When is a Lower Exchange Rate Pass-Through Associated with Greater Exchange Rate Exposure?

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Abstract

We study the relationship between exchange rate pass-through (how exchange rates affect import prices) and exchange rate exposure (how exchange rates affect profits) under flexible prices. We note that the convexity of costs is an important determinant of both pass-through and exposure, and that an increase in the convexity of costs typically reduces both pass-through and exposure. Hence, the correlation between pass-through and exposure should be positive across industries if cost functions differ across industries. This effect can be mitigated by the negative correlation between pass-through and exposure induced by changes in the price elasticity of demand.

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1 Introduction

Microeconomic theory tells us that exchange rate fluctuations affect the pricing and output decisions of exporting firms, and hence also their profits. The pass-through of exchange rate changes into import prices, as well as the effect of exchange rate fluctuations on the value of the firm are two closely related topics, yet only one previous paper study their relationship in a theoretical model, namely Bodnar et al. (2002).[1] They set up a duopoly model with an exporting firm and an import competing foreign firm, and show that exchange rate pass-through and exposure should be negatively correlated across industries.[2] The intuition for their result is that when the substitutability between the domestically produced good and the imported good increases in an industry (which in effect increases the price elasticity of demand for the firms) both firms have greater incentives to stabilize prices, and hence exchange rate pass-through falls. Profits on the other hand become more sensitive to exchange rate changes, so exposure increases. If industries differ mainly in the substitutability between domestically produced and imported goods, one should therefore see a negative relationship between exchange rate pass-through and exposure across industries.

Bodnar et al. test their model on Japanese data and are capable of explaining some, but not all of the features of the data. In particular, the estimated pass-through and exposure coefficients do not vary as predictably across industries as their theoretical analysis suggests. This is not surprising and does not constitute a critique of the paper itself. First, since the authors only examine eight different industries, the scope for a cross-sectional empirical analysis is limited. Second, in the industrial organization literature, the problems in carrying out empirical inter-industry studies

[1] For a nice survey of studies on exchange rate pass-through, see Pollard and Coughlin (2003). The literature on exchange rate exposure is vast. Previous theoretical papers include, to name a few, the seminal work by Adler and Dumas (1984), Levi (1994) and Marston (1996). Empirical papers include Jorion (1990), Ahimud (1994), Campa and Goldberg (1995), He and Ng (1998), Griffin and Stulz (2001), and lately Dominguez and Tesar (2005).

[2] Other theoretical models of exchange rate exposure in an oligopoly setting include von Ungern-Sternberger and von Weizsacker (1990) and lately Friberg and Ganslandt (2005) who simulate exchange rate exposure for firms in the Swedish bottled water market.

of relations between market structure and firm behavior and performance (commonly referred to as structure-conduct-performance analysis) are well known.[3] Individual industries differ to such a large extent that observable industry characteristics may not be sufficient to explain industry conduct and/or performance. In the case of exchange rate pass-through and exposure, there are many factors besides product substitutability that may vary substantially across industries, and also affect both exchange rate pass-through and exchange rate exposure.

In this paper we study how variation on the supply side across industries will affect the relationship between pass-through and exposure. Nonlinearities in costs act as an incentive for firms to stabilize demand, and hence prices. Since pricing affects profitability, we argue that it is important to allow for the possibility of nonlinearities in the cost function when studying the relationship between exchange rate pass-through and exposure across industries. This is especially so since the degree of scale economies, especially in the short-run, can differ across industries due to for example different labor intensities in production.

We introduce a convex cost function and study the effects of changing the convexity of costs. We do this both in a simple model of monopolistic competition as well as in the oligopoly models used by Bodnar et al. (2002). We find that increasing the convexity of costs reduces both exchange rate pass-through and exposure, both in the case of monopolistic competition as well as in the duopoly price and quantity models. The conclusion is thus that if industries differ mainly on the supply side, this implies a positive correlation between pass-through and exposure. We find that allowing for non-constant marginal costs, the model also fits the data better, both with respect to the estimated elasticities, and their correlation across industries.

In section 2 we define exchange rate pass-through and exposure, while section 3 analyzes their relationship in a basic model of monopolistic competition. Section 4 introduces the duopoly model analyzed by Bodnar et al. (2002) allowing for convex costs. In section 5 we examine how the correlation between pass-through

[3] See for example Schmalensee (1989) for a discussion on this topic.

and exposure elasticities across industries estimated in Bodnar et al. (2002) are affected by controls for the convexity of the cost function. Section 6 concludes.

