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2008-6

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ISSN 1660-7716 (printed version)
ISSN 1660-7724 (online version)

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15 May 2008

Abstract

This paper builds up an extension to the Mussa and Rosen (1978) model of quality pricing under perfect competition. Our model incorporates decreasing returns to scale. First, we predict that exchange rate shocks are imperfectly passed through into prices. Second, prices of low quality goods are more sensitive to exchange rate shocks than prices of high quality goods. Third, in response to an exchange rate appreciation, the composition of exports shifts towards higher quality and more expensive goods. We test those predictions using highly disaggregated price and quantity US import data. We find that the prices of high quality goods, proxied as high unit price goods, are more sensitive to exchange rate movements. Moreover, we find evidence that in response to an exchange rate appreciation, the composition of exports shifts towards high unit price goods.

*Contact: Email: raphael.auer@snb.ch, tchaney@uchicago.edu. We are indebted to Daron Acemoglu, Philippe Bacchetta, Rich Clarida, Giancarlo Corsetti, Ron Findlay, Xavier Gabaix, Jim Harrigan, Guido Lorenzoni, Eric Verhoogen, David Weinstein, an anonymous referee, and seminar participants at Columbia University, Dartmouth College, the European University Instititute in Florence, Gerzensee, UBC Vancouver and UT Austin for helpful comments and discussions. We are grateful to Ferdinando Monte for his invaluable research assistance. The views expressed in this paper do not represent those of the Swiss National Bank.

This paper builds up an extension to the Mussa and Rosen (1978) model of quality pricing under perfect competition. Our model incorporates decreasing returns to scale. First, we predict that real exchange rate shocks are imperfectly passed through into prices. Second, prices of low quality goods are more sensitive to exchange rate shocks than prices of high quality goods. Third, in response to an exchange rate appreciation, the composition of exports shifts towards higher quality and more expensive goods. We test those predictions using highly disaggregated price and quantity US import data. We find that the prices of high quality goods, proxied as high unit price goods, are more sensitive to exchange rate movements. Moreover, we find evidence that in response to an exchange rate appreciation, the composition of exports shifts towards high unit price goods.

This paper develops a model of international trade under perfect competition and flexible prices that accounts for the slow and incomplete pass through of exchange rate fluctuations into consumer prices. We build an extension of the Mussa and Rosen (1978) model of quality pricing. Exporters sell goods of different quality to consumers with heterogeneous preferences for quality. In equilibrium, higher quality goods are more expensive. We derive three testable predictions. First, exchange rate fluctuations are only partially passed through to consumers. Second, there is more pass through in the long run than in the short run, and more pass through for aggregate prices than for individual prices. Third, there is more pass through for low quality goods than for high quality goods. When the exchange rate of an exporting country appreciates, existing exporters scale down their production, hence driving prices up. At the same time, when exporters scale down their production their marginal cost of production decreases, and the short run equilibrium thus display positive, yet impartial pass through. In the long run, low quality exporters pull out, driving prices up even further. Since those goods are inexpensive, aggregate prices go up more than individual prices. This exit of low quality exporters has a larger impact on the price of low quality goods than on the price of high quality goods. Low quality goods prices adjust more than high quality goods prices.

We augment a competitive version of the Mussa and Rosen (1978) model with a distribution sector. In our framework, exporters pay a fixed market access cost to build a local distribution network. Some inputs to distribution are fixed in the short run, leading to decreasing returns to scale at the local level, and thus pricing to market. We analyze why cost pass through is incomplete and quality dependent. First, exchange rate fluctuations are only partially passed through to consumers because the response of each firm's output and the number of exporters counteract cost changes. Second, when the cost of production increases, the composition of exporters shifts towards more expensive goods. Thus, aggregate prices overstate good specific pass through. Third, low quality goods react stronger to cost changes than high quality goods.

We test these predictions using highly disaggregated price and quantity US import data. We find that the prices of high quality goods, proxied as high unit price goods, are more sensitive to exchange rate movements. Moreover, we find evidence that in response to an exchange rate appreciation, the composition of exports shifts towards high unit price goods.

1 Introduction

Why are movements of relative costs brought about by exchange rate fluctuations passed through to consumers partially and only gradually? We introduce quality pricing and decreasing returns to scale in a model of international trade under perfect competition and flexible prices. Our model generates three testable predictions. First, exchange rate fluctuations are only partially passed through to consumers. Second, there is more pass through for low quality goods than for high quality goods. Third, in response to an exchange rate appreciation, exports shift towards higher quality prices.

We consider a purely real model of international price setting. Exchange rate shocks are assumed to be real productivity shocks, so that there is no price stickiness, hence no money illusion, and no role for monetary policy. We develop an extension of the Mussa and Rosen (1978) model of quality pricing. We depart from their model in two important dimensions. First, we consider a perfectly competitive setting, as opposed to the original monopoly setting. Second, we introduce decreasing returns to scale at the firm level. This allows for a feedback of exchange rate shocks into both prices and quantities, which is at the heart of our model. Firms offer goods of different qualities. These goods are matched with consumers with heterogeneous preferences for quality. In equilibrium, higher quality goods are matched with higher valuation consumers. The price schedule for goods with different qualities depends on the consumers that buy those goods. Prices are higher when the valuations of consumers in the market are higher. We derive three predictions for the pass through of exchange rate shocks, where we define exchange rate shocks as real productivity shocks.

First, exchange rate shocks are only partially passed through to consumers. When an exporting country is hit by a real negative exchange rate shock, say an appreciation of its exchange rate vis à vis its trading partners, exporting firms scale down their exports. The relative scarcity of goods forces the lowest valuation consumers out of the market. As a consequence, exporters are matched with higher valuation consumers, which drives the export prices up. Part of the exchange rate shock is passed through to consumers.

Second, we predict that there is more pass through for low quality goods than for high quality goods. This prediction relies on a subtle argument. After a negative exchange rate shock, there are two forces driving all prices up. First, the exit of low quality firms shrinks the total supply of goods, forces the lowest valuation consumers out of the market. The average valuation of the remaining consumers increases, and all prices increase. Second, all firms scale down their production, which also shrinks the total supply of goods and pushes all prices up. The relative strength of this second effect is larger for higher quality goods. For the lowest quality goods actually exported, the first effect is the main source of price increase. The lowest quality exporting firm exactly breaks even, so that its price is exactly equal to its cost. Following an appreciation of the exchange rate, which amounts to a negative productivity shock for exporters, low quality firms exit until the last firm exactly breaks even. So for the lowest quality goods, prices move almost one for one with the exchange rate.[1] The price of higher quality goods on the other hand depends on the overall tightness of the market, which determines which consumer they are matched with. In the limit, infinitely high quality goods prices are, in relative terms, not at all affected by the exit of low quality firms. Their price increases only because all firms scale down their production. The pass through of exchange rate shocks is higher for low quality goods than for high quality goods.

Third, we predict that in response to an exchange rate appreciation, the composition of exports shifts towards high quality-high price goods. This predictions is due to the endogenous selection of exporters, and to the composition effect of goods with different prices. In the presence of fixed entry cost into foreign markets, only the highest quality firms are able to export. When hit by a negative exchange rate shock, the lowest quality firms pull out of the export market. These firms happen to be those firms that charge the lowest price. The exit of low quality low price exporters has two effects, on individual prices, and on aggregate prices. First, the exit of low quality exporters shrinks the total supply of goods, driving out low valuation consumers.

[1] Note that the price of the lowest quality good actually exported moves exactly one for one with the exchange rate. However, because some firms exit, the lowest quality good is no longer the same after an exchange rate appreciation. The good that becomes the lowest quality good exported after the exchange rate appreciation was strictly above the lowest quality before the exchange rate shock. Therefore, its price increases less than one for one with the exchange rate. To simplify, this is the basic intuition for the *incomplete* pass through of exchange rate.

The remaining firms are matched with higher valuation consumers, so that each individual price increases further. Second, since only the low quality low price exporters pull out, the composition of exports shifts towards high price goods.

Campa and Goldberg (2006) give an up to date review of the evidence on incomplete pass through. Even though there is almost full pass through of exchange rate shocks for prices at the dock, there is much more limited pass through for consumer prices. The order or magnitude is 40% in the short run to 60% in the long run. The empirical literature has stressed the importance of distribution margins in explaining this fact. Burstein, Neves and Rebelo (2003), Burstein, Eichenbaum and Rebelo (2005), and Campa and Goldberg (2006) argue that non tradable inputs such as distribution costs play a key role. Burstein et al. (2003) note that for a typical consumption good in the US, distribution margins account for more than 40% of the final price. Finally, and most related to our model, Campa and Goldberg (2006) note that distribution margins do not remain stable during real exchange rate fluctuations. A 1% real exchange rate depreciation leads to a .47% reduction in distribution margins. This response of local distribution margins to the exchange rate has also been documented for the case of the beer industry by Hellerstein (2005).

To capture these facts, we introduce a two tiered production function similar to Bacchetta and van Wincoop (2003). Exporters must not only ship goods, but also assemble and distribute them locally. We assume that the distribution capacity is fixed, so that supply to any foreign market is subject to decreasing returns to scale. This gives rise to incomplete pass through of exchange rate shocks, despite full pass through at the dock, and to fluctuations in the distribution margin in response to exchange rate movements. One important point is that in our model, distribution costs are paid in exporters' currency, not in local currency. We make this assumption to stress the fact that distribution costs matter, even if no part of this cost is paid in importer currency. If part of the distribution costs were paid in local currency, our results would be reinforced.

