pass-through rate we observe in the data is around 0.17, while it is only around half this rate for a car with one standard deviation above-average quality.

Our empirical approach uses the fact that the car models are produced in one location, but sold in five markets, and we can thus follow Fitzgerald and Haller (2014) and Burstein and Jaimovich (2012) and control for marginal costs by analysing the relative price of the same good sold across different markets. We also account for the role of distribution costs: as in the car industry, distribution is organized around brands rather than individual car models, we can examine the impact of quality on PTM within specific brands, thus abstracting from the impact of distribution networks.

Our paper contributes to two strands of literature: the one on PTM in international macroeconomics and the literature on quality competition in industrial organization.

The first literature our work relates to is on PTM, which addresses both the deviations from the law of one price (LOP) and on the degree of ERPT. Regarding price differences of identical goods across borders, Crucini et al. (2005), building on Engel (1993) and Engel and Rogers (1996), relate geographic price dispersion in Europe to characteristics of individual goods and services. Deviations from the LOP have also received attention in microeconomic studies of wholesale prices (see e.g. Burstein and Jaimovich, 2012), and studies that examine both wholesale and retail prices (Gopinath et al., 2011; Goldberg and Hellerstein, 2013). In particular the car industry has been a key focus of understanding both deviations from the LOP and the speed of convergence (see Knetter, 1989; Goldberg and Verboven, 2001, 2005; Garetto, 2016; Dvir and Strasser, 2013).

Regarding deviations from the LOP, our contribution is to model how market-specific preferences for quality affect the relative consumer prices for high and low-quality goods. Specifically, we examine how quality is priced-to-market depending on consumer income. Our analysis thus goes beyond the observation that goods are generally more expensive in markets with higher income (see Simonovska, 2015; Sauré, 2012; Foellmi et al., 2010). Instead, our work closely relates to Dvir and Strasser (2013), who report that car attributes such as air conditioning are priced-to-market according to the country-specific demand for these attributes. We add to this literature by providing a rational and empirical evidence for quality-specific PTM.

Our paper also relates to the work examining the degree of ERPT. This literature has generally established that ERPT is already low when measured at the border and much lower when measured at the level of consumer prices (see e.g. Goldberg and Campa, 2010 and the overview of the literature in Burstein and Gopinath, 2014).

On the theory side, previous studies emphasized the role of local distribution costs for the relation between good quality and ERPT. Auer and Chaney (2009) analyze a model of perfectly competitive firms under market-specific distribution costs, which are convex in quantity and thus give rise to variable mark-ups and quality-dependent pass-through. Chen and Juvenal (2016) and Berman et al. (2012) build on Corsetti and Dedola (2005) and develop a model where quality goods are subject to relatively high local distribution costs, leading to a negative relation between quality and pass-through. Recent empirical work has documented that pass-through rates are decreasing in good quality in both retail (see Antoniades and Zaniboni, 2016) and export prices (see Chen and Juvenal, 2016). The present paper adds to this literature by proposing market-specific preferences for quality as a determinant of ERPT. Instead of focusing on features solely related to the supply of quality (such as distribution costs), we show that the interaction of quality supply with demand for quality is a key determinant of pass-through.

Our paper also contributes to the literature on vertical competition in the field of industrial organization. In particular, we draw on the seminal works by Mussa and Rosen (1978), Gabszewicz and Thisse (1979, 1980), and Shaked and Sutton (1982, 1983). In these studies, goods of heterogeneous quality are sold to consumers with heterogeneous valuation for quality. The present paper borrows the key insight of Auer and Sauré (2017), namely that qualities are supplied in a very regular pattern when the economy is in a steady state of growth: each quality is a constant fraction better than the next best. Our theoretical contribution is to introduce international trade to this literature and analyze price discrimination across markets. Domestic firms compete with importers in the quality spectrum, and reductions in trade costs thus toughen competition. The above-mentioned results on PTM and ERPT emerge in this model of quality competition with international trade. To the best of our knowledge,

[2] Good quality thus sheds light on one of the central puzzles in international macroeconomics: the fact that prices of identical goods vary widely across markets even when they are measured at the border and thus do not include a local retail distribution component (see e.g. Obstfeld and Rogoff, 2001 or Atkeson and Burstein, 2008).

the predictions of our model of how a large set of firms price to international markets are new to this literature.[3]

The remainder of the paper is organized as follows. Section 2 presents a theoretical model of quality pricing, nests these preferences in an international economy, and derives testable predictions relating quality and income to PTM and ERPT. Section 3 presents empirical evidence and Section 4 concludes.

2. A model of international trade and quality pricing-to-market

In this section, we build a model of quality-pricing-to-market. The prime objective of this model is to analyze how the interplay between supply of different qualities on the one hand and valuation for quality – identified with per capita income – on the other shapes prices for different qualities across markets.

To that aim, we consider a world of two countries, Home and Foreign and denote Foreign's variables by $*$. On the supply side, different firms that are located in home and abroad produce different qualities of the same consumption good. On the demand side, consumers differ in their valuation for quality in the sense that, while all of them strictly prefer higher-quality levels over lower ones, individuals differ in their willingness to pay for a marginal increase of quality.

Preferences. All consumers value quality but differ in the degree of their *valuation* and thus in their willingness to pay for quality. Throughout the paper, we associate the willingness to pay for quality v with individual income.[4]

Consumers either consume one unit of the differentiated good $\mathcal{Q}$ or none at all. A consumer with the valuation v for quality who consumes the quality level q of the $\mathcal{Q}$-good and a units of good $\mathcal{A}$ derives utility $U_v(q,a) = vq + a$. Normalizing the price of good $\mathcal{A}$ to unity and writing $p(q)$ for the price of quality q, we can rewrite the utility of this consumer in the following reduced form

$$U_v(q) = v \cdot q - p(q) \quad (1)$$

An important property of these preferences is that valuation and quality are complementary. The higher a consumer's valuation for quality, the more she is willing to pay for a given quality level.[5] By writing down Eq. (1), we implicitly assume that the consumers with valuation v choose to purchase the $\mathcal{Q}$-type good, which is the case if and only if

$$v \geq \min_q \{p(q)/q\} \quad (2)$$

holds. Throughout the paper, we will focus on situations where the expression on the right of Eq. (2) is zero and the condition is trivially satisfied for all positive v. Also, we assume that the individuals' expenditure is high enough to generate positive demand for good $\mathcal{A}$. In so doing, we rule out corner solutions in individual demand.

Consumers differ in their valuation v for quality q. In particular, valuation among the individuals of total mass L is uniformly distributed on the interval $[0, v_{\max}]$, i.e. $v \sim U([0, v_{\max}])$.[6] The dispersion of valuations across individuals leads different firms to serve different market segments and allows them to charge positive markups over marginal costs. The two countries can differ in their maximal valuation $v_{\max}$ and $v^*_{\max}$, reflecting differences in per capita income.

Production and trade. Production of the $\mathcal{A}$-type good is competitive and takes place at constant returns to scale using labor as the only factor of production. Good $\mathcal{A}$ is costlessly traded, so that wages are equalized in both countries; we normalize the wage to one. Each firm in the $\mathcal{Q}$-market produces a fixed quality q at constant unit requirements of effective labor.

The marginal production cost $c(q)$ of each unit of the $\mathcal{Q}$-type good is constant, and $c(q)$ is increasing in the quality level produced. We impose the specific functional form

$$c(q) = \varphi q^{\theta} \quad (3)$$

and, by setting $\theta > 1$, assume that marginal costs are increasing and convex in quality. Firms located in Foreign face technologies parallel to Eq. (3) where φ is replaced by φ^*. Assumption (3) with $\theta > 1$ is a common way to introduce convex production costs, where in our case convexity affects the quality dimension.[7] We acknowledge that there is some degree of arbitrariness in the functional form, yet we need to put some structure on the model to derive our analytical results below. We thus offer Eq. (3) as an approximation of generic convex cost functions.

$\mathcal{Q}$-type goods can be traded subject to standard gross iceberg trade costs $\tau > 1$ and firms may price-discriminate between the export and the domestic market.[8]

On each market, firms compete in prices, *i.e.* each firm sets the price for its quality to maximize its operating profits, while taking total demand and the other firms' prices as given. We assume that firms are located at positive distance to each other.

We index firms by $n \in \mathcal{N}_0 = \{0, -1, -2, \ldots\}$ and denote the quality level produced by firm n by q_n. Without loss of generality we order firms by the quality level they produce so that firm 0 produces the highest quality level q_0 and all further quality levels satisfy $q_{n-1} < q_n$.

Quality supply and production locations. Our aim is to analyze an industry that produces the $\mathcal{Q}$-type good globally, i.e., in different countries. Since solving a fully endogenized entry game with quality choice is beyond the scope of this paper, we need to make assumptions regarding the set of qualities supplied as well as the location of each single firm. Regarding the set of quality, we assume that each quality n is a constant share higher than the previous one $n-1$, i.e.

$$q_n = \gamma q_{n-1} \quad (4)$$

holds with some $\gamma > 1$.

Eq. (4) imposes a strong structure on the supply of the quality. We however point out that this assumption is less arbitrary than it might appear: Auer and Sauré (2017) show that in the integrated

[3] Note, however, that Shaked and Sutton (1984) and Sutton (2007) have analyzed product differentiation and price setting decisions in vertically differentiated open economies characterized by the entry of a monopolist or few oligopolists.

[4] We formalize and justify this interpretation in the working paper version of this article, where we endogenize the role of per capita income on the choice of quality. Specifically, one can interpret v as a product of country-specific taste shifter b and individual valuation ($v = b\tilde{v}$), where b is a proxy for country-specific income.

[5] Our model is closely related to the setup in Fajgelbaum et al. (2011), except that we do not assume the existence of an idiosyncratic noise term that gives rise to logistic demand; rather, we derive well-defined demand curves and variable markups directly from the non-homotheticity of preferences and the granularity of firms along the quality spectrum.

[6] We inherit this assumption from the large literature on vertically differentiated markets based Shaked and Sutton (1982).

[7] Convexity of costs is a key ingredient for many firms to operate in vertically differentiated markets, as indicated by Shaked and Sutton (1982). In its absence, natural monopolies prevail.

[8] Potential trade imbalances between the aggregate of these industries are offset by costless trade in the homogeneous good $\mathcal{A}$, whose consumption levels are assumed to be high enough to do so. Nothing of the following analysis changes in presence of a larger number of $\mathcal{Q}$ -type industries, which may differ in costs and maximum valuations $v_{\max}$.

economy, the pattern (4) of qualities is indeed an equilibrium result in a dynamic entry game in which innovators choose both the time of entry and the quality level. Also, the same pattern (4) emerges in the theoretical literature of endogenous growth with vertical differentiation, because quality is upgraded at constant frequency and by a constant fraction (see Aghion and Howitt, 2009).