2 Pass-through and exposure

Consider an exporting firm that sells to a foreign market but produces domestically.[4] Profits are then

$$\pi = spq - C(q) \tag{1}$$

where s is the exchange rate, measured as the home currency price of one unit of foreign exchange, p is the price in the foreign currency, q is the quantity sold, and $C(q) = q^{\alpha}$ is the cost of producing q units of output. The (constant) elasticity of costs with respect to output is thus α, and we require that costs are (weakly) convex in the quantity, $\alpha \geq 1$. Compared to Bodnar et al. (2002) we have thus relaxed the assumption of linear costs. Demand depends on the market structure and is specified below.

We are interested in how the functional forms of cost and demand functions affect exchange rate pass-through and exposure. Exchange rate pass-through, $\varepsilon_{p,s}$, is defined as the exchange rate elasticity of the price,[5]

$$\varepsilon_{p,s} \equiv -\frac{dp}{ds}\frac{s}{p}.$$

Exposure, $\varepsilon_{\pi,s}$, is defined as the exchange rate elasticity of profits,

$$\varepsilon_{\pi,s} \equiv \frac{d\pi}{ds}\frac{s}{\pi}.$$

In the following, we analyze how pass-through and exposure are correlated across industries that differ on the demand or cost side.

[4] Bodnar et al. (2002) allow for imported intermediate inputs in production. To simplify the analysis, we assume that firms only produce in their home countries.

[5] Since $\frac{dp}{ds} < 0$, we follow the usual convention and multiply by minus one to ensure that the expression for elasticity is positive.

3 Monopolistic competition

First consider the firm's optimal strategies when the foreign market is characterized by monopolistic competition.[6] The domestic exporting firm, indexed by $z = 0$, competes with a continuum of foreign producers, indexed by $z \in (0, 1]$. We suppose that the utility function of a representative household is weakly separable (functional separability), so that we can study the consumers' consumption of the differentiated good independent of all other goods. Denoting by $q(z)$ the quantity of the differentiated good z consumed by a household in the foreign market, the household chooses quantities $q(z)$ to solve

$$\max_{q(\cdot)} \left[\int q(z)^{\rho} \, dz \right]^{1/\rho}$$

subject to

$$\int p(z) \, q(z) \, dz = Y$$

where $p(z)$ is the price charged by firm z, and Y is the household's total spending on the differentiated products. The parameter ρ measures the degree of substitutability between the products. The goods are substitutes if $\rho \in (0, 1)$ and become perfect substitutes as ρ approaches 1. The goods are compliments for $\rho \in (-\infty, 0)$ and become perfect compliments as ρ approaches $-\infty$. If $\rho = 0$ the goods are independent. For our purposes, we restrict ρ to be between zero and unity.

The household's first order condition implies that

$$q = \theta p^{-\frac{1}{1-\rho}} \tag{2}$$

where $\theta = QP^{\frac{1}{1-\rho}}$, $Q \equiv \left[\int q(z)^{\rho} \, dz\right]^{1/\rho}$ is the aggregate quantity consumed, and P is the aggregate price level for the differentiated good defined from $PQ = Y$. The price elasticity of demand is thus constant and equal to $1/(1-\rho) > 1$.

The exporting firm chooses the price p to maximize profits (1) subject to the

[6] This market structure follows Flodén and Wilander (2005).

demand function (2), resulting in an optimal price

$$p = (ks)^{-\gamma}$$

where $k = \theta^{1-\alpha}\rho/\alpha$ and $\gamma = (1-\rho)/(\alpha-\rho)$. Taking derivatives of this price and the implied optimal profit with respect to the exchange rate, we find that pass-through is

$$\varepsilon_{p,s} = \frac{(1-\rho)}{\alpha-\rho} \tag{3}$$

and that exposure is

$$\varepsilon_{\pi,s} = \frac{\alpha}{\alpha-\rho}. \tag{4}$$

Proposition 1 shows how changes in product substitutability, ρ, and in the convexity of the cost function, α, affect pass-through and exposure.

Proposition 1 *Under monopolistic competition, if $\alpha > 1$, an increase in ρ reduces pass-through, but raises exposure. An increase in α reduces both pass-through and exposure.*

Proof. The derivative of (3) with respect to ρ is given by $\frac{1-\alpha}{(\alpha-\rho)^2} < 0$ and the derivative of (4) with respect to ρ is given by $\frac{\alpha}{(\alpha-\rho)^2} > 0$. The derivative of (3) with respect to α is given by $\frac{\rho-1}{(\alpha-\rho)^2} < 0$ while the derivative of (4) with respect to α is given by $\frac{-\rho}{(\alpha-\rho)^2} < 0$. ∎

The first part of Proposition 1 is just a restatement of Bodnar et al.'s main result (albeit in a different setting) that higher product substitutability raises the price elasticity of demand, which has opposing effects on pass-through and exposure. The second part of Proposition 1 shows that an increase in the convexity of the cost function reduces both exchange rate pass-through and exchange rate exposure. So, if there is large variation across industries on the supply side, so that industries differ mainly in their cost function, we should see a positive correlation between pass-through and exposure across industries. In contrast, when there is variation across industries mainly on the demand side the correlation should be negative, as predicted by Bodnar et al.