We point out the potential importance of composition effects in estimating exchange rate pass through. Burstein, Eichenbaum and Rebelo (2005) suggest one specific composition effect, flight from quality. They point out that following a large devaluation, consumers stop buying high quality goods. Our predictions regarding this flight from quality are ambiguous. Indeed, following a devaluation, we predict that overall, since fewer quality goods are imported, many consumers switch from quality goods to generic goods. However, the consumers that still buy quality differentiated goods will typically buy higher quality goods, at a higher price. Note that we do not consider the impact of exchange rate fluctuations on disposable income, so that consumers in our model are never prevented from buying quality goods because of their budget constraint. This is an important limitation of our model, but it makes the analysis much simpler. We believe that this model describes normal exchange rate movements well enough, but may miss what happens during very large fluctuations such as large devaluations.

There is only scarce evidence of the relative pass through of exchange rate shocks for goods of different quality. Gagnon and Knetter (1995) study the exchange rate pass through for car exports from three main automobiles exporters. This remains however an understudied area. Despite a growing literature on measuring the quality of exports, there is to our knowledge little evidence on the degree of exchange rate pass through for exports of different quality.

In addition to examining the quality dimension of cost pass-through, we also highlight that incomplete pass-through can arise under perfect competition and flexible prices. The existing theoretical literature on exchange rate pass through and pricing to market has so far relied on two alternative assumptions: either price stickiness, or imperfect competition.

For example, Betts and Devreux (1996), Taylor (2001), or Bacchetta and van Wincoop (2003) show why pass through is incomplete and staggered when prices are sticky. Undoubtedly, sticky prices matter for limited pass through. Gopinath and Rigobon (2007) document that even though exchange rates fluctuate daily, prices at the dock adjust only rarely. However, the set of firms that adjust prices in a given period passes through exchange rate changes only with a rate of less than a fourth. While menu costs[2] can explain why actual prices are changed infrequently, they can not directly explain why the optimal price responds very little when costs change. Our paper rationalizes the latter aspect.

Our paper is related to the second strand of literature arguing that response of the optimal price to the exchange rate is low. The seminal papers of Krugman (1987) and Dornbusch (1987) have been followed by more elaborate models, such as Yang (1997), Corsetti, Dedola and Leduc (2005) or Atkeson and Burstein (2006). These models rely on the fact that when firms adjust their prices, they move along the demand curve and face a different demand elasticity. Under some conditions on the shape of the demand curve, exporters will adjust their markups and dampen price fluctuations, leading to pricing to market and incomplete pass through of exchange rate

[2]Kleshchelski and Vincent (2007) argue that firms and customers form long-term relationships because consumers incur costs to switch sellers. Therefore, firms may decide to keep prices perfectly stable also in the absence of menu costs.

shocks.

We depart from this assumption by assuming perfect competition, and our framework is thus more applicable in industries with a large set of competitors. In the abovementioned literature, as the number of firms competing in a sector increases, the pricing to market predictions quickly become negligible. Moving directly to a competitive setting provides more robust predictions. An alternative branch of the literature such as Melitz and Ottaviano (2005), Gust, Leduc and Vifgusson (2006) and Chen, Imbs and Scott (2006) directly assumes that prices are complement in the utility function. We propose another explanation where the matching of firms and consumers generates this complementarity in equilibrium.

Finally, our model delivers predictions for the composition effect of prices that are in stark contrast with the existing trade literature with heterogeneity in productivity. In models with heterogeneous firms following to Hopenhayn (1992) and Melitz (2003), the most productive firms charge the lowest price. When hit by a negative productivity shock, the low productivity high price firms exit. In our model, the highest quality goods are sold at the highest price, and the composition effect of endogenous entry and exit goes in the opposite direction.[3]

The remaining of the paper is organized as follows. In section 2, we present the general set up of our model of quality pricing. In section 3, we analyze a specific example and provide closed form solutions. In section 4, we derive the predictions of our model for exchange rate pass through. Section 5 presents empirical evidence in support of our theoretical model. Section 6 concludes.

2 Model

In this section, we develop a model of quality pricing and international trade.

There are two countries, home and foreign. The two countries are respectively populated by a mass L_H and L_F of consumers that share the same preferences. There are two sectors, $\mathcal{A}$ and Q. The $\mathcal{A}$ sector produces a homogeneous good, which may be freely traded. We will only consider equilibria where all consumers in each country consume some of this numeraire good. We can therefore normalize the price of this good to unity in each country. The Q sector produces a continuum of goods that differ in terms of quality. For simplicity, we assume that Q goods are differentiated by country of origin.

[3] It should be noted that once endogenous entry of new firms into the domestic market is allowed, as in Ghironi and Melitz (2005), a positive productivity shock may lead to an *appreciation* of the terms of trade. Since we do not consider the endogenous entry into the domestic market, we cannot directly compare our predictions to those.

There is a continuum of competitive firms producing each type of good. Firms in the Q sector are heterogeneous in terms of the quality of the good they produce. They face an decreasing returns to scale technology due to the presence of fixed a fixed distribution capacity. In addition, in order to enter the foreign market, they must pay a fixed entry cost. There is a continuum of (heterogeneous) consumers buying those goods. The consumers are price taker.

The timing is the following. First, firms receive their quality draw. Second, they decide whether or not to enter each market, home and foreign. Third, given the prices that they expect, they decide how much output to produce. Finally, prices are determined so as to clear all markets. The strategies of firms and consumers are the following. Firms maximize expected profits, given their expectation for prices. Consumers maximize their utility, given the set of goods available and the prices they observe.

Preferences

Consumers can consume a continuum of $\mathcal{A}$ goods. For the consumption of Q goods, we consider a discrete choice model. Consumers can consume either zero or one unit of domestic Q good, and either zero or one unit of foreign Q good. Different Q goods have different quality, and different consumers have different valuation for quality. A consumer with valuation v for quality, who consumes one unit of home good with quality q_H and one unit of foreign good with quality q_F, and A units of the homogenous good, derives a utility,

$$U_v(q_H, q_F, A) = v(q_H + q_F) + A \tag{1}$$

For simplicity, if a consumer does not consume one of the Q goods, we set its quality to zero.

Valuations for quality, v, are distributed over all consumers according to,

$$v \sim F_v(v) \tag{2}$$

where F_v is the cumulative distribution of the v's, and $f_v(v)$ the density. Valuations are distributed over the interval $[\bar{v}, v^{\max}]$.[4] We assume that there is a strictly positive density over the entire domain: $f_v(v) > 0$ for $v \in [\bar{v}, v_{\max}]$. We also assume that the distribution of income is such that consumers can always afford to buy one unit of Q good.[5]

[4] We allow for $v^{\max} = +\infty$. In our closed form example in section 3, we consider unbounded from above supports for the distribution of valuation draws.

[5] Implicitly, we assume that high valuation consumers also have a high income, so that they can afford the high price for the Q good they will buy in equilibrium.

The main property of these preferences is that valuation and quality are complementary: the higher a consumer's valuation, the more she values quality, and the more she will be willing to pay for quality. This property allows us to derive two important results. First, there is assortative matching between consumers and goods, that is higher valuation consumers will buy higher quality goods. Second, the pace at which prices increase with quality is exactly determined by the valuation of consumers. We state and prove formally these two results in the following two propositions.

Proposition 1 (assortative matching) *If an equilibrium exists, consumers' valuations and goods' quality are matched assortatively:*

$$v_1 > v_2 \Rightarrow q_1 \geq q_2$$

where consumer $i = 1, 2$ with valuation v_i is matched with a good of quality q_i.

Proof. *See appendix A, page 9.* ■

Given the complementarity between quality and valuation built into the preferences, assortative matching is a very intuitive result. High valuation consumer gain benefit more from quality. It would not be optimal to allocate high quality goods to low valuation consumers, and hence any market equilibrium must allocate higher quality goods to higher valuation consumers.

A direct corollary of this assortative matching is that, locally, relative prices are pinned down by a no arbitrage condition on the consumer side. Higher quality goods are more expensive. Moreover, prices increase with quality exactly according to the valuation of the consumers. The following proposition states this result formally.

Proposition 2 *If an equilibrium exists, the mapping from goods quality to prices is continuously differentiable. The prices are determined locally by the valuation of consumers in the following way,*

$$p'(q) = v(q)$$

where $v(q)$ is the valuation of the consumer matched with a good of quality q, $p(q)$ is the price of this good, and $p'(q)$ is the derivative of this price schedule.

Proof. *See appendix A, page 26.* ■

It is straightforward to see from the previous two propositions that prices are increasing and convex in quality. This property of prices is reminiscent of the Mussa and Rosen (1978) model of quality pricing. Whether goods are supplied by a monopolist, as in Mussa and Rosen (1978), by oligopolists as in Champsaur and Rochet (1989), or by atomistic price taking firms as in this model, prices must increase at an accelerating pace in order to prevent high valuation consumers from buying low quality goods.

In the next section, we describe the production technology, and the behavior of firms.

Production

Production in the $\mathcal{A}$ sector is made under constant returns to scale. The labor productivity at home (abroad) is Z_H (Z_F). We will only consider equilibria in which both countries produce the $\mathcal{A}$ good. Labor can freely move between sectors. So the wage w_H (w_F) of domestic (foreign) workers, in units of the $\mathcal{A}$ numeraire good, is simply equal to Z_H (Z_F).

Goods' quality: In the Q sector, there is a continuum of mass M_H (M_F) of firms in the home (foreign) country. Each of these firms produces a good of a specific quality. Firms randomly draw a quality shock from a stochastic distribution given by,

$$q \sim F_q(q) \tag{3}$$

where F_q is the cumulative distribution of the q's, and f_q the density. Qualities are distributed over the interval $[\bar{q}, q_{\max}]$.[6]

Technology: Despite their differences in quality, all firms face the same technology for producing Q goods. They are subject to decreasing returns to scale. The cost for supplying S units of Q goods is given by $w_H C(S)$, with $C(\cdot)$ increasing and convex. We denote the marginal cost of supplying the S^{th} unit of good by $w_H c(S) = w_H C'(S)$, $c'(S) > 0$. For simplicity, we assume that firms produce goods for the domestic market independently from goods for the export market. The cost function applies to each type of production separately. This allows us to study sequentially the domestic production decision and the foreign production decision. The rationale for this assumption is that upon entering a market, a firm acquires a fixed distribution capacity.