In addition to Eq. (4), we need to specify the location of production sites of the different qualities. Specifically, we assume a regular, alternating pattern and assume that q_n is produced in Home if and only if q_{n-1} is produced in Foreign. In the empirical Section 3 we show that this assumption is well in line with the data on which our analysis is based.

We also note that the two-country economy is subject to an intrinsic asymmetry, since firm 0 that produces the top quality q_0 may be located either in Home or in Foreign. Summarizing, the differences across countries only concern the set of qualities produced by local firms, productivities (φ and φ^*) and per capita income ($v_{\max}$ and $v^*_{\max}$).

2.1. Optimal pricing in the open economy

In this subsection, we derive closed-form solutions for consumer prices. To save notation, we write, referring to production costs, $c_n = \varphi q_n^\theta$ if n is located in Home and $c^*_n = \varphi^* q_n^\theta$ if n is located in Foreign. Without loss of generality, we analyze price setting in the Home market in this subsection. The corresponding expressions for the prices in Foreign – which we use in our analysis further below – follow by exchanging the country-specific parameters in the equations.

Consumer choice. Under the preferences determined by Eq. (1), a consumer in Home with valuation v is indifferent between two goods q_n and q_{n+1} if and only if their prices p_n and p_{n+1} are such that $v = (p_{n+1} - p_n)/(q_{n+1} - q_n)$. Thus, given $v_{\max}$ and given the prices $\{p_n\}_{n \le 0}$, the n^{th} firm sells to all consumers with valuations v in the range $[\underline{v}_n, \bar{v}_n]$, where

$$\underline{v}_n = \frac{p_n - p_{n-1}}{q_n - q_{n-1}} \quad \text{and} \quad \bar{v}_n = \begin{cases} v_{\max} & \text{if } n = 0 \\ \frac{p_{n+1} - p_n}{q_{n+1} - q_n} & \text{if } n < 0 \end{cases} \tag{5}$$

A consumer with valuation $v \in (\underline{v}_n, \bar{v}_n)$ demands one unit of the variety produced by firm n, so that total demand of firm n equals $D_n(p_n) = [\bar{v}_n - \underline{v}_n] L/v_{\max}$. The optimal price p_n that maximizes the operating profits solves $\max_{p_n} (p_n - c_n)[\bar{v}_n - \underline{v}_n] L/v_{\max}$ and the optimality condition is hence

$$[\bar{v}_n - \underline{v}_n] + (p_n - c_n)\left[\frac{d\bar{v}_n}{dp_n} - \frac{d\underline{v}_n}{dp_n}\right] = 0 \tag{6}$$

for all $n \le 0$. The second-order condition is quickly checked to grant a maximum. Analogous conditions hold in foreign.[9]

With these preparatory steps, we can now derive the equilibrium prices.

Proposition 1. *If all firms sell into Home's market, consumer prices in Home are*

$$p_n = \begin{cases} A\lambda^n + \alpha c_n & n \text{ in Home} \\ A\lambda^n + \alpha^* c^*_n & n \text{ in Foreign} \end{cases} \tag{7}$$

where

$$\alpha = \frac{2 + \tau \frac{\gamma^\theta + \gamma^{1-\theta}}{\gamma+1} \frac{\varphi^*}{\varphi}}{4 - \left(\frac{\gamma^\theta + \gamma^{1-\theta}}{\gamma+1}\right)^2} \qquad \alpha^* = \frac{2\tau + \frac{\gamma^\theta + \gamma^{1-\theta}}{\gamma+1} \frac{\varphi}{\varphi^*}}{4 - \left(\frac{\gamma^\theta + \gamma^{1-\theta}}{\gamma+1}\right)^2} \tag{8}$$

$$\lambda = \gamma + 1 + \sqrt{\gamma^2 + \gamma + 1} \tag{9}$$

and

$$A = \begin{cases} \frac{\lambda}{2\lambda-1}\left(-\alpha^* \frac{\varphi^*}{\varphi} \frac{\gamma^\theta - \gamma^{-\theta}}{\gamma+1} + \frac{\gamma-1}{\gamma} \frac{q_0 v_{\max}}{c_0}\right) c_0 & n = 0 \text{ in Home} \\ \frac{\lambda}{2\lambda-1}\left(-\alpha \frac{\varphi}{\varphi^*} \frac{\gamma^\theta - \gamma^{-\theta}}{\gamma+1} + \frac{\gamma-1}{\gamma} \frac{q_0 v_{\max}}{c^*_0}\right) c^*_0 & n = 0 \text{ in Foreign} \end{cases} \tag{10}$$

Proof. See appendix. ■

Before discussing the price expressions of Eq. (7), we need to specify the conditions under which all firms indeed sell in Home's market. This is the case whenever prices exceed marginal costs ($A\lambda^n + \alpha c_n \ge c_n$ for all n in Home and $A\lambda^n + \alpha^* c^*_n \ge \tau c^*_n$ for all n in Foreign – recall that τ are marginal gross trade costs). It is quick to check that these conditions hold if:[10]

$$A/c_0 + \alpha \ge 1 \quad \text{and} \quad A/c_0 + \alpha^* \ge \tau \quad \text{if } A < 0 \tag{11}$$

$$\alpha \ge 1 \quad \text{and} \quad \alpha^* \ge \tau \quad \text{if } A \ge 0 \tag{12}$$

Throughout our analysis, we will assume that these conditions are met and the equilibrium prices are described by Eq. (7). In the subsequent empirical part, we will verify that the assumption that all qualities are sold in all relevant markets is a good approximation.

We can now turn to the discussion of the equilibrium prices (7), which consist of two additive terms $\left(\alpha^{(*)} c_n^{(*)} \text{ and } A\lambda^n\right)$. The first term, $\alpha^{(*)}$, describes the part of the markup over marginal production costs that is common for all firms located within one country. Moreover, while $\alpha^{(*)}$ does depend on trade costs, relative productivities and the spacing parameter γ, this term is independent of Home's income ($v_{\max}$) as well as the specific quality level (n). Thus, in the absence of the second term, $A\lambda^n$, the model would be similar to models with constant elasticities along the quality spectrum.

The second term in the pricing equation is $A\lambda^n$, which depends positively on Home's income $v_{\max}$ and impacts prices the more, the higher the quality n (because $\lambda > 1$). We remind the reader that the central theme of our paper is the analysis of effects of quality and income on firms' pricing decision and markups. All key results of the current paper will thus operate through the central term $A\lambda^n$. For future references, we will call to the first part of this term, A, the *perturbation term*. To understand where this perturbation term derives from, recall that models of quality choice feature an intrinsic asymmetry that affects price elasticities. Specifically, all but one firms face two direct competitors, one supplying a higher and one a lower quality level. The only exception to this rule is the top-quality firm, which faces just one direct competitor at the lower end. This implies that it loses fewer consumers when it increases its price – i.e., it has a less elastic demand. The top firm therefore charges a distorted markup

[9] See Auer and Sauré (2017) for a more detailed discussion of the pricing strategies.

[10] We show in the working paper version of this article that these conditions do not define an empty set.

(formally reflected by the perturbation term A). The distorted price of the top firm also affects all other firms: firm 1 with the second highest quality, having a direct competitor with non-standard pricing behavior, prices its product in a non-standard way as well. The resulting distortion of its price, however, is milder than the one for the top-quality firm. The same logic applies to all other firms, successively down the quality spectrum. Formally, the perturbation term A is 'discounted' by λ^n and essentially vanishes for firms supplying very low qualities.

The asymmetries of the quality spectrum and the resulting feature of the perturbation term imply that higher-quality firms tend to have more variable markups.[11] Since variable markups are the key element of pricing to market, pricing to market tends to be more pronounced for high than for low-quality firms.

Fig. 1 illustrates how the two price components combine to Home's consumer prices by plotting them on a logged scale as a function of quality q for the case $A > 0$ and $\alpha^{(*)} > 0$ and assuming that the top quality q_0 is produced in Home. The straight lines indicate the log-linear components αc_n and $\alpha^* c_n^*$, respectively (compare Eq. (3)). The figure illustrates that the discounted term $A\lambda^n$ is the less important, the lower the qualities ($n \to -\infty$). In this figure, each solid dot represents a firm located in Home and each lined dot represents a firm located in Foreign. Domestic and foreign firms are placed at alternating locations on the quality spectrum. Each firm serves a range of consumers. Because foreign firms face the transportation cost when selling to home, they charge higher prices and thus serve a relatively smaller group of consumers.[12]

We also notice that the expressions $\alpha^{(*)}$ from Eq. (7) can be positive or negative, depending on the sign of the denominator. It can be checked that $\alpha^{(*)}$ is positive if and only if

$$\lambda > \gamma^\theta, \tag{13}$$

is satisfied.

Throughout the paper, we focus on the cases where $\alpha^{(*)} > 0$, i.e., we assume that condition (13) holds. We make this assumption partly for convenience, as it avoids excessively many distinctions of cases in our analysis. More importantly, however, we point out that $\alpha^{(*)} < 0$ is a very restrictive case, as can be seen as follows. All cases with $\alpha^{(*)} < 0$ require $A > 0$ in order to grant non-negative markups (otherwise, firms will abandon the market). Hence, if Eq. (13) is violated, the relative markups $A(\lambda/\gamma^\theta)^n + \alpha^{(*)}$ are necessarily decreasing in n, i.e., higher-quality firms must have lower relative markups. Such a built-in negative correlation between markups and quality seems at odds with available evidence (see, e.g., Kugler and Verhoogen, 2012). Conversely, the parameter range defined by Eq. (13) allows markups to be either decreasing or increasing in quality, because A may be positive or negative. We focus on this more admissible parameter range, which ultimately allows the data to tell whether there is a correlation between markups and quality.

2.2. Quality, income and pricing-to-market (PTM)

Having derived closed-form solutions for prices, we now turn to the central aim of our paper, which is to examine the impact of income and qualities on equilibrium consumer price differences. To investigate relative prices, we will look at different qualities n and m that are produced in the same location (either both in Home or both in Foreign) and their price ratio p_n/p_m in the Home market. In addition, we will analyze the ratio of the export price over the domestic price of a given quality. To that aim, we define p_n^* as the price of quality n charged in the Foreign market. When n is produced in Home, we will refer to the ratio p_n^*/p_n as *relative export prices*.[13] With this convention, we formulate the following proposition.