To understand the first part of Proposition 1, note that fluctuating production raises average costs if the cost function is convex. Demand fluctuations therefore reduce average profits, and firms then want to stabilize import prices by limiting exchange rate pass-through. Obviously this effect is stronger the more convex are costs. However, given that costs are convex, this effect is also stronger the more price sensitive is demand. An increase in ρ therefore also reduces pass-through.

While higher ρ and α both imply lower pass-through, the impact on exposure is different. Differentiating profits with respect to the exchange rate, we get that (by the envelope theorem) $d\pi/ds = pq$. It follows then that exposure, $\frac{d\pi}{ds}\frac{s}{\pi}$, equals sales divided by profits. Increasing ρ reduces sales, but results in a proportionately larger fall in profits since it also reduces the markup. Exposure then increases. For an increase in α, the opposite occurs. Sales fall, but profits fall proportionately less.[7] Exposure then falls.

4 Oligopolistic competition

Assume now that the foreign market is characterized by oligopolistic competition as in Bodnar et al. (2002). The exporting firm competes with only one foreign firm, and households in the foreign market choose quantity q of the exporting firm's good and q_f of the foreign firm's good to solve

$$\max_{q,q_f} \left[\gamma q^{\rho} + (1-\gamma)\, q_f^{\rho}\right]^{1/\rho}$$

subject to

$$pq + p_f q_f = Y$$

where $0 < \gamma < 1$ is the relative preference for the exporting firm's good.

[7] Given the functional forms here, the markup is independent of α.

The solution to the households' problem can be represented as the direct demand functions

$$q = \frac{Y/p}{1+\beta^{\frac{1}{\rho-1}}\left(\frac{p_f}{p}\right)^{\frac{\rho}{\rho-1}}} \tag{5}$$

$$q_f = \frac{Y/p_f}{1+\beta^{\frac{-1}{\rho-1}}\left(\frac{p}{p_f}\right)^{\frac{\rho}{\rho-1}}} \tag{6}$$

or as the indirect demand functions

$$p = \frac{Y/q}{1+\beta^{-1}\left(\frac{q_f}{q}\right)^{\rho}} \tag{7}$$

$$p_f = \frac{Y/q_f}{1+\beta\left(\frac{q}{q_f}\right)^{\rho}} \tag{8}$$

where $\beta = \gamma/(1-\gamma)$.

In the following subsections we analyze the equilibrium outcomes under Cournot and Bertrand competition. Since we are interested in how price setting is affected by exchange rate movements, Bertrand competition with price as the strategic variable is the natural starting point. The analysis turns out to be less complicated under Cournot competition, however, so we first examine that market structure.

4.1 Cournot competition

Assume that competition between the exporting firm and the foreign firm is characterized by Cournot competition. The exporting firm then chooses quantity q to maximize profits (1), and the foreign firm chooses q_f to maximize $p_f q_f - q_f^{\alpha}$ subject to the indirect demand functions (7) and (8). We only consider the pure strategy Nash equilibrium, although mixed strategy equilibria may exist. This equilibrium is characterized by the home and foreign firms' first order conditions,

$$\frac{\partial \pi}{\partial q} = s\left(1+\frac{\partial p}{\partial q}\frac{q}{p}\right) - \frac{\alpha q^{\alpha-1}}{p} = 0 \tag{9}$$

and

$$\frac{\partial \pi_f}{\partial q_f} = 1 + \frac{\partial p_f}{\partial q_f}\frac{q_f}{p_f} - \frac{\alpha q_f^{\alpha-1}}{p_f} = 0. \tag{10}$$

Let $\lambda = pq/Y$ denote the market share of the exporting firm, and take derivatives of the demand functions to find that $1 + \frac{\partial p}{\partial q}\frac{q}{p} = \rho(1-\lambda)$ and $1 + \frac{\partial p_f}{\partial q_f}\frac{q_f}{p_f} = \rho\lambda$. The Cournot equilibrium quantity for the exporting firm and the associated price is

$$q = \left[\frac{s\rho\lambda Y(1-\lambda)}{\alpha}\right]^{\frac{1}{\alpha}}$$

$$p = \left[\frac{\alpha}{s\rho(1-\lambda)}\right]^{\frac{1}{\alpha}} (\lambda Y)^{\frac{\alpha-1}{\alpha}}$$

and the equilibrium market share is $\lambda = \beta s^{\frac{\rho}{\alpha}} / \left(1 + \beta s^{\frac{\rho}{\alpha}}\right)$.