Trade barriers: In order to export abroad, domestic firms must overcome both a variable cost for shipping each unit of good abroad, and a fixed cost of entering the foreign market. Those costs are symmetric. The variable cost takes the traditional form of iceberg transportation costs,

[6] As for valuations, we allow for unbounded supports for the distributino of quality shocks.

with fraction $(\tau - 1)$ of all shipments melting on the way $(\tau > 1)$. The fixed cost of entry is equal to $\tau w_H f^E$, which is paid in units of the $\mathcal{A}$ numeraire good.

We now consider the decision of a domestic firm that decides to export abroad. Leaving aside for the moment the question of whether or not it is profitable to pay the fixed entry cost, we characterize the quantity an exporter would supply abroad. Firms are price taker, so they decide to increase their supply of goods until their marginal cost equals the price of their good. In equilibrium, a firm that expects a price p for its good supplies $S(p)$ units abroad, with $S(p)$ defined by, $\tau w_H c(S(p)) = p$. We can rewrite this optimality condition as,

$$S(p) = c^{-1}\left(\frac{p}{\tau w_H}\right) \tag{4}$$

where c^{-1} is the inverse of the cost function. Note that the marginal cost of selling the S^{th} unit of good abroad is the marginal cost of production multiplied by τ. To sell one unit abroad, a firm must export τ units, each at a cost $w_H c(S)$. The marginal cost is strictly increasing in the quantity supplied, so that the quantity supplied S is strictly increasing in the price p. All firms follow the same strategy and supply a quantity which depends of the price they expect to receive for their quality.

Entry decision: Firms must decide whether or not to pay the fixed entry cost into the foreign market. They compare the profits they would earn from exporting to the fixed entry cost. Only those firms whose gross profits are above the entry cost export. There is minimum price $p_{\min}$ below which it is not profitable to export. The minimum price is given by the following zero profit cutoff condition,

$$p_{\min} S(p_{\min}) - \int_0^{S(p_{\min})} \tau w_H c(s)\, ds - \tau w_H f^E = 0 \tag{5}$$

It states that the net profit from exporting if the price abroad is $p_{\min}$ is exactly zero. Since $c(\cdot)$ and $S(\cdot)$ are strictly increasing, $p_{\min}$ is uniquely determined by Eq. (5).

Note that for the moment, we know the price of the lowest quality exported, but we still have not determined the actual level of the lowest quality exported. It is determined in equilibrium, which we define in the next section.

Equilibrium

An equilibrium consists of a price schedule such that the goods market clears if consumers optimally chose which good to consume, if any, and if firms optimally chose how much to produce and whether or not to enter the foreign market. We will construct the equilibrium in the following way. First, we match goods to consumers. Given this matching, we define the price schedule matching quality to price, up to a constant. We then identify the quality of the good matched with the lowest valuation consumer.

First, note that there are potentially three possible types of equilibrium: a sellers' market where there are more consumers than goods, a buyers' market where there are more goods than consumers, or a third case where neither all exporting firms sell their good, nor all consumers buy a Q good. We will consider the case of a sellers market, where all exporting firms sell their goods, but not all consumers buy a Q good.

We can rewrite the matching implied by proposition 1 and define formally the matching between quality and consumers. A good of quality q will be matched to a consumer with quality $v(q)$, according to,

$$N_H \int_q^{q_{\max}} S(p(\chi)) f_q(\chi) \, d\chi = L_F \int_{v(q)}^{q_{\max}} f_v(v) \, dv \tag{6}$$

for any $q \in [q_{\min}, q_{\max}]$, where $q_{\min}$ is the lowest quality exported, and $S(p(\chi))$ is the quantity of good supplied by a firm with quality χ. The left hand side is the number of goods with quality q and above, whereas the right hand side is the number of consumers with valuation $v(q)$ and above. For any level of quality q, these two must be equal.

Given the matching between goods and consumers, we can derive prices from proposition 6. Integrating prices over quality, we get the price the price $p(q)$ of a good of quality q,

$$p(q) = \int_{q_{\min}}^{q} v(\chi) \, d\chi + p_{\min} \tag{7}$$

for any $q \in [q_{\min}, q_{\max}]$, where $v(\chi)$ is the valuation of the consumer matched with quality χ given in Eq. (6), and $p_{\min}$ is the price of the lowest quality exported, given by the zero cutoff profit condition (5).

We now have to determine the quality of the good matched with the lowest valuation consumer. Since we are in a sellers' market, some consumers will not buy any Q goods. The last consumer must be indifferent between buying and not buying good $q_{\min}$, or in other words, she must be indifferent between buying $q_{\min}$ or buying $\mathcal{A}$ goods instead. The lowest quality exported $q_{\min}$ is defined by,

$$v(q_{\min}) \, q_{\min} = p_{\min} \tag{8}$$

where $v(q_{\min})$ is the valuation of the consumer matched with quality $q_{\min}$ given in Eq. (6), and $p_{\min}$ is the price of the lowest quality exported, given by the zero cutoff profit condition (5).

An equilibrium price schedule will be solution to the zero cutoff profit condition (5), the matching equation (6), the pricing equation (7), and to equation (8) defining the lowest quality exported. The following proposition states the existence of such an equilibrium.

Proposition 3 *There exists a* $(p(\cdot),\ v(\cdot),\ p_{\min},\ q_{\min})$ *solution to Eqs. (5), (6), (7) and (8), not necessarily unique.*

Proof. *See appendix A, page 27.* ■

In order to derive closed form solutions for the path of exchange rate pass through, we introduce a specific functional form for the distribution of valuation and quality draws. We present this example in the next section.

3 A closed form example

In order to analyze the properties of exchange rate pass through in our model, we consider a specific example. We are able to derive closed form solutions for the equilibrium and for all variable of interest in this case.

First, we assume that both valuation shocks and quality shocks are Pareto distributed. The distribution of both shocks are as follows,

$$\begin{cases} F_v(v) = 1 - \left(\frac{v}{\bar{v}}\right)^{-\lambda_v} \\ F_q(q) = 1 - \left(\frac{q}{\bar{q}}\right)^{-\lambda_q} \end{cases} \tag{9}$$

Next, we assume that the marginal cost function takes the following form,

$$c(S) = \tau w_H + \tau w_H S^{1/\eta} \tag{10}$$

Implicitly, we assume a two tiered production function. In order to sell one unit of Q good, a firm must first ship its good to the destination market, and then distribute those goods locally. We assume that firms have a fixed installed distribution capacity (that they acquired when they paid the fixed cost of entry), and that distribution is subject to decreasing returns to scale. The first term, τw_H, in the cost function in Eq. (10) corresponds to the cost of shipping one additional unit of good abroad. The second term, $\tau w_H S^{\eta}$, corresponds to the cost of assembly. Because of decreasing returns, the cost of assembling one additional unit of good increases with the total quantity supplied, S. This simple functional form for the marginal cost ensures that in equilibrium, the supply elasticity will be constant and equal to η for all firms.

Firms equalize their marginal cost to the price they face, so that we have the following expression for the supply of Q goods as a function of price,

$$S(p) = \left(\frac{p}{\tau w_H} - 1 \right)^{\eta} \tag{11}$$

We are now able to solve for the equilibrium price schedule, as the following proposition shows.

Proposition 4 *If the entry cost is such that* $f^E = \left(\frac{\lambda_q - \eta}{(1+\eta)(\lambda_q + \lambda_v)} \right)^{1+\eta}$, *then there exists a unique equilibrium price schedule, lowest quality exported, and lowest price, defined as,*

$$\begin{cases} p(q) = \gamma \left(\tau w_H\right)^{\eta/(\lambda_v+\eta)} q^{(\lambda_v+\lambda_q)/(\lambda_v+\eta)} + \tau w_H \\ q_{\min} = \gamma' \left(\tau w_H\right)^{\lambda_v/(\lambda_v+\lambda_q)} \\ p_{\min} = \left(\frac{\lambda_q+\lambda_v}{\lambda_q-\eta} \right) \tau w_H \end{cases}$$

with γ *and* γ' *some constants*[7]*.*

Proof. *See appendix A, page 29.* ∎

Asymptotically, the elasticity of the price with respect to quality converges to $\frac{\lambda_v+\lambda_q}{\lambda_v+\eta} > 1$. The more elastic the supply of goods by each individual exporter, that is the larger η, the less responsive are prices to changes in quality. If the technology of production is such that large changes in the quantity supplied are needed to generate some change in the marginal cost of production (η high), then firms with a higher quality will supply much larger quantities than firms with a lower quality. Instead of the price adjusting to make demand for and supply of quality meet, most of the adjustment will come through quantities. The price of higher quality goods will not be very high.

The other two key parameters that determine how prices are responsive to changes in quality are the measure of the fatness of the tails of the distributions of quality and valuation for quality, λ_q and λ_v. If the quality of firms is more homogenous (λ_q high), or if the valuation of consumers is more heterogeneous (λ_v small), prices will be more responsive to changes in quality. This is entirely driven by the sensitivity of either supply or demand to changes in prices. If firms are very homogenous, that is if most of the mass of firms is concentrated around the bottom of the

[7] $\gamma = \left(a^{\lambda_v} \frac{\lambda_v \bar{v}^{\lambda_v}}{\lambda_q \bar{q}^{\lambda_q}} \left(\frac{\lambda_v+\eta}{\lambda_v+\lambda_q} \right)^{\lambda_v} \frac{\lambda_q-\eta}{\lambda_q+\lambda_v} \frac{L_F}{N_H} \right)^{1/(\lambda_v+\eta)}$ and $\gamma' = \left(\frac{\lambda_v+\eta}{\lambda_q-\eta} \right)^{(\lambda_v+\eta)/(\lambda_v+\lambda_q)}$.

distribution, higher qualities are very scarce. The price of those higher qualities will therefore be high. By the same token, if the distribution of consumers' valuations is very dispersed, there are relatively many consumers that a high valuation for quality, and who are therefore willing to pay a high price for higher qualities. The price of higher quality goods will therefore be high.