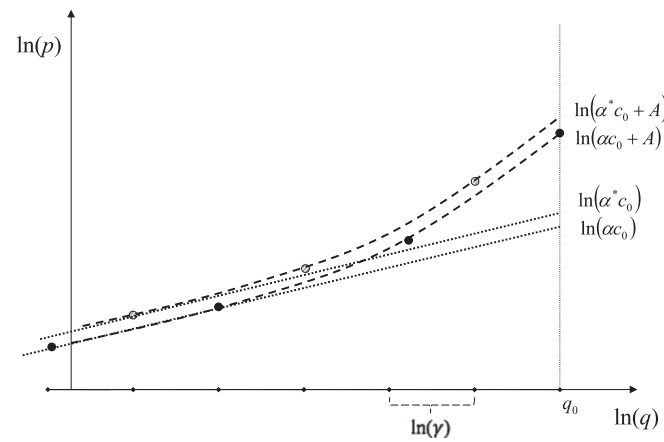

Fig. 1. Equilibrium prices of foreign and domestic qualities. Equilibrium consumer prices of quality with costly trade between two economies. Lined dots represent qualities produced by foreign firms, solid dots represent those produced by domestic firms.

Proposition 2.

(i) *Consider firms n and m located in the same country and $n > m$. Their relative price p_n/p_m is increasing in $v_{\max}$:*

$$\frac{d}{dv_{\max}} \ln(p_n/p_m) > 0$$

(ii) *Consider firm n located in Home. The slope of the relative export price in quality is increasing in Foreign's income and decreasing in Home's income:*

$$\frac{d}{dv_{\max}^*}\frac{d}{dn} \ln(p_n^*/p_n) > 0$$
$$\frac{d}{dv_{\max}}\frac{d}{dn} \ln(p_n^*/p_n) < 0$$

Proof. (i) Consider two firms located in Home indexed by n and m with $n > m$. The relative price of their products in the domestic market is

$$\frac{p_n}{p_m} = \frac{A\lambda^n + \alpha c_n}{A\lambda^m + \alpha c_m} = \frac{\frac{A}{\alpha c_n}\lambda^n + 1}{\frac{A}{\alpha c_m}\lambda^m + 1}\frac{\alpha c_n}{\alpha c_m} = \frac{\frac{A}{\alpha c_0}(\lambda/\gamma^\theta)^n + 1}{\frac{A}{\alpha c_0}(\lambda/\gamma^\theta)^m + 1}\frac{\alpha c_n}{\alpha c_m}.$$

Prices are positive so that numerator and denominator are positive. As $(\lambda/\gamma^\theta)^m < (\lambda/\gamma^\theta)^n$ and since A is increasing in $v_{\max}$, this means that the fraction is increasing in $v_{\max}$.

Similarly, the price in Home charged by two firms that are located in Foreign is

$$\frac{p_n}{p_m} = \frac{\frac{A}{\alpha^* c_0}(\lambda/\gamma^\theta)^n + 1}{\frac{A}{\alpha^* c_0}(\lambda/\gamma^\theta)^m + 1}\frac{\alpha^* c_n^*}{\alpha^* c_m^*}.$$

[11] We point out that the asymmetry cannot affect the lowest quality at the bottom end of the quality spectrum, even if quality supply is different than assumed in Eq. (4). The reason is that the bottom firm can always lose market share by consumers deciding not to purchase any quality good (or losing market shares to a virtual firm supplying quality level zero at the price zero).

[12] This statement only holds if $\tau\varphi^* > \varphi$.

[13] Notice that the prices charged by Home's firms in Foreign exhibit the same functional form as the prices which Foreign firms charge in Home, i.e., Eq. (7) when exchanging φ and φ^*.

By the same argument, the fraction p_n/p_m is increasing in $v_{\max}$.

(ii) Confirm with Eq. (7) that Home's consumer prices are independent of $v^*_{\max}$:

$$\frac{d}{dv^*_{\max}}\frac{d}{dn}\ln(p^*_n/p_n) = \frac{d}{dv^*_{\max}}\frac{d}{dn}\ln(p^*_n)$$

The first part of the statement then follows by applying part (i) to prices in Foreign.

Similarly,

$$\frac{d}{dv_{\max}}\frac{d}{dn}\ln(p^*_n/p_n) = -\frac{d}{dv_{\max}}\ln(p_n)$$

and the second part of the statement then follows by applying part (i) to prices in Home. ■

Part (i) of the proposition shows how the two elements of Eq. (7) yield a unique prediction regarding how quality is priced to market. Like in many pricing-to-market frameworks, a markup term α linearly multiplies the marginal cost of production. On its own, this term would imply equal markups for all firms, with the markups depending on the density of competition in the quality space, i.e., on γ. Additionally, the perturbation term A introduces a unique quality dimension to relative markups that varies with income of the destination market. First, the term A is market-specific as it is increasing in the maximal valuation $v_{\max}$. Second, because A is more important to high-quality firms (due to the presence of the factor λ^n), higher A implies larger price differences between high- and low-quality firms. The model generates the unique prediction that high-income markets have high demand for top-quality goods. High demand for top qualities, in turn, increases the market power of high-quality producers and thus the relative price of quality. This mechanism is related to the one proposed by Dornbusch (1987) and Atkeson and Burstein (2008). In the latter class of models, preferences are homothetic, but mark-ups increase in firms' market shares as the pricing decisions of large firms also affect the industry-wide price level.[14]

Part (ii) of the proposition then translates these findings to relative export prices: as $v^*_{\max}$ increases, the relative export price of high qualities increases by more than the relative export price of low qualities. The reverse holds for increases in $v_{\max}$. The formulation regarding relative export prices in part (ii) will prove especially convenient in the empirical section of this paper. In particular, by analyzing price ratios of export over domestic prices of one good, unobserved movements in marginal costs can be controlled for.

2.3. Quality, income and the exchange rate pass-through (ERPT)

In this section, we analyze how exchange rate changes, or more generally cost changes, are passed through into consumer prices. To that aim, we define the rate of cost pass-through as the elasticity of Home's consumer prices of imported goods with respect to Foreign's marginal production cost. We stress that the key parameter for Home's consumer prices is the effective supply cost of Foreign firms to Home's market ($\tau\varphi^*$), so that the interpretation of cost-pass-through corresponds one to one to an interpretation of an exchange-rate-pass-through.

In the following proposition, we first analyze the rate of cost pass-through and, specifically, how the pass-through rate varies with quality. Formally, we determine the sign of the cross derivative $d^2 ln(p_n)/(dnd\varphi^*)$. Second, we analyze how domestic prices change as the marginal production cost of imported goods changes. These changes of domestic prices will be a reaction to the shift in competition induced by changing import prices. This second part will enable us to assess the pass-through into *relative export prices*, defined as the price of a locally produced good in the export market divided by the price of the same good in the domestic market.

Proposition 3. *Consider firm n located in Foreign. Then,*

(i) *The pass-through of Foreign supply costs into Home's import prices p_n is decreasing in quality, i.e.,*

$$\frac{d}{dn}\frac{d}{d\varphi^*}\ln(p_n) < 0 \tag{14}$$

if and only if firm 0 is located in Home or firm 0 is located in Foreign and income is large in the sense that

$$v_{\max} > \frac{\varphi q_0^{\theta-1}}{2}\frac{\gamma}{\gamma-1}\frac{\gamma^{\theta}-\gamma^{-\theta}}{\gamma+1}. \tag{15}$$

(ii) *The pass-through of Home's supply costs into Foreign's domestic prices p^*_n is decreasing in quality, i.e.*

$$\frac{d}{dn}\frac{d}{d\varphi}\ln(p^*_n) < 0 \tag{16}$$

Proof. See Appendix. ■

Part (i) of the proposition relates directly to the ERPT. It states that a uniform proportional increase in the effective supply costs of all foreign goods – induced, e.g., by an appreciation of Foreign's currency – affects prices of different imported qualities differentially. Specifically, the pass-through rate into consumer prices tends to be higher for lower qualities and lower for higher qualities. This statement applies, provided that either the top-quality firm is located in the destination market or when income in the destination market is high enough.

In connection with Eq. (7), we have discussed in detail that the top firm is peculiar in a very specific dimension: it has only one direct competitor. This peculiarity translates into more variable markups for higher-quality firms, formally captured by the perturbation term A in Eq. (7). The variable markups, in turn, are key for the intuition of Proposition 3 (i). To see this, observe that a cost shock may impact firm pricing in two very different ways: the shock either induces a price change or it induces a change in firms' markups (or a combination of both).[15] Specifically, the stronger a markup reacts to cost shocks, the lower is the cost pass-through. Therefore, the more variable markups of high-quality firms imply that high-quality firms exhibit lower pass-through rates.[16]

Part (ii) of Proposition 3 specifies how prices of locally produced goods change with exchange rates. As Home's exchange rate appreciates (φ increases), the price of locally produced goods in Foreign's market (p^*_n) change the less, the higher their quality. The intuition

[14] While the intuition is thus highly related on the technical level, only a non-homothetic preference framework can give rise to our result that the income of a market plays a crucial role for prices. In almost all models of homothetic preferences, the market share of a good is independent of the local income distribution.

[15] See, e.g., Burstein and Gopinath (2014).

[16] The only exception to that rule may occur if income in the destination market is extremely low, so that the top-quality firm in Foreign has a very small market share and charges a price close to marginal costs. In this case, the top quality firms cannot react with adjustments in margins.

for this result rests on two effects. First, the prices of direct competitors of higher-quality producers (p^*_{n-1} and p^*_{n+1}, both of which are import prices) change relatively little by part (i) of the proposition. Consequently, there is less urge for local high-quality firms to react with price changes on their own. Second, the top-quality firm is less susceptible to competitor prices because it has only one direct competitor. Thus, top firms tend to react less to the shocks considered. The combination of both effects makes the sign of the cross-derivative in Eq. (16) unambiguously negative.

The two parts of Proposition 3 can be combined to determine ERPT into *relative export prices*, defined as p_n/p^*_n for n located in Foreign. Since local factor costs expressed in local currencies do not change under exchange rate changes, the thus defined ERPT is modeled by a percentage increase in φ^* applied to Home's consumer prices and a simultaneous percentage decrease in φ applied to Foreign's consumer prices. Formally, we analyze whether the inequality

$$\frac{d}{dn}\left(\frac{d\ln(p_n)}{d\ln(\varphi^*)}+\frac{d\ln\left(1/p^*_n\right)}{d\ln(1/\varphi)}\right)<0 \tag{17}$$

holds. Observing $d\ln\left(1/p^*_n\right)/d\ln(1/\varphi) = d\ln\left(p^*_n\right)/d\ln(\varphi)$ and applying both parts of the proposition above, we derive that Eq. (15) is a sufficient condition for Eq. (17) to hold: Foreign's relative export prices exhibit a lower ERPT, the higher their quality. This statement constitutes one of the hypotheses that we will test in the following empirical part.