Taking derivatives of the equilibrium price and profits we find that exchange rate pass-through is

$$\varepsilon_{p,s} = \frac{1-\rho(1-\lambda)}{\alpha} + \frac{\rho(1-2\lambda)}{\alpha^2}$$

and that exposure is

$$\varepsilon_{\pi,s} = 1 + \frac{\rho(1-\lambda)}{\alpha} + \frac{\rho^2\lambda(1-\lambda)}{\alpha-\rho(1-\lambda)}.$$

Parts (i) and (ii) of Proposition 2 confirm the main result in Bodnar et al (2002) also when allowing for non-linearity in costs.[8] More interestingly, parts (iii) and (iv) show that an increase in the convexity of the cost function typically reduces both pass-through and exposure. If industries differ mainly on the production side (i.e. have different α, for example because of different labor intensities), theory thus predicts a positive correlation between pass-through and exposure across industries, just as in the case of monopolistic competition.

Proposition 2 *Under Cournot competition, if $s = 1$, (i) an increase in ρ reduces*

[8] We only consider the case when $s = 1$ so that costs in the two countries are symmetric. The equilibrium market share λ is then unaffected by changes in ρ and α. Alternatively we could also consider the case where $s \neq 1$ and holding market share fixed (that is, we ignore $\frac{\partial\lambda}{\partial\rho}$ and $\frac{\partial\lambda}{\partial\alpha}$).

pass-through; (ii) an increase in ρ raises exposure; (iii) an increase in α reduces pass-through unless $\lambda > \frac{2}{3}$ and $\rho > \frac{\alpha}{(4-\alpha)\lambda+\alpha-2}$; and (iv) an increase in α reduces exposure;

Proof. Evaluate derivatives of pass-through and exposure with respect to ρ and α at $s = 1$. To show part (i), note that

$$\frac{\partial \varepsilon_{p,s}}{\partial \rho}|_{s=1} = \frac{-(\alpha-1)+(\alpha-2)\lambda}{\alpha^2} < 0$$

where the inequality follows from $\alpha - 1 > (\alpha - 2)\lambda$. To show part (ii), note that

$$\frac{\partial \varepsilon_{\pi,s}}{\partial \rho}|_{s=1} = \frac{(1-\lambda)}{\alpha} + \frac{\rho\lambda(1-\lambda)[2\alpha-\rho(1-\lambda)]}{[\alpha-\rho(1-\lambda)]^2} > 0.$$

The ambiguous sign in part (iii) follows from

$$\begin{aligned}\frac{\partial \varepsilon_{p,s}}{\partial \alpha}|_{s=1} &= -\frac{\alpha[1-\rho(1-\lambda)]+2\rho(1-2\lambda)}{\alpha^3} \\ &\begin{cases} > 0 & \text{if } \lambda > \frac{2}{3} \text{ and } \rho > \frac{\alpha}{(4-\alpha)\lambda+\alpha-2} \geq \frac{1}{2} \\ \leq 0 & \text{otherwise} \end{cases}\end{aligned}$$

and part (iv) follows from

$$\frac{\partial \varepsilon_{\pi,s}}{\partial \alpha}|_{s=1} = \frac{-\rho(1-\lambda)}{\alpha^2} - \frac{\rho^2\lambda(1-\lambda)}{[\alpha-\rho(1-\lambda)]^2} < 0.$$

■

Under monopolistic competition, there was an unambiguous and intuitive result that more convex costs raise the incentives to stabilize production and thus reduces pass-through. For most parameter values, this result also applies under Cournot competition, but if ρ and λ are high and α is low, an increase in α raises pass-through. This result is less intuitive, and is generated by the foreign firm's reaction to the exchange rate shock.[9] When both ρ and λ are large the price response of the foreign firm to output (demand) changes of the exporting firm is high[10] and this effect can dominate for low convexity of the cost function.

The effect on exposure of a higher convexity α is unambiguously negative. Intuitively, the effect is not as obvious. The exposure elasticity can be divided into two parts, $d\pi/ds$ and s/π. When the convexity of the cost function increases, industry profits will go up. This is because higher α reduces competitive behavior in the industry, as the incentives to expand production are lower. Hence, s/π will fall. Unless the sensitivity of profits with respect to the exchange rate, $d\pi/ds$, increases sufficiently when α increases, this implies that the exposure elasticity will fall.