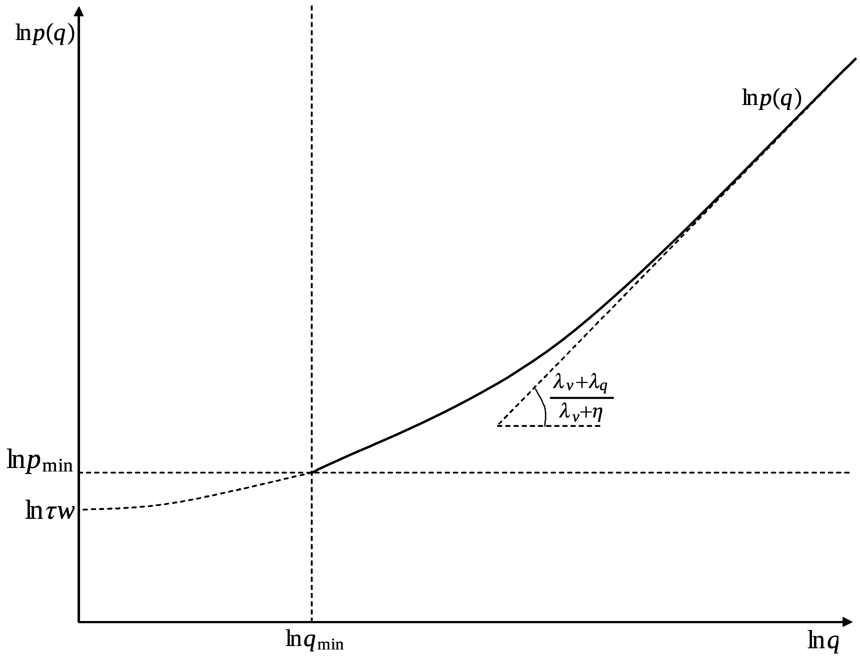

Figure 1: Equilibrium price-quality schedule.

The equilibrium price schedule is presented on Figure 1, which plots the log of quality versus the log of price. $\ln \tau w_H$ is the cost of shipping one unit of good abroad, absent of any assembly cost. Because of the existence of a fixed entry cost, firms must sell more than one unit of good in order to generate enough profit to recover this entry cost. There is a minimum quality, $q_{\min}$, that commands a minimum price $p_{\min}$, and this minimum price is strictly above $\ln \tau w_H$. Below that price, no firm is willing to export. So any firm with a quality below $q_{\min}$ will not export its good abroad. The equilibrium price schedule starts at $p_{\min}$ and is then increasing and convex, and it converges asymptotically to a log linear relationship.

Now that we have characterized the equilibrium price schedule, we can describe the impact of exchange rate shocks on prices.

4 Exchange rate pass through

In this section, we describe the impact of exchange rate shocks on prices. We first define exchange rate shocks as shocks to real wages arising from productivity shocks. We then characterize the response to those shocks on individual prices, on the composition of exporters, and on aggregate prices.

We define a shock to the exchange rate of the home country as a shock to the domestic wage in terms of the international numeraire $\mathcal{A}$ good. When the domestic productivity in the $\mathcal{A}$ sector Z_H increases, as long as some labor is employed in each sector, the domestic wages will have to increase proportionally with productivity. For firms in the Q sector, this amounts to a negative productivity shock: firms must pay their workers a higher wage, in units of the numeraire. In this section, we will therefore define an appreciation of the domestic exchange rate as an increase in the real wage w_H.

What is the response of export prices to such an exchange rate shock? There are two margins that will adjust to such an exchange rate shock. First, firms, facing a higher marginal cost, scale down their production and export smaller quantities abroad. This is the intensive margin of adjustment. Second, facing this higher cost, some low quality firms stop exporting altogether. This is the extensive margin of adjustment. Those two margins lead to an overall reduction of the total quantity of Q goods exported, so a relative scarcity of home Q goods abroad. Low valuation consumers are pushed out of the market and stop buying Q goods altogether. Overall, goods are matched with higher valuation consumers, so that prices increase. This is the source of exchange rate pass through into prices in our model. As fewer goods are exported, prices increase. Because some low quality firms exit the export market, and because supply responds to changes in marginal cost with some finite elasticity, the pass through is incomplete.

The response of prices to an exchange rate shock is depicted on Figure 2, which plots the log of quality versus the log of price for two levels of the exchange rate. The exchange rate appreciates from τw at date $t = 0$, to $\tau w \times \Delta$ at date $t = 1$, with the constant $\Delta > 1$. Following an appreciation of the exchange rate, the price of the lowest quality exported, $p_{\min}$, increases proportionally with the exchange rate. However, the lowest quality firms pull out of the export market, so that the lowest quality exported, $q_{\min}$, increases. This exit of firms, as well as the reduction in the quantities exported by all firms, leads to an increase of the prices charged for exports. For every level of quality, the price increase is less than proportional to the exchange

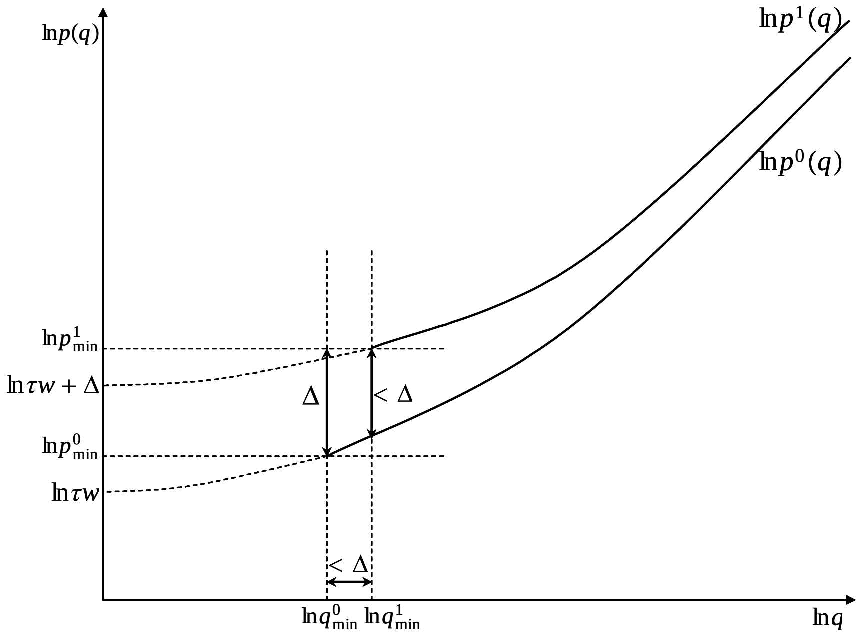

Figure 2: Exchange rate pass through.

rate. Moreover, the price increase is lower for higher quality goods.

In the remaining of this section, we describe formally the response of individual prices to exchange rate shocks, the composition effect of exchange rate shocks, and the response of aggregate prices.

Proposition 5 (exchange rate pass through) *There is incomplete pass through of exchange rate shocks into the price of individual goods. The lower the quality of a good, the higher the pass through.*

Proof. *See appendix A, page 29.* ■

When the exchange rate appreciates, firms scale down their production, and some low quality exporter exit the export market altogether. There are two forces that drive all prices up. First, the lowest quality exported is now higher. The valuation of the consumer buying the lowest quality good increases. Since this consumer is willing to pay a higher price for the Q good she buys, the price of the low quality goods increase. Second, the overall supply of Q goods abroad shrinks, so that goods are now matched with higher valuation consumers. The slope of the price schedule gets steeper, and all prices increase. Prices of goods at different level of quality are affected by these two forces in different ways. For very high quality goods, the exit of low quality firms and the effect this has on prices is negligible. Only the second force, the overall tightening of the market, matters. For low quality goods on the other hand, both the change in the lowest quality exported, and the overall tightening of the supply matter. In relative terms, low quality goods prices increase more than high quality goods prices. There is more pass through for low quality goods.

In order to understand the composition effect due the endogenous selection of firms into the export market, we have to characterize precisely the response of the extensive and intensive margins of trade to exchange rate fluctuations. The following proposition describes how both the lowest price and the lowest quality exported respond to exchange rate shocks.

Proposition 6 *The price of the lowest quality exported moves one for one with the exchange rate. The lowest quality exported increases less than proportionally with the exchange rate.*

Proof. *See appendix A, page 32.* ■

As the exchange rate appreciates, both the price of the lowest quality exported, $p_{\min}$, and the actual lowest quality exported, $q_{\min}$, increase. Mechanically, since the fixed entry cost is paid in foreign labor, $p_{\min}$ goes up one for one with the exchange rate. Therefore, the lowest minimum price at which any firm is willing to export increases one for one with the exchange rate. However, because of the increase in the marginal cost of production, some firms exit the export market altogether, so that the lowest quality exported increases. Therefore, even for the lowest quality exporter, the price charged abroad increases less than one for one with the exchange rate. After an appreciation of the exchange rate, the new lowest quality exporter has a quality higher than that of the lowest quality exporter prior to the exchange rate shock. Since the price strictly increases with the quality, the new lowest quality good exported experiences an increase in its price that is less than proportional to the exchange rate shock. In addition, in response to an exchange rate appreciation, the share of high quality exports compared to low quality exports increases.