In Sections 2.2 and 2.3 we have stated the two key sets of results of our theory, summarized in Proposition 2, Proposition 3 and inequality (17). In the following section, we take these results to the data and test the corresponding hypotheses with price data from the European car market.

3. The role of quality and income for PTM and ERPT – evidence from the European car industry

In this section, we document how the interplay between good quality and demand for quality (per capita income) determines differences in consumer prices across markets. We focus on the PTM decisions by firms and their ERPT in the European car industry.

Led by our theory, we test two hypotheses: first, the increase of good prices in quality is higher in richer markets (Proposition 2). Here, we test whether the export price relative to the local price of a car model is increasing in the ratio of per capita income in the export and per capita income in the domestic market (Proposition 2 (ii)). By taking the relative export prices as the dependent variable, we also control for unobserved heterogeneity in production costs in most of our empirical specifications. The second hypothesis is based on Proposition 3 and concisely captured by inequality (17). We test whether the rate of ERPT is decreasing in quality and, given that Eq. (15) is a sufficient condition, whether that effect is stronger in richer destination markets.

3.1. A glance at the data

We examine a panel of price data for cars sold in five markets from 1970 to 1999. Our data is from Goldberg and Verboven (2001, 2005) and includes model-specific car characteristics, based on which we can construct indices of *car quality*.

We follow the approach of Goldberg and Verboven (2001) and construct two indices for car quality based on different characteristics such as horse power, fuel efficiency, cylinder volume, weight, length, width, height, and maximum speed and by how much, on average, these attribute characteristics matter for prices. We emphasize that we run these regressions on all markets jointly and include destination and origin dummies. Therefore, the resulting coefficients are not affected by market-specific pricing of quality. We also point out that we use the resulting quality measures only in a relative sense: for example, we compare the hedonic quality indices to the relative price of a model on two markets.[17]

With this measure of car quality we analyze how PTM and ERPT of the same good differ with income in the respective markets, along the quality dimension and the interaction of both quality and income.

Since we are in many cases analyzing the export price relative to the price charged in the country of production, our baseline sample is restricted to car models sold and produced in one of the five countries. This baseline sample consists of 254 car models and 2064 combinations of model-year-destination.

Before turning to our empirical analysis, we address concerns related to that fact that our theory rests on a number of restrictions and assumptions. In particular, we try to address as many of these assumptions by either checking their validity directly or, if this is impossible, their direct implications.

First, we note that, when deriving our pricing formula (7) we have imposed assumptions (11) and (12). These assumptions grant that all qualities are sold in all markets. This assumption is well met in our data: specifically, we observe that 171 (or 67.3%) of the total of 254 models were sold in all of the five markets and 206 (or 81.1%) of all models were sold in at least four of the markets. On average 4.2 markets were supplied by each model. Further, when a model was sold in one of the markets in one specific year, it was simultaneously sold in all five markets in 54.6% of the cases (1127 out of 2064 model-year-market combinations) and in at least four markets in 74.8% (1543 out of 2064). On average 4.0 markets were supplied by each model in each year. We take these numbers as an imperfect but a reasonably close reflection of the assumption made in the theoretical analysis.

Second, through the structure on the qualities supplied specified in Eq. (4) and alternating locations of neighboring quality goods, we have assumed strong regularities of the supply of quality. We do not, of course, read this assumption entirely literally, but rather view it as a reflection that the sets of good qualities produced are relatively evenly distributed across countries, i.e., qualities from different countries span approximately the same quality range. (Conversely, goods from distinct countries should not have very different or disjoint quality ranges.) To verify this assumption (4) in an informal way, Fig. 2 illustrates the dispersion of qualities for each destination country and origin country. Each of the five panels corresponds to one destination country. The hedonistic Quality Index 1 is plotted on the horizontal axis; different locations on the vertical axis indicate origin countries. The figure shows that each pair of countries has a large overlap in any destination market. While Belgium (production origin of models by Ford and Volvo) consistently supplies the fewest number of models across destination counties and Germany the highest qualities, the ranges of qualities supplied by origin-destination pairs have a large overlap. We view these patterns as an imperfect but reasonable reflection of our second assumption made in the theoretical analysis.

Unfortunately, we cannot directly verify whether conditions are met regarding the structure of marginal costs (3) nor to what extent the technical restriction (13) is met.

[17] For summary statistics, we refer the reader to Tables A2 and A3 in the online appendix to this paper, where we also define and explain our quality measures in detail.

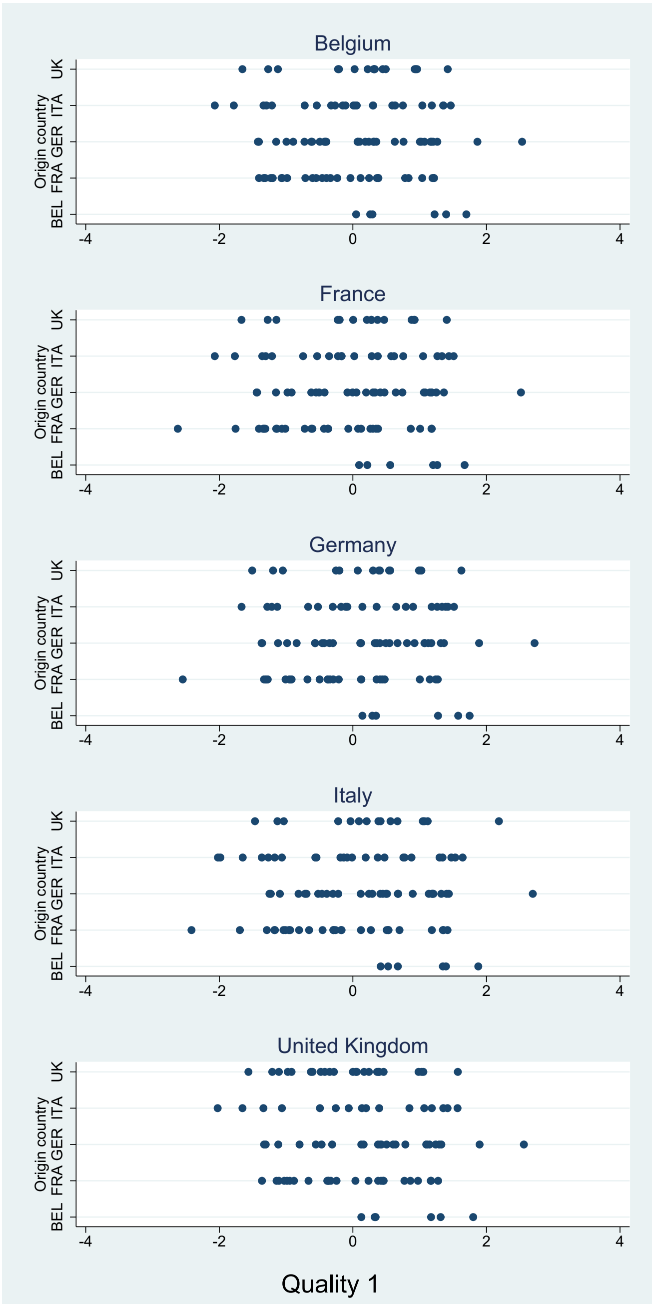

Fig. 2. Quality supply by destination country. Dispersion of quality supplied by destination country (separate panels) and by country of origin (horizontal axis within panels). Each dot represents the average quality level of one car model sold in at least one year during 1991–1999.

3.2. Quality and pricing-to-market

In this section, we test whether the interaction between good quality and per capita income determines consumer prices according to our theory, in particular, by Proposition 2 (ii).

Our focus is to evaluate how the relative price – i.e. the price of the same car sold in two different markets – varies with the car's quality. We view especially this price ratio as informative, as the marginal cost of production factors out and the exercise thus informs us about markup differences (see also Fitzgerald and Haller, 2014 on this point). Specifically, we estimate the econometric model

$$p_{i,c,t} = \alpha + \beta q_i + \gamma q_i I_{c,t} + \delta x_{i,t} + \epsilon_{i,c,t}, \tag{18}$$

the subscripts indicate the car model (i), country where the car is sold (c) and time (t); q_i is the model's hedonistic quality index and $I_{c,t}$ a measure of income per capita in the destination market; $x_{i,t}$ is a set of included covariates (including, among others, income per capita and country fixed effects of destination and origin markets), and $\epsilon_{i,c,t}$ the error.

The dependent variable $p_{i,c,t}$ is defined as the logarithm of the price in the importing nation relative to the price of the same model charged in the exporting country and expressed in the same currency (for expositional clarity SDR):

$$p_{i,c,t} = \ln\left[\frac{SDR \text{ Price in importing country } c_{i,t}}{SDR \text{ Price in exporting country}_{i,t}}\right] \tag{19}$$

We begin by establishing some regularities of quality and prices in export versus domestic markets. Specifically, we estimate model (18) disregarding the terms that include per capita income. Table 1 reports our first set of results related to quality. In Column (1), the car's 'class' is used as a measure of quality. The coefficient is estimated significantly positive at 0.015. This variable 'class' takes values from 1 (subcompact cars) to 5 (luxury cars) so that the estimated coefficient implies the following: compared to subcompact cars, luxury cars are $(5-1)*0.015$ or 6% more expensive abroad than at home. This finding shows that quality is priced significantly higher in foreign markets than in the market of origin. In Columns (2) and (3), we include two measures of quality.[18] Again, we find that quality is priced higher when exporting than when selling domestically.

We note that when we compare the relative price abroad, we cannot guarantee to always compare the exact same car model as manufacturers sell slightly different model configurations in the different markets. Such upgrading might indeed arise in the spirit of the argument of "shipping the good apples out" (see Hummels and Skiba, 2004; Boorstein and Feenstra, 1987 analyze upgrading in the car industry). Further, Dvir and Strasser (2013) show that car producers price-discriminate across markets by manipulating the menu of included car features available in each country, which might affect our results as it could be correlated with both quality and income.

We control for potential quality upgrading in the estimations reported in Columns (4) and (5), documenting that quality upgrading does not explain why the relative price abroad is increasing in quality. To do so, we include, in addition to the quality measure of the model sold in the country of production, the difference in the quality indices between the car model sold abroad and the one sold in the market of production. When using Quality Index 1 (Column (4)) and Quality Index 2 (Column (5)), we find that differences in car qualities across the exporter and importer market are indeed important for understanding price differences.