The sensitivity of profits with respect to the exchange rate can be written as

$$d\pi/ds = (\lambda Y)\left(\frac{1-\rho(1-\lambda)}{\alpha}\right) + sY\left(\frac{\alpha-\rho}{\alpha}\right)\frac{\partial\lambda}{\partial s}. \tag{11}$$

Profits thus change due to a valuation effect on the initial net foreign currency position, and as a result of a change in the foreign currency position due to a change in the market share. Substituting for $\frac{\partial\lambda}{\partial s}$ and taking the derivative with respect to α yield[11]

$$\frac{d^2\pi}{dsd\alpha}|_{\lambda=\overline{\lambda}} = -\frac{2\lambda(1-\lambda)\rho(1-\rho)}{\alpha^3} < 0.$$

Hence also the sensitivity of profits, $d\pi/ds$, falls as the convexity of costs increases, which establishes the result.

4.2 Bertrand competition

Assume now that competition between the exporting firm and the foreign firm is characterized by Bertrand competition. The exporting firm then chooses price p to

[9] This is confirmed by deriving the exporting firm's pass-through conditional on the foreign firm's price being fixed, so that the foreign firm does not react to the exchange rate change. Numerical simulations of this expression show that it is decreasing in alpha.

[10] $\left(\frac{\partial p_f}{\partial q}\frac{q}{p_f} = -\rho\lambda\right)$

[11] We ignore the effect $\frac{\partial\lambda}{\partial\alpha}$.

maximize profits (1) and the foreign firm chooses p_f to maximize $p_f q_f - q_f^\alpha$ subject to the demand functions (5) and (6).

The equilibrium price-quantity pairs for the exporter and the foreign firm are given by

$$p = \left[\frac{(\lambda Y)^{\alpha-1}(1-\rho\lambda)\alpha}{s(1-\lambda)\rho}\right]^{\frac{1}{\alpha}}, \; q = \left[\frac{s\rho(1-\lambda)\lambda Y}{(1-\rho\lambda)\alpha}\right]^{\frac{1}{\alpha}} \tag{12}$$

and

$$p_f = \left[\frac{((1-\lambda)Y)^{\alpha-1}(1-\rho(1-\lambda))\alpha}{\lambda\rho}\right]^{\frac{1}{\alpha}}, \; q_f = \left[\frac{\rho\lambda(1-\lambda)Y}{(1-\rho(1-\lambda))\alpha}\right]^{\frac{1}{\alpha}} \tag{13}$$

where the equilibrium market share for the exporter is

$$\lambda = \frac{\beta(zs)^{\frac{\rho}{\alpha}}}{1+\beta(zs)^{\frac{\rho}{\alpha}}}$$

and $z = [1-\rho(1-\lambda)]/(1-\rho\lambda)$. Note that the expression for λ is an implicit function since z is a function of λ. The equilibrium profits for the exporter are then

$$\pi = s\lambda Y\left[1-\frac{(1-\lambda)\rho}{(1-\rho\lambda)\alpha}\right]. \tag{14}$$

We show in the appendix that the implied pass-through and exposure elasticities are

$$\varepsilon_{p,s} = \frac{1}{\alpha}\left[1-\frac{\rho(1-\rho+\rho\lambda)[(1-\rho\lambda)(1-\lambda)(\alpha-1)+\lambda(1-\rho)]}{\alpha(1-\rho\lambda)(1-\rho+\rho\lambda)-\rho^2\lambda(1-\lambda)(2-\rho)}\right]$$

and

$$\varepsilon_{\pi,s} = 1+\frac{\rho(1-\lambda)(1-\rho+\rho\lambda)\left[\alpha(1-\rho\lambda)^2-(1-\rho\lambda)(1-\lambda)\rho+\rho\lambda(1-\rho)\right]}{((1-\rho\lambda)\alpha+(\lambda-1)\rho)[\alpha(1-\rho\lambda)(1-\rho+\rho\lambda)-\rho^2\lambda(1-\lambda)(2-\rho)]}.$$

Note that with $\alpha = 1$ these expressions reduce to $\varepsilon_{p,s} = \frac{(1-\rho\lambda)}{1-\rho^2\lambda(1-\lambda)}$ and $\varepsilon_{\pi,s} = 1+\frac{(1-\lambda)(1-\rho+\rho\lambda)\rho}{[1-\rho^2\lambda(1-\lambda)](1-\rho)}$ which is identical to the expressions in Bodnar et al. (2002) for the case of no imported intermediate inputs.