In this section, we have proved three main results. First, following a shock to the real exchange rate, there is only incomplete pass through into prices for all goods. Second, the pass through of exchange rate shocks is higher for lower quality goods. Third, the composition effect due to the exit of low quality exporters, implies that in response to an exchange rate appreciation, the composition of exports shifts towards high quality/high price goods. In the next section, we test those predictions using highly disaggregated US import data on prices and quantities.

5 Empirical evidence

In this section, we test the main predictions of our theoretical model using highly disaggregated US import data on prices and quantities. We find evidence in support of our theoretical model. First, high quality exports, as proxied by high unit value exports, experience less exchange rate pass through. Second, in response to an exchange rate appreciation, we find evidence of a composition effect such that the share of high price goods increases. We do not however find any significant evidence that goods are more likely to exit in response to an exchange rate appreciation, nor that the probability of exit decreases with unit values.

We use a panel of highly disaggregated annual price and quantity data for US imports, from 1991 to 2001. Goods are disaggregated at the 10-digit Harmonized System, and grouped into 3-digit sectors. We use nominal bilateral exchange rates with the US trading partners. The data sources are described in Appendix B.

To test the predictions of the theoretical model, we measure the response of prices in the US of goods imported from a given country to a shock of the bilateral nominal exchange rate of the US vis à vis this country. We control for local demand shocks in the US by including the current US GDP as a control. We also control for the marginal cost of production in the exporting country as well as for the overall level of inflation in the exporting country. We will be interested in both the response of prices of individual goods to exchange rate shocks, and the response of aggregate prices to the same shocks.

5.1 Exchange rate pass-through and quality

In this section, we run exchange rate pass-through regressions for individual goods. We find first that there is a large heterogeneity in the response of export prices of individual goods to exchange rate shocks. This heterogeneity is partially explained by differences in quality. Higher quality goods, proxied by high unit value goods, tend to be less sensitive to exchange rate shocks than low quality goods.

We define a good (denoted ω) as a 10 Harmonized System category. This is the highest level of disaggregation available for most goods imported by the US. Following Campa and Goldberg (2005), we adopt the following specification for estimating the degree of exchange rate pass-through for each HS-10 good ω,

$$\Delta \ln P_t^c(\omega) = \alpha(\omega) + \beta(\omega)\,\Delta \ln RGDP_t^{US} + \delta(\omega)\,\Delta \ln W_t^c + \gamma(\omega)\,\Delta \ln CPI_t^c + \lambda(\omega)\,\Delta \ln E_t^c + \varepsilon_t^c(\omega) \tag{12}$$

where the price $P_t^c(\omega)$ is the unit value of good ω imported form country c at time t, expressed in US dollars, $RGDP_t^{US}$ is the real US GDP, W_t^c is a measure of labor cost in country c, CPI_t^c is the consumption price index in country c, and E_t^c is the bilateral exchange rate between country c and the US, expressed as the price in US dollar of the foreign currency (so that an increase in E corresponds to an appreciation of the foreign currency).

Table 1: Exchange rate pass-through.

	DLog Unit Value			
	(1)	(2)	(3)	(4)
DLog Exch. Rate	.26***	.36***	.35***	.35***
	(25.03)	(28.84)	(27.09)	(26.88)
DLog CPI		.21***	.20***	.17***
		(4.35)	(4.18)	(3.42)
DLog Labor Cost			.04	.00
			(1.37)	(.02)
DLog GDP				-.01***
				(5.39)
Constant	.01***	.00*	.00*	.02***
	(6.67)	(1.85)	(1.88)	(5.66)
Observations	814,460	776,172	738,432	738,432

Notes: This table explains the change in individual prices in response to exchange rate shocks. The dependent variable is the log difference in unit values. The explanatory variables are: the log change in the bilateral exchange rate, the log change in the CPI of the exporting country, the log change in the US GDP, the log change in the exporting country's labor cost. *, **, and *** means statistically different from zero at 10, 5 and 1% level of significance. (absolute values of T-stats in parenthesis).

We first run this regression for all goods together (estimating a single λ). As documented in the literature, there is strong evidence of incomplete exchange rate shocks into import prices. Table 1 shows the results of this regression. Depending on the set of controls included, pass-through ranges between 26% and 36%. We then run this regression separately and estimate the parameter $\lambda(\omega)$ for each individual good ω. This parameter is a simple measure of the elasticity

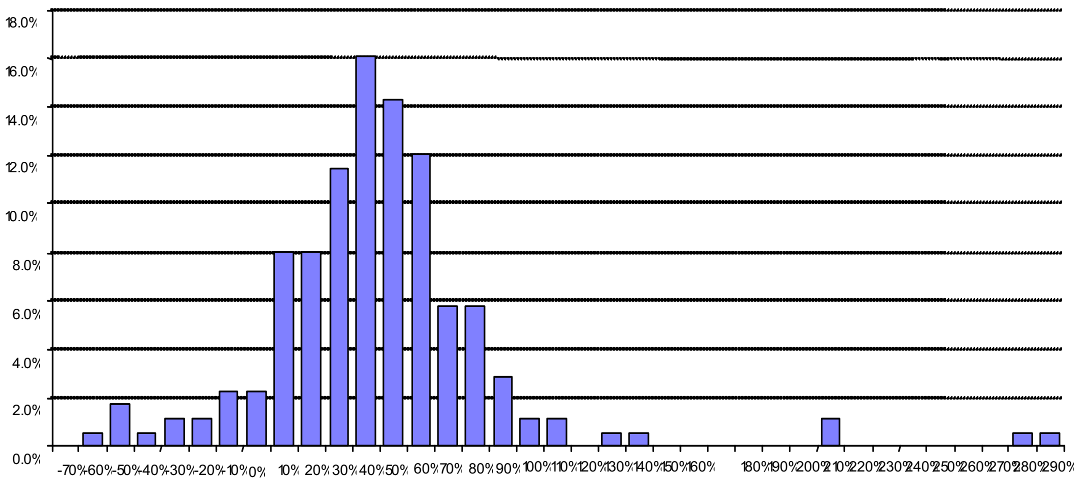

Figure 3: Distribution of exchange rate pass-through across individual prices (the exchange rate pass-through is estimated from Eq. (12); it measures the percentage change of export prices to a 1% appreciation of the exporting country's currency vis à vis the USD).

of individual prices to exchange rate shocks.

The most salient feature of the data is the very large degree of heterogeneity in the degree of exchange rate pass-through across different goods. Figure 3 describes the distribution of exchange rate pass-through across individual goods. The degree of exchange rate pass-through for different goods is averaged out within 3-digit sectors for readability. For most sectors, the average exchange rate pass-through is between 0 (no sensitivity of export prices to exchange rate movements) and 100% (full pass-through, export prices move one for one with the exchange rate). For a few goods, exchange rate pass-through is above 100%, or even negative. Most goods are characterized by incomplete pass-through of exchange rate shocks into export prices. The main feature of the data is the large heterogeneity in the degree of exchange rate pass-through.

We find that part of the dispersion of exchange rate pass-through can be explained by differences in quality, as proxied by unit values. Table 2 describes the relationship between the degree of exchange rate pass-through to our measure of quality. We find that higher quality goods have a significantly lower degree of exchange rate pass-through. The difference of exchange rate pass-through across goods of different quality is economically significant. A 1% increase in quality corresponds to a degree of exchange rate pass-through that is 3 percentage points lower. This relation remains and becomes even stronger if the data are winsorized, so that it does not seem to be driven by outliers.

Table 2: Exchange rate pass-through and quality.

	Pass-through by 3-digit	Pass-through by 3-digit (winsorized)
	(1)	(2)
Log of avg. unit value in 3-digit	-.03*	
	(1.87)	
Log of avg. unit value in 3-digit (winsorized)		-.03**
		(2.29)
Constant	.55***	.52***
	(6.54)	(7.56)
Observations	174	172

Notes: This table explains the degree of exchange rate pass-through for different qualities. The dependent variable is the averega exchange rate pass-through within a 3-digit sector. The explanatory variables is the average unit value within the sector. Column (1) considers all the data, whereas data are winsorized in column (2). *, **, and *** means statistically different from zero at 10, 5 and 1% level of significance. (absolute values of T-stats in parenthesis).

In the next section, we show that the composition of exports changes in response to exchange rate shocks.

5.2 Measuring composition effects

In this section, we test our main prediction that exchange rate fluctuations induce changes in the composition of exports. We find evidence that in response to an appreciation of the exchange rate of an exporting country, the composition of goods shifts towards higher quality goods both on the extensive and on the intensive margin: the set of goods shifts towards higher quality goods, and the share of high quality goods increases.