Columns (6) and (7) include year dummies to control for global trends or shocks such as the oil crises. Indeed, common trends in trade integration, average car quality, and differences in price discrimination over time might interact in ways that generate the correlation between the relative price abroad and car quality (see Goldberg and Verboven, 2001). Columns (6) and (7) show that time effects do not explain why high-quality cars are relatively more expensive abroad.[19]

Overall, Table 1 shows that quality is priced higher in export markets than in domestic markets. The central question of our work,

[18] As opposed to Quality 1, the defining regressions for Quality 2 include brand fixed effects and information on the model's 'class', respectively, see the online appendix.

[19] We point out that local input sourcing is unlikely to affect our results as the dataset includes information on the location of production and we only include those car models with a unique origin, i.e., a VW Jetta produced in Germany that is sold in Belgium is – up to differences in some car options that are extremely unlikely to be sourced locally – the same car as a VW Jetta sold in Spain, with no differences in the origin of sourced inputs.

Table 1
Relative price levels (random effects estimations).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Cla and rel. price	Quality 1 and rel. price	Quality 2 and rel. price	Adjusting for quality differences		Adding time dummies	
Dependent variable: Ln (price SDR importer/price SDR exporter)							
Class	0.015**						
(1 = subcompact, 5 = luxury)	(0.003)						
Quality Index 1		0.051**					
		(0.003)					
Quality Index 2			0.040**				
			(0.004)				
Quality Index 1				0.032**		0.031**	
Home market				(0.004)		(0.004)	
Quality Index 1				0.125**		0.130**	
Diff. home and abroad				(0.011)		(0.011)	
Quality Index 2					0.030**		0.030**
Home market					(0.004)		(0.004)
Quality Index 2					0.260**		0.262**
Diff. home and abroad					(0.028)		(0.027)
Year dummies	n	n	n	n	n	y	y
Location dummies	y	y	y	y	y	y	y
Market dummies	y	y	y	y	y	y	y
Observations	5926	5926	5926	5926	5926	5926	5926
Number of groups	809	809	809	809	809	809	809
R2 - Overall	0.398	0.409	0.410	0.432	0.429	0.459	0.456
R2 - Between	0.496	0.505	0.504	0.532	0.507	0.565	0.543
R2 - Within	0	0.0538	0.0337	0.0726	0.0678	0.114	0.103

Notes for Table 1: all specifications are estimated using random effects (groups: Market-Co-Location (all combinations) where "Co" is the narrow car model definition of Goldberg and Verboven (2005)). In Columns (4) to (7), the difference in the quality index of a model is included to capture changes of the quality of a car during the lifecycle of a model. The interpretation of the quality index coefficient is the effect a change in a model's quality has on the price. The sample consists of all models that are produced in and exported to BEL, FRA, ITA, GER and UK. Robust standard errors reported in parentheses *significant at 5%; ** significant at 1%.

however, concerns how the interaction of income of the destination market and the supply of quality shapes the firm's optimal prices of quality. We turn to this question next.

3.2.1. *Income, quality and PTM*

We now examine how relative prices depend on the income in the respective market. As before, our dependent variable is defined as relative export prices – i.e., the price charged in the export countries over the price charged domestically. We include relative per capita income as an explanatory variable in our regressions, which is defined as

$$I_{c,o,t} = \ln\left[\frac{GDP/CAP \text{ in importing nation}_t}{GDP/CAP \text{ in exporting nation}_t}\right] \quad (20)$$

where c indicates the importing country and o the exporting country. For all countries, per capita GDP is denominated in the same currency.

With relative income thus defined, we estimate the empirical model (18). This specification then corresponds exactly to Proposition 2 (ii), where the differential effect of per capita income in the destination and in the origin country is jointly captured by the coefficient γ, the one on the interaction term $q_i I_{c,o,t}$ in Eq. (18).

Table 2 reports how quality is priced across the five markets depending on relative income $I_{c,o,t}$. The result reported in Column (1) shows that income alone, i.e., not interacted with quality, does not have an impact on the relative prices.

The regressions including the interaction term are reported in Columns (2) to (9) and represent the main set of results. The coefficient in Column (2) is statistically significant and its level of 0.153 is also economically quite significant. For example, consider two cars exported from a high-income market to a low-income market (the 10*th* percentile of relative income is −0.188). One of these cars is of low quality (10*th* percentile of car quality at −1.359), the other is of high quality (90*th* percentile of car quality at +1.321). The relative export price of the low-quality car is equal to 1.7%, i.e. the low-quality car is 1.7% more expensive in the low-income destination market. In contrast, the relative export price of the high-quality car is equal to −4.6%, i.e. the high-quality car is 4.6% more expensive in the high-income source market. In total, in this example, the interaction of car quality and market income can thus account for relative price differences in the order of magnitude of 6–7%, which is significant compared to the margins in this industry.[20]

We note that the specification of Column (2) includes year-fixed effects. Therefore, it is unlikely that the findings are driven by common trends of prices, qualities, and income. They could, however, be driven by temporary country-specific fluctuations. To address this concern, we add year-market fixed effects to the specification corresponding to Column (3). The coefficient of interest drops but remains positive and significant, showing that our findings are not driven by large country-specific fluctuations.

Next, Column (4) reports regressions including dummies for each combination of year, brand and market. The results show that the interaction between income and quality matters for pricing even when exclusively utilizing variation in car quality within firms. This finding reported in Column (4) allows to address alternative theories based on distribution costs. Specifically, in the case that local distribution costs as a share of total costs are increasing in quality, then quality can be shown to have higher markups in foreign markets, to similar pricing behavior as in our model (see Chen and Juvenal (2016)). In regard to this explanation, we notice that cars are distributed to consumers via brand-specific dealer networks (see Brenkers and Verboven (2006)). Hence, the associated distribution costs thus vary by brand but not by car within each brand. The

[20] The figures of 1.7% and −4.6%, respectively, result from the following computations, where we take the coefficients 0.005, 0.080 nad 0.153 from Table 2, Column 2. $0.005 * (-1.359) + 0.08 * (-0.188) + 0.153 * (-1.359) * (-0.188) = 0.017$ and $0.005 * 1.321 + 0.08 * (-0.188)) + 0.153 * 1.321 * (-0.188) = -0.046$.

Table 2
Relative prices and income (random effects and absorption estimations).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Quality and income	Interaction w. quality	BRD-YE-MA effects	YE-MA effects	PPI*Quality	YE-MA effects	PPI*Quality	YE-MA effects	PPI*Quality
	Income: GDP p.c.					Income: consumption p.c.		Income: GNI p.c.	
Dependent variable: Ln (Price SDR importer/price SDR exporter)									
Quality Index 1	0.002	0.005	0.041**	0.016*	0.033**	0.000	0.031**	-0.010	0.019
	[0.007]	[0.008]	[0.003]	[0.007]	[0.011]	[0.008]	[0.010]	[0.007]	[0.010]
Ln rel. income	−0.020	0.080**	−0.232**	−0.010	0.345**	0.202*	−0.196	−0.216**	−0.634**
(Importer/exporter)	[0.015]	[0.018]	[0.085]	[0.019]	[0.051]	[0.090]	[0.118]	[0.084]	[0.089]
Quality 1 * Ln rel. income		0.153**	0.039**	0.090**	0.215**	0.130*	0.767**	0.096	0.852**
		[0.013]	[0.010]	[0.013]	[0.041]	[0.063]	[0.105]	[0.058]	[0.091]
Relative PPI level					0.103*		−0.178**		−0.124**
					[0.051]		[0.029]		[0.029]
Quality 1 * rel. price level					−0.013		−0.220**		−0.088**
					[0.048]		[0.024]		[0.022]
Fixed effects			y						
Year-market dummies				y		y		y	
Year dummies	y	y			y		y		y
Market dummies	y	y			y		y		y
Observations	5640	5640	5640	5640	3692	5926	3978	5926	3978
Number of groups	764	764		764	547	809	592	809	592
R2 - Overall	0.321	0.321	0.84	0.508	0.356	0.500	0.372	0.504	0.402
R2 - Between	0.402	0.317		0.490	0.316	0.522	0.430	0.532	0.476
R2 - Within	0.0323	0.152		0.427	0.335	0.403	0.188	0.401	0.159

Notes for Table 2: all specifications except (3) are estimated using random effects (groups: Market-co-location (all combinations) where "Co" is the narrow car model definition of P. Goldberg and Verboven (2005)); (1), (2), (5), (7) and (9) include year dummies and market dummies, while (4), (6) and (8) include year-by-market dummies. Column (3) presents results of a fixed effect regression where Brand-Market-Year variation is absorbed. The quality index is as constructed in main text, relative income is equal to the ratio of real income in importer and exporter nation. The sample consists of all models that are produced in and exported to BEL, FRA, ITA, GER and UK. Robust standard errors reported in parentheses *significant at 5%; ** significant at 1%.

Table 3
Relative exchange rate pass-through (fixed effects regressions).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
					rel. GDP p.c.		rel. Consumption p.c.		rel. GNI p.c.	
	Baseline	Quality	Interact.	Trend	Low	High	Low	High	Low	High
Dependent variable: Ln change of the ratio of importer over exporter price (local currencies)										
dExrate = Ln change exchange rate	0.171**	0.178**	0.151**	0.143**	0.069	0.294**	0.243**	−0.051	0.153*	0.114*
	[0.044]	[0.044]	[0.041]	[0.040]	[0.051]	[0.056]	[0.046]	[0.062]	[0.064]	[0.045]
Quality Index 1		0.025**	0.025**	0.062**	0.080**	0.059*	0.044*	0.138**	0.078**	0.058*
		[0.008]	[0.008]	[0.015]	[0.021]	[0.025]	[0.017]	[0.038]	[0.022]	[0.023]
dExrate * Quality Index 1			−0.085*	−0.084*	−0.042	−0.063	−0.083	−0.126*	−0.071	−0.111*
			[0.038]	[0.038]	[0.043]	[0.065]	[0.044]	[0.056]	[0.062]	[0.047]
Ln change relative CPI	0.803**	0.881**	0.858**	0.810**	0.702**	0.789**	0.752**	0.653**	0.724**	0.846**
(importer infl. - exporter infl.)	[0.051]	[0.055]	[0.056]	[0.057]	[0.086]	[0.102]	[0.061]	[0.151]	[0.068]	[0.112]
Trend (year)				−0.002**	−0.002*	−0.003*	−0.002*	−0.002	−0.003**	−0.002
				[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
Observations	4976	4976	4976	4976	2859	2117	3038	1938	2384	2592
Number of groups	719	719	719	719	494	482	458	427	425	499
R-squared (within)	0.0800	0.0828	0.0851	0.0900	0.0507	0.110	0.143	0.0585	0.107	0.0581