It is complicated to analyze analytically how these expressions are affected by the degree of product substitutability and the convexity of costs. Instead we provide numerical examples. Figure 1 plots pass-through and exposure as a function of ρ. The solid line plots the expressions for $\alpha = 1$ and the dotted line for $\alpha = 1.5$. The figure shows that increasing the convexity of costs will generally reduce pass-through, as the line corresponding to $\alpha = 1.5$ is everywhere below the line for $\alpha = 1$. Increasing α also lowers exposure, and this effect is typically stronger when products are closer substitutes. Once again this happens since increasing the convexity of costs reduces competitive behavior in the industry and thus raises profits. Provided that the exporter's market share is not too large, the effect (on industry profits) of increasing α is larger when products are closer substitutes (ρ is high), which is intuitive since it is when products are close substitutes that competition is toughest. Moreover, just as found in the case of Cournot competition, increasing ρ reduces pass-through and raises exposure even in the presence of convex costs.

[**Figure 1**]

A second finding in Bodnar et al. (2002) is the reduction in both pass-through and exposure as the market share of the exporting firm, λ, increases. This holds also in the presence of convex costs, as can be seen from Figure 2.

[**Figure 2**]

Allowing for convex costs improves the price competition model. One problem with the price competition model under constant marginal costs is that pass-through is generally too high compared to what is estimated from data, unless the market share is close to unity. With convex costs however, the pass-through estimates in the model are typically well below unity, even at lower market shares.

Figure 3 plots pass-through and exposure as functions of α. For the parameter values used, both pass-through and exposure fall as α increases. This finding holds for most parameter values and is once again understood by the incentive to stabilize demand when the cost function is convex. But as under Cournot competition, pass-through is a hump-shaped function of α when both λ and ρ are high. It is then possible that an increase in α raises pass-through and reduces exposure for low values of α.[12]

[Figure 3]

5 A quick look at the data

Bodnar et al. (2002) simultaneously estimate exchange rate pass-through and exposure coefficients for eight Japanese industries, using data from 1986-1995. The cross industry correlation between pass-through and exposure across these industries is $-.0873$. In this section, we make a back-of-the-envelope empirical analysis where we control for the convexity of the cost-function. Based on our theoretical analysis, we expect that the negative correlation then will become stronger since we control for a variable that has a positive effect on the cross-industry correlation.

Let us assume that labor is the only production factor that is flexible in the short run.[13] More specifically, assume that the short-run production function is $y = l^{\frac{1}{\alpha}}$ so that $\frac{1}{\alpha}$ is the labor share in production. The short-run cost function is then $c(y) = y^{\alpha}$, implying that firms/industries with higher labor-intensity (intensity of the flexible production factor), have lower convexity of costs. Firms/industries with different labor intensities may then at least in the short-run also differ in the response of prices and profits to changes in the exchange rate.

Using data from the 1998 Japanese Census of Manufacturers from the Ministry of the Economy, Trade and Industry (METI) we divide the total wage payments and worker compensations by the value of manufactured goods in each industry and use this as a proxy for labor intensity. The resulting values, along with the coefficients on pass-through and exposure from Bodnar et al. (2002) are shown in Table 1.

[Table 1]

[12] Once again this is due to the reaction of the foreign firm.

[13] This is clearly a simplifying assumption. For example, imported intermediate goods or raw materials are important in some of the Japanese industries in Bodnar et al.'s study, and these inputs may also be variable in the short run.

Table 2 shows the partial correlation of exposure with pass-through and labor share as well as the simple correlation coefficients of exposure, pass-through and labor intensity. We would expect that the negative correlation between pass-through and exposure is stronger when we control for labor intensity, and that the correlation between labor intensity and exposure is positive. We would also expect that the correlation between pass-through and labor-intensity is positive, although we know from the theoretical section that for some parameter values an increase in the convexity of the cost function may increase pass-through.

[Table 2]

Table 2 confirms our prior in that the partial correlation coefficient between exposure and pass-through is larger than the simple correlation coefficient. Moreover, the correlation between the labor intensity proxy and both exposure and pass-through is positive. Obviously this is a too simple exercise to draw any strong conclusions from. With only eight industries none of the above reported correlations are significant. Nonetheless it is comforting that all results go in the direction predicted by the theoretical analysis.

6 Concluding remarks

This paper has analyzed the relationship between exchange rate pass-through and exposure under flexible prices. Changes in a firm's or industry's demand and cost structure affects both exposure and pass-through, and we show that increasing the convexity of the cost function usually reduces both pass-through and exposure. This effect is found in a simple model of monopolistic competition, but also in the oligopoly model studied by Bodnar et al. (2002), for a wide range of plausible parameter values.