To test those predictions, we run the same exchange rate pass-through regressions as in the previous section at the aggregate level, for different definitions of changes in aggregate prices. We define a sector, denoted by Ω, as the set of HS-10 categories in a given 3-digit sector (we perform robustness checks at other levels of aggregation, 2, 4, 5 and 6-digit). The generic exchange rate pass-through regression we run is the following,

$$\Delta \ln P_t^c(\Omega) = \alpha(\Omega) + \beta(\Omega)\Delta \ln RGDP_t^{US} + \delta(\Omega)\Delta \ln W_t^c + \gamma(\Omega)\Delta \ln CPI_t^c + \lambda(\Omega)\Delta \ln E_t^c + \varepsilon_t^c(\Omega) \tag{13}$$

In order to isolate changes in the composition of exports in response to exchange rate shocks, we use three definitions of aggregate prices ($\Delta \ln P_t^c$),

$$\begin{cases} \Delta \ln P_t^c(\Omega) = \ln \sum_{\omega \in \Omega_t} s_t^c(\omega) P_t^c(\omega) - \ln \sum_{\omega \in \Omega_{t-1}} s_{t-1}^c(\omega) P_{t-1}^c(\omega) & (A) \\ \Delta \ln P_t^c(\Omega) = \ln \sum_{\omega \in \Omega_{t-1} \cap \Omega_t} s_t^c(\omega) P_t^c(\omega) - \ln \sum_{\omega \in \Omega_{t-1} \cap \Omega_t} s_{t-1}^c(\omega) P_{t-1}^c(\omega) & (B) \\ \Delta \ln P_t^c(\Omega) = \ln \sum_{\omega \in \Omega_t} s_{t-1}^c(\omega) P_t^c(\omega) - \ln \sum_{\omega \in \Omega_{t-1}} s_{t-1}^c(\omega) P_{t-1}^c(\omega) & (C) \end{cases}$$

where $P_t^c(\omega)$ is the price in US dollars of good ω imported from country c at time t, Ω_t is the set of goods in sector Ω imported from country c at time t, $s_t^c(\omega)$ is the share of the good ω in the total imports of goods in sector Ω imported from country c. The first definition, (A), allows both the set of goods exported (Ω_t) and the trade shares, $s_t^c(\omega)$, to change from one year to the next. Therefore, under definition A, both the extensive and the intensive margins of trade are allowed to adjust. The second definition, (B), keeps the set of goods constant. Under definition B, only the intensive margin is allowed to adjust. Finally, the third definition, (C), keeps the trade shares constant, so that only the extensive margin is allowed to adjust.

Table 3 presents the regression results for 3-digit sectors. It is evidence of the presence of a

Table 3: Measuring composition effects.

	DLog Price		
	(A)	(B)	(C)
DLog Exch. Rate	.327***	.246***	.139***
	(6.05)	(5.01)	(2.93)
DLog CPI	.340***	-.064	-.299**
	(2.35)	(.48)	(2.33)
DLog GDP	.0004	-.011***	.001
	(.92)	(3.13)	(.34)
DLog Labor Cost	-.001	.224**	.396***
	(.01)	(2.12)	(3.89)
Constant	-.001	.046***	-.189***
	(.06)	(3.38)	(14.25)
Observations	33,733	32,738	32,281

Notes: This table explains the change in aggregate prices in response to exchange rate shocks. The dependent variable is the log difference in aggregate prices, according to three definition. Under definition (A), aggregate prices are measured as trade weighted unit prices, where both the set of goods and the trade shares change from one year to the next. Under definition (B), the set of goods is kept constant. Under definition (C), trade shares are kept constant. The explanatory variables are: the log change in the bilateral exchange rate, the log change in the CPI of the exporting country, the log change in the US GDP, the log change in the exporting country's labor cost. *, **, and *** means statistically different from zero at 10, 5 and 1% level of significance. (absolute values of T-stats in parenthesis).

strong composition effect in response of exchange rate shocks that are consistent with our theoretical model. Aggregate prices respond more to exchange rate shocks when both the set of goods exported (32.7%>24.6%) and the share of those exports are allowed to change (327%>13.9%). The fact that the exchange rate pass-through is lower when the set of goods is kept constant is evidence that in response to an appreciation, the composition of goods shifts towards more expensive/ high unit value goods. In addition, the fact that the exchange rate pass-through is lower when the trade shares are kept constant is evidence that in response to an appreciation, the share of expensive/ high unit value goods increases.

We run those same regressions at several other levels of disaggregation and find that this composition effect is robust. For both lower (2-digit) and higher (4, 5, 6-digit), the ranking of exchange rate pass-through for each definition of aggregate prices is the same: the exchange rate pass-through is higher when both the set of goods and trade shares are flexible than when either is kept constant. However, we found no significant evidence that exchange rate shocks have a significant impact on the probability of exit of individual goods, nor that this probability is different for goods of different qualities.

We are aware that this procedure is sensitive to changes in the units of measurement used for the collection of data. A change in the measurement units will change the ranking of unit values, and their relative contribution to aggregate price shocks. To test that this does not affect our results, we randomly reassign unit values. We assign to each of the 19500 goods a random number between 0 and 1, divide all the quantities by this number and multiply all the unit prices by the same number. We run the same regressions on this simulated trade dataset and find similar results compared to the original data.

In this section, we have found empirical support for our theoretical model. First, there is incomplete pass-through of exchange rate shocks into export prices. Second, the degree of pass-through varies greatly across different goods, and it is typically lower for high quality (high unit value) goods. Third, we find evidence of a strong composition effect. In response to an appreciation of an exporting country's currency, composition of exports shifts towards higher quality goods.

6 Conclusion

The contribution of this paper is to explain how – in the presence of complete markets and perfect competition – cost changes brought about by movements of the real exchange rate are transmitted internationally and what factors explain the magnitude of pass-through. Our model delivers three main predictions. First, there is incomplete pass through of exchange rate shocks into consumer prices of imported goods. Second, there is more pass through for low quality goods than for high quality goods. Third, in response to an exchange rate appreciation, the composition of exports shifts towards high quality goods

We develop a perfectly competitive economy featuring heterogeneity of both good qualities and consumer valuations. In equilibrium, high valuation customers and high quality firms are matched, and the relative scarcity of goods of different qualities leads to pricing-to-market, with prices determined by the local tightness of competition. We analyze how of changes in the relative cost of production affect prices. Firms accommodate changes in the relative cost brought about by a change in the exchange rate by adjusting the quantity of its exports. Since the quantities supplied decrease when the home currency appreciates, export markets get relatively less crowded and thus prices measured in foreign currency increase, leading to partial exchange rate pass-through. Moreover, the range of firms that are actively exporting changes. In the presence of fixed costs of market access, some low quality firms no longer export. While the change in the intensive margin (volume of exports per firm) affects all firms equally, this change in the extensive margin affects low quality firms relatively more, with two associated consequences. First, fewer firms are active in the export sector. Second, low quality goods prices respond more to exchange rate shocks than high quality goods prices. A further consequence of the change in the set of exporters is that the average composition of firms changes, leading to an even larger pass through when both the set of goods exported and the export shares are allowed to adjust.

We find strong empirical evidence in support of our theoretical model. First, there is incomplete exchange rate pass-through both at the individual good level and at the aggregate level. Second, high quality goods typically are less sensitive to exchange rate shocks. And third, we find evidence of a composition effect that increases the share of high quality goods in response to an exchange rate appreciation.

Appendix A: proofs

Proof of proposition 1 (assortative matching)

Proposition 1 (reminded) *If an equilibrium exists, consumers' valuations and goods' quality are matched assortatively:*

$$v_1 > v_2 \Rightarrow q_1 \geq q_2$$

where consumer $i = 1, 2$ *with valuation* v_i *is matched with a good of quality* q_i*.*

Proof. By way of contradiction, assume there is an equilibrium such that,

$$v_1 > v_2 \text{ and } q_1 < q_2$$

In such a case, consumer 1 with valuation for quality v_1 is willing upgrade quality by exchanging his good of quality q_1 against consumer 2's good of quality q_2 and in addition pay her as much as $v_1 (q_2 - q_1)$ units of the $\mathcal{A}$ good. Consumer 2 on the other hand is willing to downgrade his quality by exchanging his good q_2 against good q_1 in exchange for at least $v_2 (q_2 - q_1)$ units of the $\mathcal{A}$ good. Note that

$$v_1 > v_2 \text{ and } q_2 > q_1 \Rightarrow v_1 (q_2 - q_1) > v_2 (q_2 - q_1)$$

so that both consumers will agree to exchange their goods and at least one of them will be strictly better off. This cannot be an equilibrium. Hence, in any equilibrium, it must be that

$$v_1 > v_2 \Rightarrow q_1 \geq q_2$$

■

Proof of proposition 2

Proposition 2 (reminded) *If an equilibrium exists, the mapping from goods quality to prices is continuously differentiable. The prices are determined locally by the valuation of consumers in the following way,*

$$p' (q) = v (q)$$

where $v (q)$ *is the valuation of the consumer matched with a good of quality* q*,* $p (q)$ *is the price of a good of quality* q*, and* $p' (q)$ *is the derivative of this price schedule.*

Proof. Suppose that an equilibrium exists. Take any two consumers with valuation $v_1 > v_2$, who are matched respectively with goods of quality q_1 and q_2, with prices p_1 and p_2. Given those prices, consumer 1 would strictly prefer to buy q_2 instead of q_1 if $v_1(q_1 - q_2) > (p_1 - p_2)$. In the same way, consumer 2 would strictly prefer to buy q_1 instead of q_2 if $v_2(q_1 - q_2) < (p_1 - p_2)$. If we are in equilibrium, given prices, consumers must not be willing to change their consumption bundles. So it must be that,

$$v_2 \leq \frac{p_1 - p_2}{q_1 - q_2} \leq v_1$$

These inequalities must hold for any q_1 and q_2, which implies that for any $q_0 \in \left[q^{\min}, q^{\max}\right]$,

$$\lim_{q \to q_0^+} \frac{p(q) - p(q_0)}{q - q_0} = \lim_{q \to q_0^-} \frac{p(q) - p(q_0)}{q - q_0} = p'(q) = v(q)$$

where $q^{\min}$ is the lowest quality actually consumed in equilibrium, with the left derivative only for $q_0 = q^{\min}$, and the right derivative only for $q_0 = q^{\max}$.

Therefore, prices increase with quality. The price schedule mapping qualities to prices is continuous and continuously differentiable. And the derivative of the price schedule is exactly equal to the valuation for quality, denominated in units of marginal utility of the $\mathcal{A}$ good. ■

Proof of proposition 3

Proposition 3 (reminded) *There exists a $(p(\cdot),\ v(\cdot),\ p_{\min},\ q_{\min})$ solution to Eqs. (5), (6), (7) and (8), not necessarily unique.*

Let us assume for simplicity that the cost function is quadratic, so that $c^{-1}(p) = p$, and that $\tau w_H = 1$. As pointed out by Rochet and Stole (2002, p. 282, footnote 10), this is not a restrictive assumption. As they argue, the cost function could be any strictly convex function: "since the measurement of units of consumers' [valuations] and product qualities are not intrinsic, they can be redefined in such a way that costs are quadratic [...]".