Notes for Table 3: in all specifications, the dependent variable is the change in the natural logarithm of the relative car price in common currency (importer SDR price divided by exporter SDR price). The independent variable "Ln change relative CPI" measures the change in the natural logarithm of the ratio of importer CPI to the exporter CPI. Columns (2) to (10) include the quality index to control for changes of the relative quality of a car during its lifecycle. The interpretation of the coefficient on the quality index is the effect a change in a model's quality has on the relative price. All specifications include fixed effects by Market-Co-Location. In the sample of Column (5) the importer has a lower per capita GDP than the exporter, in the sample of Column (6) the reverse is true. In Columns (7) to (10) the sample split is based on per capita consumption and per capita GNP. The sample consists of all models that are produced in and exported to BEL, FRA, ITA, GER and UK. Robust standard errors reported in parentheses *significant at 5%; ** significant at 1%.

specification corresponding to Column (6) thus controls for these distribution costs, demonstrating that they do not drive our findings.[21]

In Column (5) we include the importer nation's producer price index (PPI) and its interaction term with quality. Here again, the coefficient of interest remains significant. We notice that Goldberg and Verboven (2001) use national producer price indices as a gauge of local distribution costs, which would again suggest that distribution costs are not a key driver of our results.[22]

3.3. Quality and ERPT

We next examine the implications of our theory regarding the pass-through of cost and exchange rate shocks, in particular, inequality (17). To estimate the price response to exchange rate fluctuations, we adopt the standard approach of the literature (see Goldberg and Verboven, 2005 or Goldberg and Campa, 2010), estimating one year pass-through regressions of the type

$$\Delta p_{i,c,t} = \alpha_{i,c} + \beta \Delta e_{c,o,t} + \gamma q_i \Delta e_{c,o,t} + \delta \Delta x_t + \epsilon_{i,c,t}, \tag{21}$$

Here, $p_{i,c,t}$ is model i's relative export price, defined as the pre-tax price in destination country c relative to its price in the origin country o, both in local currencies; Δ indicates annual percentage changes (log changes). $\alpha_{i,c}$ the model-market fixed effect; $\Delta e_{c,o,t}$ the annual percentage change in the bilateral nominal exchange rate between destination country c and origin country o; q_i the car's hedonistic quality index; Δx_t the set of included covariates, and $\epsilon_{i,c,t}$ the error. The exchange rate is always the bilateral year end value from Goldberg and Verboven (2001, 2005).

We point out that, by examining export prices relative to those charged in the origin country, we eliminate firm-specific shocks that might correlate with exchange rates. If, for example, firms that produce high-quality cars have a relatively high share of imported intermediates, their marginal cost of production moves more with the exchange rate in the low-quality segment, generating a bias towards low ERPT of higher qualities. Such a bias does not arise when analyzing price ratios. All estimations control for fixed effects and relative consumer price inflation, i.e. the change in the natural logarithm of the ratio of CPI_i/CPI_o, which reflects the fact that we analyze relative prices. Finally, we weight the estimations by the number of a model's sales. Heteroscedasticity robust standard errors are reported in brackets below the coefficient point estimates.

Table 3 reports our ERPT estimations based on prices changes. Column (1) shows that the pass-through-rate is estimated at 17.1%, which is on the lower side but still in line with ERPT rates found in microeconomic dataset spanning multiple industries (compare for example, to Auer and Schoenle, 2016). The estimated coefficient rises slightly once we also control for quality in Column (2). The coefficient of quality shows that quality is a significant determinant of average price changes.[23]

In Columns (3)–(10) we add the interaction of Quality Index 1 and the exchange rate change, thus allowing pass-through rates to be quality-dependent. Corresponding to our theory, particularly inequality (17), we expect that the pass-through rate is lower for higher-quality cars. Consistent with this prediction, the coefficient on the interaction term is negative throughout: the degree of ERPT appears to be decreasing in quality. Column (3) documents that relative price pass-through is lower for higher qualities: a one standard deviation in quality is associated with a −8.5 percentage points lower rate of pass-through. The coefficient is significant at the 5 % level. For example, compare the 10*th* percentile of car quality to the 90*th* percentile. The respective percentiles are −1.26 and 1.37, so

[21] In the working paper version of this study, we also collect data on distribution margins of various car brands, showing little evidence in favor of a positive correlation between quality or car prices on the one hand and the share of distribution costs on the other.

[22] We note that in all specifications, differences in toughness of competition are absorbed by the inclusion of market fixed effects (all specifications reported in Table 2). The inclusion of market–year fixed effects further absorbs the impact of time-varying market concentration (see columns 4, 6 and 8).

[23] Because we include fixed effects for each model sold in each market, the coefficient on quality has to be interpreted with care: if the quality of a model does not change during its life cycle, the fixed effects absorb all the variation associated with quality differences between cars. However, car manufacturers often upgrade the engine and other features of a model during its life cycle, and therefore the quality of a model can change slightly. Thus, the coefficient of "Quality Index 1" has the interpretation of how much a change in the quality of a car affects its price during its life cycle.

that the pass-through rate of these two car qualities is 25.4% versus 3.1%, implying an eight-fold difference. Clearly, these effects are economically important. Column (4) adds a trend, to which the previous finding in robust. We also refer the reader to Table A4 in the Online Appendix for additional robustness checks of this finding, including, among others, inclusion for producer price indices and alternative definitions of car models as used in Goldberg and Verboven (2001, 2005).

3.3.1. Income, quality and ERPT

We have taken the prediction of Proposition 3 to the data, while neglecting that inequality (17) has been derived under the sufficient condition (15). We interpret this latter condition in light of the main theme of our theory: the interaction between per capita income and the supply of quality shapes the pricing decisions by firms. Specifically, we hypothesize that the decrease of the pass-through in quality is stronger for higher-income markets. We test this hypothesis in the specifications reported in Columns (5)–(10) of Table 3. To do so, we split the sample into two subsamples: in the first, per capita income in the destination country is lower than in the origin country, while in the second the reverse is true. This split is done based on the same variables used in Table 2, Columns (5) and (6), and the underlying variable is per capita income (in SDR). In the subsamples, the coefficients on the interaction of quality and the exchange rate changes drop and are not significant any more, yet both remain negative. Moreover, in line with our theory, the coefficient in the subsample of low per capita income in the destination market is smaller. This observation is stronger in terms of economic magnitude and statistical significance when splitting the sample based on per capita consumption expenditure (Columns (7) and (8)) or per capita GNI (Columns (9) and (10)). We point out that in all subsamples, the coefficients are negative. Moreover, the coefficients in the low-income market samples (Columns (7) and (9)) are smaller in magnitude than the coefficient of the corresponding high-income subsamples (Columns (8) and (10)).

Overall, our findings suggest that quality is not only an important determinant of the degree of ERPT. Instead, the interaction between quality on the one hand and demand for quality (proxied through various measures of per capita income) is key for understanding how exchange rate changes affect export prices.[24]

The literature on ERPT has shown that the full effect of exchange rate changes materializes in longer horizons. Therefore, in Table 4 we document that the pass-through rates of longer horizons also vary along the quality dimension. Following Gopinath and Rigobon (2008), we measure pass-through by estimating a stacked regression where we regress yearly import price changes on yearly lags of the respective measure of the exchange rate.

$$\Delta p_{i,t} = \alpha_i + \sum_{j=1}^{n} \beta_j \Delta e_{t-j+1} + \sum_{j=1}^{n} \gamma_j \left(q_i \Delta e_{t-j+1}\right) + \sum_{j=1}^{n} \delta_j \Delta x_{t-j+1} + \epsilon_{i,t} \quad (22)$$

We estimate Eq. (22) up to the 5−year horizon.

The ERPT rates differ between high and low-quality exporters at all horizons. Table 4 reports the (i.e. $\sum_{j=1}^{n} \beta_j$ and $\sum_{j=1}^{n} \gamma_j$ for main and interaction coefficient respectively). Panel A does this for the case of using quality measure 1. Here, the average rate of ERPT (equal to the main effect since the quality measure is of mean 0) is increasing from 13.2% at the one year horizon to 53.4% after five years. Also the difference in the ERPT rate between high and low-quality exporters increases with the time horizon. The magnitude of the interaction coefficient increases from 11% at the one year horizon to 14.7%, 15%, and 23% at the two, three, and four year horizon respectively. At the five year horizon, the interaction coefficient is estimated at only −15.6%. When using Quality Index 2 in panel B, the effect of quality on pass-through is smaller in magnitude, but still significant.

Table 4
The time profile of ERPT and quality.

No. of lags included	Sum of coefficients on change exchange rate	Sum of coefficients on ch. exchange rate * Quality Index 1
Panel A - Using Quality Index 1		
0	0.132	−0.111
	[0.038]**	[0.037]**
0 -1	0.248	−0.147
	[0.049]**	[0.045]**
0 -2	0.447	−0.150
	[0.050]**	[0.054]*
0 -3	0.483	−0.230
	[0.070]**	[0.061]**
0 -4	0.534	−0.156
	[0.116]**	[0.078]*
Panel B - Using Quality Index 2		
0	0.146	−0.074
	[0.039]**	[0.035]*
0 -1	0.269	−0.099
	[0.050]**	[0.040]*
0 -2	0.465	−0.121
	[0.049]**	[0.050]*
0 -3	0.502	−0.220
	[0.070]**	[0.062]**
0 -4	0.539	−0.166
	[0.112]**	[0.075]*

Notes for Table 4: All specifications present the results from stacked regressions relating import price changes on lags of the exchange rate changes as in Gopinath and Rigobon (2008). The sum of the coefficients over the respective lags is reported (first column for the main effect of the exchange rate change and second column for the interaction effect of quality and exchange rate change). Panel A presents results from specifications that include the interaction of Quality 1 with the exchange rate change, while Panel B presents results from specifications that include the interaction of Quality 2 with the exchange rate change; robust standard errors reported in brackets *significant at 5%; ** significant at 1%.

4. Conclusion

This paper shows that the interaction of good quality and consumer income is an important dimension of firms' PTM. We first examine such decisions in a model of vertical product differentiation. The industry is populated by a large number of firms, each producing a good of unique quality. Foreign and domestic firms sell goods of heterogeneous quality to consumers with non-homothetic preferences, who differ in their income and thus their marginal willingness to pay for quality increments. We show that the relative price of high-quality goods compared to that of low-quality goods is an increasing function of income in the destination market. Our framework thus predicts that low-quality goods are relatively more expensive in poor markets, while high-quality goods are relatively more expensive in rich markets. We also examine the relation between income, quality, and the degree of ERPT. Our theory suggests that a good's quality in itself is crucial for firms' PTM decisions and, moreover, the interaction of quality with market-specific valuation for quality plays a crucial role. Specifically, the decrease of the ERPT in quality is especially pronounced in higher income markets.