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Appendix A

A.1 Pass-through and exposure under monopolistic competition

Let p be the exporter's price in foreign currency. Profits are

$$\pi = \theta s p^{-\frac{\rho}{1-\rho}} - \theta^{\alpha} p^{-\frac{\alpha}{1-\rho}}.$$

The optimal flexible price is then

$$p^*(s) = (ks)^{-\gamma},$$

where $k = \theta^{1-\alpha}\frac{\rho}{\alpha}$ and $\gamma = (1-\rho)/(\alpha-\rho)$. The derivative with respect to s is given by

$$\frac{dp^*(s)}{ds} = -\gamma k (ks)^{-\gamma-1}.$$

Multiplying by $-s$ and dividing by p^* implies that the pass-through elasticity is

$$\varepsilon_{p,s} = -\frac{dp^*(s)}{ds}\frac{s}{p^*(s)} = \gamma = (1-\rho)/(\alpha-\rho).$$

Profits are given by

$$\pi^*(s) = \theta s (ks)^{\frac{\gamma\rho}{1-\rho}} - \theta^{\alpha}(ks)^{\frac{\alpha\gamma}{1-\rho}}.$$

Since $1 + \frac{\gamma\rho}{1-\rho} = \frac{\alpha\gamma}{1-\rho}$, this expression can be simplified to

$$\pi^*(s) = s^{\frac{\alpha\gamma}{1-\rho}}\left[\theta k^{\frac{\gamma\rho}{1-\rho}} - \theta^{\alpha}(k)^{\frac{\alpha\gamma}{1-\rho}}\right].$$

Differentiating the above expression with respect to s, multiplying by s and dividing by $\pi^*(s)$ implies that exposure elasticity is

$$\frac{d\pi^*(s)}{ds}\frac{s}{\pi^*(s)} = \frac{\alpha}{\alpha - \rho}.$$

A.2 Pass-through and exposure under quantity competition

Under Cournot competition,

$$p = \left[\frac{\alpha}{s\rho\left(1-\lambda\right)}\right]^{\frac{1}{\alpha}} \left(\lambda Y\right)^{\frac{1-\alpha}{\alpha}}$$

and

$$q = \left[\frac{s\rho\lambda Y\left(1-\lambda\right)}{\alpha}\right]^{\frac{1}{\alpha}}$$

and the equilibrium market share is $\lambda = \beta s^{\frac{\rho}{\alpha}} / \left(1 + \beta s^{\frac{\rho}{\alpha}}\right)$. Substituting p and q into (1), using $C\left(q\right) = q^{\alpha}$ gives

$$\pi = s\lambda Y\left[1 - \frac{\rho\left(1-\lambda\right)}{\alpha}\right].$$

The derivative of π w.r.t. the exchange rate is given by

$$\frac{d\pi}{ds} = \left(sY\frac{d\lambda}{ds} + \lambda Y\right)\left(1 - \frac{\rho\left(1-\lambda\right)}{\alpha}\right) - s\lambda Y\frac{\rho}{\alpha}\frac{d\lambda}{ds}.$$

Inserting for $\frac{d\lambda}{ds}$ and multiplying by $\frac{s}{\pi}$yield

$$\varepsilon_{\pi,s} = 1 + \frac{\rho\left(1-\lambda\right)}{\alpha} + \frac{\rho^2\lambda\left(1-\lambda\right)}{\alpha - \rho\left(1-\lambda\right)}.$$

Differentiating p with respect to s we get

$$\frac{dp}{ds} = -\frac{1}{\alpha}s^{-\frac{1}{\alpha}-1}\left(\frac{\alpha}{\rho\left(1-\lambda\right)}\right)^{\frac{1}{\alpha}}\left(\lambda Y\right)^{\frac{1-\alpha}{\alpha}} + s^{-\frac{1}{\alpha}}\left(\lambda Y\right)^{\frac{1-\alpha}{\alpha}}\left(\frac{\alpha}{\rho\left(1-\lambda\right)}\right)^{\frac{1}{\alpha}}\left(\frac{1}{\alpha\left(1-\lambda\right)} + \frac{1-\alpha}{\alpha\lambda}\right)\frac{d\lambda}{ds}$$

Multiplying $\frac{dp}{ds}$ by $-\frac{s}{p}$ and using $\frac{d\lambda}{ds} = \frac{\rho}{\alpha}\frac{\lambda(1-\lambda)}{s}$, the expression for pass-through is

$$\varepsilon_{p,s} = \frac{1-\rho\left(1-\lambda\right)}{\alpha} + \frac{\rho\left(1-2\lambda\right)}{\alpha^2}.$$