Before turning to the proof of proposition 3, it will be useful to first prove the following lemma.

Lemma 1 *There exists a unique α solution to,*

$$\begin{cases} \alpha = \frac{p_{\min}}{F_v^{-1}\left[\frac{N}{L} p_{\min} F_q(\beta(\delta(\alpha)))\right]} \\ \beta(\delta) = \frac{p_{\min}}{F_v^{-1}\left[\frac{N}{L}\delta\right]} \\ \delta(\alpha) = \int_\alpha^{q_{\max}} F_v^{-1}\left[\frac{N}{L}\int_\chi^{q_{\max}} p_{\min} f_q(q)\, dq\right] d\chi + p_{\min} \end{cases}$$

Proof. In the third equation, the function δ is continuously decreasing in α. Since F_v^{-1} is a decreasing function, in the second equation, the denominator is decreasing in α, so that the function β is increasing in $\delta(\alpha)$. In the first equation, the counter-cumulative function F_q is decreasing, F_v^{-1} is decreasing, so that the denominator is increasing in β. $\beta(\alpha)$ is increasing in α, so that in the first equation, the denominator is increasing in α. Therefore the right hand side of the first equation continuously decreases in α, crossing the $45°$ line only once. ■

We can now turn to the proof of the existence of an equilibrium.

Proof. It is straightforward to prove that the zero cutoff profit condition (5) determines a unique price $p_{\min}$. Eq. (6) mechanically defines the matching function $v(\cdot)$. We now prove that there exists a solution $(p(\cdot), q_{\min})$ to Eqs. (7) and (8).

Let E be the set of continuous functions from any interval $I \subset [\alpha, \beta]$ to $[\gamma, \delta]$ normed by $\|(p, q_{\min})\| = \sqrt{\sup_q |p(q)|^2 + |q_{\min}|^2}$. α, β, γ and δ are positive real numbers (defined below). Let Γ be a mapping from $S = E \times [\alpha, \beta]$ into itself (proven below), such that $\Gamma(p_1, q_1) = (p_2, q_2)$ is defined as follows,

$$\begin{cases} p_2(q) = \int_{q_1}^{q} \bar{F}_v^{-1}\left[\frac{N}{L}\int_{\xi}^{q_{\max}} p_1(\chi) f_q(\chi)\, d\chi\right] d\xi + p_{\min}, \ \forall Q \in [q_1, q_{\max}] \\ q_2 = \frac{p_{\min}}{F_v^{-1}\left[\frac{N}{L}\int_{q_1}^{q_{\max}} p_1(q) f_q(q) dq\right]} \end{cases}$$

α is defined in Lemma 1. δ is defined by $\delta(\alpha)$ as in Lemma 1. $\gamma = p_{\min}$ and β is defined by $\beta(\delta)$ as in Lemma 1.

- S is a Banach space: the set of continuous functions over a closed interval of the real line, normed by the sup norm, is a Banach space; the Cartesian product of this space and a closed interval with the Euclidean norm is a Banach space too. Since Cauchy sequences converge in both E with the sup norm, and in $[\alpha, \beta]$ with the absolute value norm, then Cauchy sequences converge in S with the conjugated norm.

- Γ maps S into itself, or, if $(p_1, q_1) \in S$, then $\Gamma(p_1, q_1) = (p_2, q_2) \in S$:

  - if $p_1 \in E$, then by construction, $\bar{F}_v^{-1}$ and f_q being continuous, p_2 is continuous.
  - F_v^{-1} takes only positive values, so for $q \in [q_1, q_{\max}]$, $p_2(q) \geq p_{\min} = \gamma$.
  - F_v^{-1} takes only positive values, so for $q \in [q_1, q_{\max}]$, $p_1(q) \geq p_{\min}$. F_v^{-1} is decreasing and takes only non negative values, so that $p_2(q) \leq \int_{\alpha}^{q_{\max}} \bar{F}_v^{-1}\left[\frac{N}{L}\int_{\xi}^{q_{\max}} p_{\min} f_q(\chi)\, d\chi\right] d\xi + p_{\min} = \delta$.
  - for any $q \in [q_1, q_{\max}]$, $p_1(q) \geq p_{\min}$. Therefore, for $q_1 \in [\alpha, \beta]$, $\int_{q_1}^{q_{\max}} p_1(\chi) f_q(\chi)\, d\chi \geq p_{\min} F_q(\beta)$. F_v^{-1} is decreasing, so that $q_2 \geq \alpha$.

- for any $q \in [q_1, q_{\max}]$, $p_1(q) \leq \delta$. Moreover, f_q is a well defined density function, so that $\int_{q_1}^{q_{\max}} p_1(\chi) f_q(\chi) d\chi \leq \frac{N}{L}\delta$. F_v^{-1} is decreasing, so that $q_2 \leq \beta$.
- We have therefore proven that if $(p_1, q_1) \in S$, then $\Gamma(p_1, q_1) = (p_2, q_2) \in S$: $p_2 \in E$ (it is a continuous function that from an interval included in $[\alpha, \beta]$ into $[\gamma, \delta]$), and $q_2 \in [\gamma, \delta]$.

- Γ is continuous, or $\forall\, \varepsilon > 0$, $\exists\, \delta > 0$ s.t. if $\|(p_1, q_1) - (p_1', q_1')\| \leq \delta$, then $\|\Gamma(p_1, q_1) - \Gamma(p_1', q_1')\| \leq \varepsilon$, for any (p_1, q_1) and (p_1', q_1') in S. TO BE DONE.

Applying Schauder fixed point theorem, there exists a fixed point (not necessarily unique) $(p, q_{\min})$ such that $(p, q_{\min}) = \Gamma(p, q_{\min})$ ■

Proof of proposition 4

Proposition 4 (reminded) *If the entry cost is such that* $f^E = \left(\frac{\lambda_q - \eta}{(1+\eta)(\lambda_q + \lambda_v)}\right)^{1+\eta}$, *then there exists a unique equilibrium price schedule, lowest quality exported, and lowest price, defined as,*

$$\begin{cases} p(q) = \gamma (\tau w_H)^{\eta/(\lambda_v+\eta)} q^{(\lambda_v+\lambda_q)/(\lambda_v+\eta)} + \tau w_H \\ q_{\min} = \gamma' (\tau w_H)^{\lambda_v/(\lambda_v+\lambda_q)} \\ p_{\min} = \left(\frac{\lambda_q+\lambda_v}{\lambda_q-\eta}\right) \tau w_H \end{cases}$$

with γ *and* γ' *some constants*[8].

Proof. An equilibrium is defined by the following 4 equations,

$$\begin{cases} v(q) = \bar{F}_v^{-1}\left(\frac{N_H}{L_F}\int_q^{\infty} c^{-1}\left(\frac{p(x)}{\tau w_H}\right) f_q(x)\, dx\right) \\ p(q) = \int_{q_{\min}}^{q} v(\chi)\, d\chi + p_{\min} \\ p_{\min} = v(q_{\min})\, q_{\min} \\ \tau w_H f^E = p_{\min} S(p_{\min}) - \int_0^{S(p_{\min})} \tau w_H c(s)\, ds \end{cases}$$

where $\bar{F}_v$ is the "counter cumulative distribution" of valuations v. In our closed form example, we have the following functional forms,

$$\begin{cases} \bar{F}_v^{-1}(m) = \bar{v} m^{-1/\lambda_v} \\ f_q(q) = \lambda_q \left(\frac{q}{\bar{q}}\right)^{-\lambda_q} q^{-1} \\ c^{-1}\left(\frac{p}{\tau w_H}\right) = \left(\frac{p}{\tau w_H} - 1\right)^{\eta} \end{cases}$$

[8] $\gamma = \left(a^{\lambda_v} \frac{\lambda_v \bar{v}^{\lambda_v}}{\lambda_q \bar{q}^{\lambda_q}} \left(\frac{\lambda_v+\eta}{\lambda_v+\lambda_q}\right)^{\lambda_v} \frac{\lambda_q-\eta}{\lambda_q+\lambda_v} \frac{L_F}{N_H}\right)^{1/(\lambda_v+\eta)}$ and $\gamma' = \left(\frac{\lambda_v+\eta}{\lambda_q-\eta}\right)^{(\lambda_v+\eta)/(\lambda_v+\lambda_q)}$.

We guess that the equilibrium price schedule is of the following form,

$$p(q) = \alpha \tau w_H q^{\beta} + \tau w_H$$

with α and β some positive constant to be determined. We have now 5 equations and 6 unknowns $(v(\cdot), p(\cdot), p_{\min}, q_{\min}, \alpha, \beta)$. This system is underidentified. Generically, there will not be a solution that satisfies our guess. We will therefore need to impose one additional condition on the size of the fixed entry cost, f^E.