We then test the predictions of our theory using a dataset of prices and product attributes in the European car industry. Our first main finding is that higher-quality cars are relatively more expensive on richer markets. This observation is in line with our theory: high-quality cars are especially expensive on rich markets, where demand for quality is high. Our second main finding is that the ERPT is larger for low than for high-quality cars, Moreover, we present some

[24] The latter findings are well in line with Chen and Juvenal (2016), who report that quality significantly determines the ERPT into export prices for high-income destination markets, but less so for low-income destination markets.

evidence that this latter relation is stronger in richer destination markets.

The effects we uncover are economically highly significant. For example regarding price levels, we find that the interaction of car quality and market income can account for relative price differences in the order of magnitude of 10 percentage points, which is very significant compared to the margins in this industry. Also the estimates of ERPT rates suggest that quality is a main determinant of firm's pricing decisions: the pass-through rate is below 10% for the highest decile of car quality, while it is around 20% the lowest decile of car quality.

Appendix A

Proof of Proposition 1. First, using Eq. (4) to obtain the firms' first order conditions (6) for prices in Home's market become

$$p_n = \begin{cases} \frac{1}{2}\left[c_0 + (1-\gamma^{-1})\, q_0 v_{\max} + p_{-1}\right] & \text{if } n=0 \text{ and firm 0 is in Home} \\ \frac{1}{2}\left[\tau c_0^* + (1-\gamma^{-1})\, q_0 v_{\max} + p_{-1}\right] & \text{if } n=0 \text{ and firm 0 is in Foreign} \\ \frac{1}{2}\left[c_n + \frac{1}{1+\gamma} p_{n+1} + \frac{\gamma}{\gamma+1} p_{n-1}\right] & \text{if } n<0 \text{ is in Home} \\ \frac{1}{2}\left[\tau c_n^* + \frac{1}{1+\gamma} p_{n+1} + \frac{\gamma}{\gamma+1} p_{n-1}\right] & \text{if } n<0 \text{ is in Foreign} \end{cases} \tag{23}$$

Now set $p_n = u_n + \alpha c_n$ if firm n is located in the domestic market and $p_n = u_n + \alpha^* c_n^*$ if not. Off the border condition, the system (23) for the consumer prices in Home is

$$\begin{aligned} 2\left[u_n + \alpha c_n\right] &= c_n + \frac{1}{\gamma+1}\left[u_{n+1} + \alpha^* c_{n+1}^*\right] \\ &\quad + \frac{\gamma}{\gamma+1}\left[u_{n-1} + \alpha^* c_{n-1}^*\right] \quad n \text{ in Home} \\ 2\left[u_n + \alpha^* c_n^*\right] &= \tau c_n^* + \frac{1}{\gamma+1}\left[u_{n+1} + \alpha c_{n+1}\right] \\ &\quad + \frac{\gamma}{\gamma+1}\left[u_{n-1} + \alpha c_{n-1}\right] \quad n \text{ in Foreign} \end{aligned}$$

The terms multiplied by c_n and c_n^* vanish iff

$$\begin{aligned} 2\alpha &= 1 + \left\{\frac{\gamma^\theta}{\gamma+1} + \frac{\gamma^{1-\theta}}{\gamma+1}\right\}\frac{\varphi^*}{\varphi}\alpha^* \\ 2\alpha^*\frac{\varphi^*}{\varphi} &= \tau\frac{\varphi^*}{\varphi} + \left\{\frac{\gamma^\theta}{\gamma+1} + \frac{\gamma^{1-\theta}}{\gamma+1}\right\}\alpha \end{aligned}$$

Solving for α and α^* leads to Eq. (8). The remaining problem is

$$2u_n = \frac{1}{\gamma+1}u_{n+1} + \frac{\gamma}{\gamma+1}u_{n-1} \qquad n<0$$

with the general solution

$$u_n = A\lambda^n + B\mu^n$$

where $\lambda = \gamma + 1 + \sqrt{\gamma^2+\gamma+1}$ and $\mu = \gamma + 1 - \sqrt{\gamma^2+\gamma+1}$. The transversality condition $\lim_{n\to-\infty} p_n = 0$ and $\mu < 1$ imply $B = 0$. Eq. (23) leads to

$$\begin{aligned} 2A + 2\alpha c_0 &= c_0 + \frac{\gamma-1}{\gamma} q_0 v_{\max} + A/\lambda + \alpha^*\gamma^{-\theta}\frac{\varphi^*}{\varphi}c_0 \quad \text{if } n=0 \text{ in Home} \\ 2A + 2\alpha^* c_0^* &= \tau c_0^* + \frac{\gamma-1}{\gamma} q_0 v_{\max} + A/\lambda + \alpha\gamma^{-\theta}\frac{\varphi}{\varphi^*}c_0^* \quad \text{if } n=0 \text{ in Foreign} \end{aligned}$$

Solving for A yields

$$A = \begin{cases} \frac{\lambda}{2\lambda-1}\left(1 - 2\alpha + \alpha^*\gamma^{-\theta}\frac{\varphi^*}{\varphi} + \frac{\gamma-1}{\gamma}\frac{q_0 v_{\max}}{c_0}\right)c_0 & n=0 \text{ in Home} \\ \frac{\lambda}{2\lambda-1}\left(\tau - 2\alpha^* + \alpha\gamma^{-\theta}\frac{\varphi}{\varphi^*} + \frac{\gamma-1}{\gamma}\frac{q_0 v_{\max}}{c_0^*}\right)c_0^* & n=0 \text{ in Foreign} \end{cases}$$

Finally, use Eq. (8) to check that

$$2\alpha - 1 = \alpha^*\frac{\varphi^*}{\varphi}\frac{\gamma^\theta + \gamma^{1-\theta}}{\gamma+1} \quad \text{and} \quad 2\alpha^* - \tau = \alpha\frac{\varphi}{\varphi^*}\frac{\gamma^\theta + \gamma^{1-\theta}}{\gamma+1}$$

holds. Substituting $2\alpha - 1$ and $2\alpha^* - \tau$ in the expressions for A then proves Eq. (10). ■

Proof of Proposition 2. (i) Consider two firms located in Home indexed by n and m with $n > m$. The relative price of their products in the domestic market is

$$\frac{p_n}{p_m} = \frac{A\lambda^n + \alpha c_n}{A\lambda^m + \alpha c_m} = \frac{\frac{A}{\alpha c_n}\lambda^n + 1}{\frac{A}{\alpha c_m}\lambda^m + 1}\frac{\alpha c_n}{\alpha c_m} = \frac{\frac{A}{\alpha c_0}\left(\lambda/\gamma^\theta\right)^n + 1}{\frac{A}{\alpha c_0}\left(\lambda/\gamma^\theta\right)^m + 1}\frac{\alpha c_n}{\alpha c_m}.$$

Prices are positive so that numerator and denominator are positive. As $(\lambda/\gamma^\theta)^m < (\lambda/\gamma^\theta)^n$ and since A is increasing in $v_{\max}$, this means that the above ratio is increasing in $v_{\max}$.

Similarly, the price in Home charged by two firms that are located in Foreign market is

$$\frac{p_n}{p_m} = \frac{\frac{A}{\alpha^* c_0}\left(\lambda/\gamma^\theta\right)^n + 1}{\frac{A}{\alpha^* c_0}\left(\lambda/\gamma^\theta\right)^m + 1}\frac{\alpha^* c_n^*}{\alpha^* c_m^*}.$$

By the same argument above, the fraction p_n/p_m is increasing in $v_{\max}$.

(ii) Confirm with Eq. (7) that Home's consumer prices are independent of $v_{\max}^*$:

$$\frac{d}{dv_{\max}^*}\frac{d}{dn}\ln\left(p_n^*/p_n\right) = \frac{d}{dv_{\max}^*}\frac{d}{dn}\ln\left(p_n^*\right)$$

The first part of the statement then follows by applying part (i) to prices in Foreign.

Similarly,

$$\frac{d}{dv_{\max}}\frac{d}{dn}\ln\left(p_n^*/p_n\right) = -\frac{d}{dv_{\max}}\ln\left(p_n\right)$$

which proves the statement. ■

Proof of Proposition 3. Part (i). First, we rewrite prices (7) conveniently as

$$p_n = \left[\frac{A\left(\lambda/\gamma^\theta\right)^n}{\alpha^*\varphi^* q_0^\theta} + 1\right]\alpha^*\varphi^* q_n^\theta$$

with A and α^* from Eqs. (8) and (10). Observing next that $\frac{d(\alpha^*\varphi^*)}{dn} = \frac{dq_n^\theta}{d\varphi^*} = 0$ yields

$$\frac{d}{dn}\frac{d}{d\varphi^*}\ln(p_n) = \frac{d}{dn}\frac{d}{d\varphi^*}\ln\left[\frac{A(\lambda/\gamma^\theta)^n}{\alpha^*\varphi^* q_0^\theta}+1\right]$$

Setting $g(\varphi^*) = A/(\alpha^*\varphi^* q_0^\theta)$ and $h(n) = (\lambda/\gamma^\theta)^n$, we compute

$$\frac{d}{dn}\frac{d}{d\varphi^*}\ln[g(\varphi^*)h(n)+1] = \frac{g'h'}{[gh+1]^2}$$

In order to prove Eq. (14), it thus suffices to show that

$$\frac{dg}{d\varphi^*} < 0$$

holds, because $h' > 0$ (by $\lambda > \gamma^\theta$) and $gh + 1 > 0$. To show this inequality, we distinguish two different cases.

Case I. $n = 0$ in Home. In this case, the function g becomes with Eqs. (7)–(10)

$$g(\varphi^*) = \frac{\lambda}{2\lambda-1}\frac{-\alpha^*\frac{\varphi^*}{\varphi}\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1}+\frac{\gamma-1}{\gamma}\frac{q_0 v_{\max}}{c_0}}{\alpha^*\varphi^*}\varphi$$

Taking derivatives, we compute

$$\frac{dg}{d\varphi^*} = \frac{\lambda}{2\lambda-1}\frac{\gamma-1}{\gamma}\frac{q_0 v_{\max}}{c_0}\left[-\frac{1}{(\alpha^*\varphi^*)^2}\frac{d(\alpha^*\varphi^*)}{d\varphi^*}\right]\varphi$$

Since the derivative

$$\frac{d(\alpha^*\varphi^*)}{d\varphi^*} = \frac{2\tau}{4-\left(\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\right)^2} \tag{24}$$

is positive, we obtain that the claim holds for $n = 0$ in Home.

Case II. $n = 0$ in Foreign. In this case, we rewrite

$$g(\varphi^*) = \frac{\lambda}{2\lambda-1}\frac{-\alpha\varphi\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1}+\frac{\gamma-1}{\gamma}\frac{q_0 v_{\max}}{q_0^\theta}}{\alpha^*\varphi^*}$$

Taking derivatives, we compute

$$\left[\frac{\lambda}{2\lambda-1}\right]^{-1}\frac{dg}{d\varphi^*} = -\frac{\varphi\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1}}{\alpha^*\varphi^*}\frac{d\alpha}{d\varphi^*} - \frac{-\alpha\varphi\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1}+\frac{\gamma-1}{\gamma}\frac{q_0 v_{\max}}{q_0^\theta}}{(\alpha^*\varphi^*)^2}\frac{d(\alpha^*\varphi^*)}{d\varphi^*}$$

With (24) and with

$$\frac{d\alpha}{d\varphi^*} = \frac{\tau\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\frac{1}{\varphi}}{4-\left(\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\right)^2}$$

this is

$$\begin{aligned}\left[\frac{\lambda}{2\lambda-1}\right]^{-1}\frac{dg}{d\varphi^*} &= \frac{1}{4-\left(\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\right)^2}\left[\frac{\varphi\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1}}{\alpha^*\varphi^*}\tau\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\frac{1}{\varphi}\right.\\ &\quad\left.-\frac{-\alpha\varphi\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1}+\frac{\gamma-1}{\gamma}\frac{q_0 v_{\max}}{q_0^\theta}}{(\alpha^*\varphi^*)^2}2\tau\right]\\ &= \frac{\tau(\alpha^*\varphi^*)^{-1}}{4-\left(\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\right)^2}\left[\frac{(\gamma^\theta-\gamma^{-\theta})(\gamma^\theta+\gamma^{1-\theta})}{(\gamma+1)^2}\right.\\ &\quad\left.+2\frac{\alpha\varphi\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1}-\frac{\gamma-1}{\gamma}\frac{q_0 v_{\max}}{q_0^\theta}}{\alpha^*\varphi^*}\right]\end{aligned}$$

The sign of that term is negative if and only if

$$\frac{\gamma-1}{\gamma}\frac{q_0 v_{\max}}{q_0^\theta} > \left(\alpha\varphi - \frac{1}{2}\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\alpha^*\varphi^*\right)\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1}$$

With Eq. (8), the term on the left is

$$\begin{aligned}\ldots &= \left(2\varphi+\tau\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\varphi^* - \frac{1}{2}\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\left(2\tau\varphi^*+\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\varphi\right)\right)\\ &\quad\times\frac{\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1}}{4-\left(\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\right)^2}\\ &= \left(2\varphi-\frac{1}{2}\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\varphi\right)\frac{\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1}}{4-\left(\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\right)^2}\\ &= \frac{\varphi}{2}\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1}\end{aligned}$$

which proves the claim.

Part (ii). First, we rewrite prices (7) conveniently as

$$p_n^* = \left[\frac{\tilde{A}(\lambda/\gamma^\theta)^n}{\tilde{\alpha}^*\varphi^* q_0^\theta}+1\right]\tilde{\alpha}^*\varphi^* q_n^\theta$$

where, using the symmetry between Home and Foreign, the following expressions apply

$$\tilde{A} = \begin{cases}\frac{\lambda}{2\lambda-1}\left(-\tilde{\alpha}\frac{\varphi}{\varphi^*}\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1}+\frac{\gamma-1}{\gamma}\frac{q_0 v_{\max}^*}{c_0^*}\right)c_0^* & n=0 \text{ in Foreign}\\ \frac{\lambda}{2\lambda-1}\left(-\tilde{\alpha}^*\frac{\varphi^*}{\varphi}\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1}+\frac{\gamma-1}{\gamma}\frac{q_0 v_{\max}^*}{c_0}\right)c_0 & n=0 \text{ in Home}\end{cases}$$

and

$$\tilde{\alpha}^* = \frac{2+\tau\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\frac{\varphi}{\varphi^*}}{4-\left(\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\right)^2} \qquad \tilde{\alpha} = \frac{2\tau+\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\frac{\varphi^*}{\varphi}}{4-\left(\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\right)^2} \tag{25}$$

As the above, observing that $\frac{d(\tilde{\alpha}^*\varphi^*)}{dn} = \frac{dh(n)}{d\varphi} = 0$ yields

$$\frac{d}{dn}\frac{d}{d\varphi}\ln(p_n^*) = \frac{d}{dn}\frac{d}{d\varphi}\ln\left[\frac{\tilde{A}(\lambda/\gamma^\theta)^n}{\tilde{\alpha}^*\varphi^* q_0^\theta}+1\right]$$

Setting $\tilde{g}(\varphi) = \tilde{\Lambda}/(\tilde{\alpha}^*\varphi^* q_0^\theta)$ and $h(n) = (\lambda/\gamma^\theta)^n$, we compute

$$\frac{d}{dn}\frac{d}{d\varphi}\ln\left[\tilde{g}(\varphi)h(n)+1\right] = \frac{\tilde{g}'h'}{\left[\tilde{g}h+1\right]^2}$$

In order to prove Eq. (16), it thus suffices to show that

$$\frac{d\tilde{g}}{d\varphi} < 0$$

holds, because $h' > 0$ (by $\lambda > \gamma^\theta$) and $\tilde{g}h + 1 > 0$. Again, we distinguish two different cases.

Case I. $n = 0$ in Home. In this case, the function $\tilde{g}$ is

$$\tilde{g}(\varphi) = \frac{\lambda}{2\lambda-1}\frac{-\tilde{\alpha}^*\varphi^*\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1} + \frac{\gamma-1}{\gamma}\frac{q_0 v^*_{\max}}{q_0^\theta}}{\tilde{\alpha}^*\varphi^*}$$

Taking derivatives, we compute

$$\frac{d\tilde{g}}{d\varphi} = \frac{\lambda}{2\lambda-1}\frac{\gamma-1}{\gamma}\frac{q_0 v^*_{\max}}{\varphi^* q_0^\theta}\frac{-1}{(\tilde{\alpha}^*)^2}\frac{d\tilde{\alpha}^*}{d\varphi}$$

and obtain the claim for $n = 0$ in Home, since

$$\frac{d\tilde{\alpha}^*}{d\varphi} = \frac{\tau\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\frac{1}{\varphi^*}}{4-\left(\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\right)^2} > 0 \tag{26}$$

Case II. $n = 0$ in Foreign. In this case, we have

$$\tilde{g}(\varphi) = \frac{\lambda}{2\lambda-1}\frac{-\tilde{\alpha}\frac{\varphi}{\varphi^*}\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1} + \frac{\gamma-1}{\gamma}\frac{q_0 v^*_{\max}}{c_0^*}}{\tilde{\alpha}^*}$$

Taking derivatives, we compute

$$\begin{aligned}\left[\frac{2\lambda-1}{\lambda}\right]^{-1}\frac{d\tilde{g}}{d\varphi} &= \frac{-\frac{1}{\varphi^*}\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1}}{\tilde{\alpha}^*}\frac{d(\tilde{\alpha}\varphi)}{d\varphi} - \frac{-\tilde{\alpha}\varphi\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1} + \frac{\gamma-1}{\gamma}\frac{q_0 v^*_{\max}}{q_0^\theta}}{(\tilde{\alpha}^*)^2\varphi^*}\frac{d\tilde{\alpha}^*}{d\varphi} \\ &= \left[-\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1}\frac{d(\tilde{\alpha}\varphi)}{d\varphi} - \frac{-\tilde{\alpha}\varphi\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1} + \frac{\gamma-1}{\gamma}\frac{q_0 v^*_{\max}}{q_0^\theta}}{\tilde{\alpha}^*}\frac{d\tilde{\alpha}^*}{d\varphi}\right] \\ &\quad\times\frac{1}{\tilde{\alpha}^*\varphi^*}\end{aligned}$$

By Eq. (26) and

$$\frac{d(\tilde{\alpha}\varphi)}{d\varphi} = \frac{2\tau}{4-\left(\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\right)^2}$$

we get

$$\begin{aligned}\left[\frac{2\lambda-1}{\lambda}\right]^{-1}\frac{d\tilde{g}}{d\varphi} &= \frac{\frac{\tau}{\tilde{\alpha}^*\varphi^*}\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}}{4-\left(\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\right)^2}\left[-2\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma^\theta+\gamma^{1-\theta}}\right. \\ &\quad\left.-\frac{-\tilde{\alpha}\varphi\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1} + \frac{\gamma-1}{\gamma}\frac{q_0 v^*_{\max}}{q_0^\theta}}{\tilde{\alpha}^*\varphi^*}\right]\end{aligned}$$

The expression in square brackets is negative if and only if the inequality

$$\frac{\gamma-1}{\gamma}\frac{q_0 v^*_{\max}}{q_0^\theta} > \tilde{\alpha}\varphi\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma+1} - 2\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma^\theta+\gamma^{1-\theta}}\tilde{\alpha}^*\varphi^* \tag{27}$$

holds. The expression on the right hand side of the inequality can be rewritten with Eq. (25)

$$\begin{aligned}\ldots &= \frac{\gamma^\theta-\gamma^{-\theta}}{4-\left(\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\right)^2}\left(\left(2\tau\varphi + \frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\varphi^*\right)\frac{1}{\gamma+1}\right. \\ &\quad\left.-\frac{2}{\gamma^\theta+\gamma^{1-\theta}}\left(2\varphi^* + \tau\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\varphi\right)\right) \\ &= \frac{\gamma^\theta-\gamma^{-\theta}}{4-\left(\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\right)^2}\left(\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\frac{\varphi^*}{\gamma+1} - \frac{4\varphi^*}{\gamma^\theta+\gamma^{1-\theta}}\right) \\ &= \frac{\gamma^\theta-\gamma^{-\theta}}{4-\left(\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\right)^2}\frac{1}{\gamma^\theta+\gamma^{1-\theta}}\varphi^*\left(\left(\frac{\gamma^\theta+\gamma^{1-\theta}}{\gamma+1}\right)^2-4\right) \\ &= -\frac{\gamma^\theta-\gamma^{-\theta}}{\gamma^\theta+\gamma^{1-\theta}}\varphi^*\end{aligned}$$

So that condition (27) is trivially satisfied. ■

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jinteco.2017.11.003.

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