Plugging the equilibrium conditions into our guess for the price schedule, the following simple algebra gives us,

$$\begin{aligned}
p(q) &= \int_{q_{\min}}^{q} v(\chi)\, d\chi + p_{\min} \\
&= \int_{q_{\min}}^{q} \bar{F}_v^{-1}\left(\frac{N_H}{L_F}\int_{\chi}^{\infty} c^{-1}\left(\frac{p(x)}{w_H \tau}\right) f_q(x)\, dx\right) d\chi + p_{\min} \\
&= \int_{q_{\min}}^{q} \bar{F}_v^{-1}\left(\frac{N_H}{L_F}\int_{\chi}^{\infty} \left(\frac{p(x)}{\tau w_H} - 1\right)^{\eta} f_q(x)\, dx\right) d\chi + p_{\min} \\
&= \int_{q_{\min}}^{q} \bar{F}_v^{-1}\left(\frac{N_H}{L_F}\int_{\chi}^{\infty} \alpha^{\eta} x^{\beta\eta} \lambda_q \left(\frac{x}{\bar{q}}\right)^{-\lambda_q} x^{-1} dx\right) d\chi + p_{\min} \\
&= \int_{q_{\min}}^{q} \bar{F}_v^{-1}\left(\frac{N_H}{L_F}\frac{\alpha^{\eta}\lambda_q}{\lambda_q - \eta\beta}\chi^{\eta\beta - \lambda_q}\right) d\chi + p_{\min} \\
&= \frac{\bar{v}}{\bar{q}^{\lambda_q/\lambda_v}}\left(\frac{N_H}{L_F}\frac{\alpha^{\eta}\lambda_q}{\lambda_q - \eta\beta}\right)^{-1/\lambda_v} \int_{q_{\min}}^{q} \chi^{(\lambda_q - \eta\beta)/\lambda_v} d\chi + p_{\min} \\
&= \frac{\bar{v}}{\bar{q}^{\lambda_q/\lambda_v}}\left(\frac{N_H}{L_F}\frac{\alpha^{\eta}\lambda_q}{\lambda_q - \eta\beta}\right)^{-1/\lambda_v} \frac{\lambda_v}{\lambda_v + \lambda_q - \eta\beta}\left(q^{(\lambda_q + \lambda_v - \eta\beta)/\lambda_v} - q_{\min}^{(\lambda_q + \lambda_v - \eta\beta)/\lambda_v}\right) + p_{\min}
\end{aligned}$$

For our guess to be correct for any quality, it must be that,

$$\begin{aligned}
\beta &= \frac{\lambda_v + \lambda_q}{\lambda_v + \eta} \\
\tau w_H \alpha &= \left(\frac{\lambda_v \bar{v}^{\lambda_v}}{\lambda_q \bar{q}^{\lambda_q}}\left(\frac{\lambda_v + \eta}{\lambda_v + \lambda_q}\right)^{\lambda_v} \frac{\lambda_q - \eta}{\lambda_q + \lambda_v}\frac{L}{N}\right)^{1/(\lambda_v + \eta)} \times (\tau w_H)^{\eta/(\lambda_v + \eta)}
\end{aligned}$$

This gives us the following expression for the equilibrium price schedule,

$$\begin{aligned}
p(q) &= \gamma (\tau w_H)^{\eta/(\lambda_v + \eta)} q^{(\lambda_v + \lambda_q)/(\lambda_v + \eta)} + \tau w_H \\
\text{with } \gamma &= \left(\frac{\lambda_v \bar{v}^{\lambda_v}}{\lambda_q \bar{q}^{\lambda_q}}\left(\frac{\lambda_v + \eta}{\lambda_v + \lambda_q}\right)^{\lambda_v} \frac{\lambda_q - \eta}{\lambda_q + \lambda_v}\frac{L_F}{N_H}\right)^{1/(\lambda_v + \eta)}
\end{aligned}$$

Note that $\frac{\lambda_v + \lambda_q}{\lambda_v + \eta} > 1$ iif $\lambda_q > \eta$. We need the assumption that $\lambda_q > \eta$, otherwise, there are too many large firms (λ_q small), or large firms are too big (η large), and our integrals would not converge.

If this equilibrium price schedule holds for every quality, it holds for the lowest quality $q_{\min}$, so that

$$p_{\min} = \gamma \left(\tau w_H\right)^{\eta/(\lambda_v+\eta)} q_{\min}^{(\lambda_v+\lambda_q)/(\lambda_v+)} + \tau w_H$$

This together with the equation defining the lowest valuation $q_{\min}$, we get a solution for the lowest price and for the lowest valuation,

$$\begin{cases} p_{\min} = \left(\frac{\lambda_q+\lambda_v}{\lambda_q-\eta}\right) \tau w_H \\ q_{\min} = \gamma' \left(\tau w_H\right)^{\lambda_v/(\lambda_v+\lambda_q)} \\ \text{with } \gamma' = \left(\frac{\lambda_v+\eta}{\lambda_q-\eta}\right)^{(\lambda_v+\eta)/(\lambda_v+\lambda_q)} \end{cases}$$

However, $p_{\min}$ is independently defined by the zero profit cutoff condition,

$$\begin{aligned} \tau w_H f^E &= p_{\min} S\left(p_{\min}\right) - \int_0^{S(p_{\min})} \tau w_H c\left(s\right) ds \\ p_{\min} &= \left(1 + \left(\left(1+\eta\right) f^E\right)^{1/(1+\eta)}\right) \tau w_H \end{aligned}$$

For our guess to be correct, we need that,

$$f^E = \left(\frac{\lambda_q - \eta}{\left(1+\eta\right)\left(\lambda_q+\lambda_v\right)}\right)^{1+\eta}$$

■

Proof of proposition 5 (exchange rate pass through)

Proposition 5 (reminded) *There is incomplete pass through of exchange rate shocks into the price of individual goods. The lower the quality of a good, the higher the pass through.*

Proof. Formally, define $\sigma_{p(q)}$ as the elasticity of the price $p\left(q\right)$ of a quality q good with respect to the exchange rate,

$$\sigma_{p(q)} \equiv \frac{\partial \ln p\left(q\right)}{\partial \ln \tau w_H}$$

From the definition of the equilibrium price schedule in proposition 4,

$$p\left(q\right) = \gamma \left(\tau w_H\right)^{\eta/(\lambda_v+\eta)} q^{(\lambda_v+\lambda_q)/(\lambda_v+\eta)} + \tau w_H$$

and differentiating with respect to τw_H, we immediately get that,

$$\begin{aligned} \sigma_{p(q)} &= \frac{\partial \ln p\left(q\right)}{\partial \ln \tau w_H} \\ &= 1 - \frac{\lambda_v}{\lambda_v - \eta} \times \frac{1}{1 + \gamma^{-1} \left(\tau w_H\right)^{\lambda_v/(\lambda_v+\eta)} q^{-(\lambda_v+\lambda_q)/(\lambda_v+\eta)}} \end{aligned}$$

From this expression, it is straightforward to prove that,

$$\begin{aligned} \frac{\partial \sigma_{p(q)}}{\partial q} &< 0 \\ \lim_{q \to +\infty} \sigma_{p(q)} &= \frac{\eta}{\lambda_v + \eta} \\ \lim_{q \to 0} \sigma_{p(q)} &= 1 \end{aligned}$$

Since the lowest quality is strictly above 0, we know that for any $q \geq q_{\min}$, we have,

$$\frac{\eta}{\lambda_v + \eta} < \sigma_{p(q)} < 1$$

There is incomplete pass through of exchange rate shocks into the prices of individual goods (the elasticity $\sigma_{p(q)}$ is smaller than 1 for all goods), and the lower the quality of a good, the higher the pass through (the elasticity $\sigma_{p(q)}$ is increasing with the quality q). ∎

Proof of proposition 6 (aggregate pass through)

Proposition 6 (reminded) *The price of the lowest quality exported moves one for one with the exchange rate. The lowest quality exported increases less than proportionally with the exchange rate.*

Proof. Formally, define $\sigma_{q_{\min}}$ as the elasticity of the lowest quality exported ($q_{\min}$) with respect to the exchange rate, and $\sigma_{p_{\min}}$ as the elasticity of the lowest price ($p_{\min}$) with respect to the exchange rate,

$$\begin{aligned} \sigma_{p_{\min}} &\equiv \frac{\partial \ln p_{\min}}{\partial \ln \tau w_H} \\ \sigma_{q_{\min}} &\equiv \frac{\partial \ln q_{\min}}{\partial \ln \tau w_H} \end{aligned}$$

From the definition of the equilibrium price schedule in proposition 4,

$$\begin{aligned} q_{\min} &= \gamma' \left(\tau w_H\right)^{\lambda_v/(\lambda_v + \lambda_q)} \\ p_{\min} &= \left(\frac{\lambda_q + \lambda_v}{\lambda_q - \eta}\right) \tau w_H \end{aligned}$$

and differentiating with respect to τw_H, we immediately get that,

$$\begin{aligned} \sigma_{q_{\min}} &= \frac{\lambda_v}{\lambda_v + \lambda_q} < 1 \\ \sigma_{p_{\min}} &= 1 \end{aligned}$$

∎

Appendix B: data

Us imports - C.I.D. at UCDavis:

Unit value is calculated as total value of export, including freight and insurance cost, excluding duty, divided by quantity. Observations are expressed in log change, year over year. All variable are winsorized.

Exchange rates - IMF, International Financial Statistics:

Avg. nominal exchange rates, USD per foreign currency. For countries adopting the Euro are all expressed in USD per 1 Euros also for years before the fixed parity was established, to insure comparability over time. The conversion has been made at the parity established in 1999 or 2001 (for Greece) (See http://www.ecb.int/bc/intro/html/index.en.html#fix). Data come from International Financial Statistics, IMF). Observations are expressed in log change, year over year. All variable are winsorized.

Real Unit Labor costs – OECD:

This reports the annual labor income share, calculated for this database as total labor costs divided by nominal output. The OECD documentation states that: "The term labour income share [. . .] relates to compensation of employees adjusted for the self employed and thus essentially relates to labour income. The division of total labour costs by nominal output is sometimes also referred to as a real unit labour cost - as it is equivalent to a deflated unit labour cost where the deflator used is the GDP implicit price deflator for the economic activity (i.e. sector) concerned". Observations are expressed in log change, year over year. All variables are winsorized.

Consumer Price Index, All items – OECD:

Observations are expressed in log change, year over year. Variables are winsorized.

US gdp growth – OECD:

Observations are expressed in log change, year over year. Variables are winsorized.

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