A.3 Pass-through and exposure under price competition

In order to derive the pass-through elasticity under Bertrand competition, we totally differentiate the equilibrium price

$$p = \left[\frac{\left(\lambda Y\right)^{\alpha-1}\left(1-\rho\lambda\right)\alpha}{s\left(1-\lambda\right)\rho}\right]^{\frac{1}{\alpha}}$$

with respect to the exchange rate, s, taking into account the fact that the market share, λ, depends on s. By the chain rule the pass-through elasticity is given by

$$\varepsilon_{p,s} \equiv -\frac{dp}{ds}\frac{s}{p} = -\left[\frac{d\left(\left(\lambda Y\right)^{\frac{\alpha-1}{\alpha}}\right)}{ds}\left(\frac{\left(1-\rho\lambda\right)\alpha}{s\left(1-\lambda\right)\rho}\right)^{\frac{1}{\alpha}} + \frac{d\left(\left(\frac{(1-\rho\lambda)\alpha}{s(1-\lambda)\rho}\right)^{\frac{1}{\alpha}}\right)}{ds}\left(\lambda Y\right)^{\frac{\alpha-1}{\alpha}}\right]\frac{s}{p}$$

which is equal to

$$s\left[\frac{\alpha-1}{\alpha\lambda}\frac{d\lambda}{ds} - \frac{1}{\alpha s}\right] + s\left[\frac{1}{\alpha}\frac{\left(1-\lambda\right)\rho}{\left(1-\rho\lambda\right)\alpha}\frac{\alpha\left(1-\rho\right)\frac{d\lambda}{ds}}{\left(1-\lambda\right)^2\rho}\right].$$

It then remains to solve for $\frac{d\lambda}{ds}$. Under price competition, the exporting firm's market share is given by $\lambda = \frac{\beta(zs)^{\frac{\rho}{\alpha}}}{1+\beta(zs)^{\frac{\rho}{\alpha}}}$, where $z = \left[1-\rho\left(1-\lambda\right)\right]/\left(1-\rho\lambda\right)$. Totally differentiating λ with respect to s, and solving for $\frac{d\lambda}{ds}$ yields

$$\frac{d\lambda}{ds} = \frac{\rho\lambda}{\alpha s}\frac{\left(1-\lambda\right)\left(1-\rho\lambda\right)\left(1-\rho+\rho\lambda\right)}{\left(1-\rho+\rho\lambda\right)\left(1-\rho\lambda\right) - \frac{\rho\lambda}{\alpha}\left(1-\lambda\right)\left(2\rho-\rho^2\right)}.$$

Substituting for $\frac{d\lambda}{ds}$ in the above expression and simplifying yields the pass-through elasticity

$$\varepsilon_{p,s} = \frac{1}{\alpha} - \frac{\left(1-\rho+\rho\lambda\right)\rho\left[\left(1-\rho\lambda\right)\left(1-\lambda\right)\left(\alpha-1\right)+\lambda\left(1-\rho\right)\right]}{\left(\alpha^2\left(1-\rho\lambda\right)\left(1-\rho+\rho\lambda\right)-\rho\lambda\left(1-\lambda\right)\left(2\rho-\rho^2\right)\alpha\right)}.$$

Using the expression for profits, (14), we get

$$\frac{d\pi}{ds} = \left[\lambda Y + sY\frac{d\lambda}{ds}\right]\left[1 - \frac{(1-\lambda)\,\rho}{(1-\rho\lambda)\,\alpha}\right] + s\lambda Y\left[\frac{\rho\left[(1-\rho\lambda)-(1-\lambda)\,\rho\right]\frac{d\lambda}{ds}}{(1-\rho\lambda)\alpha(1-\rho\lambda)}\right].$$

Inserting for $\frac{d\lambda}{ds}$ and multiplying by $\frac{s}{\pi}$ yields the exposure elasticity

$$\varepsilon_{\pi,s} = 1 + \frac{\frac{\rho}{\alpha}\,(1-\lambda)\,(1-\rho+\rho\lambda)\left[(1-\rho\lambda)^2\,\alpha - (1-\rho\lambda)\,(1-\lambda)\,\rho + \rho\lambda\,(1-\rho)\right]}{((1-\rho\lambda)\,\alpha + (\lambda-1)\,\rho)\left[(1-\rho\lambda)\,(1-\rho+\rho\lambda) - \frac{\rho\lambda}{\alpha}\,(1-\lambda)\left(2\rho-\rho^2\right)\right]}.$$

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Table 1: Pass-through, exposure, and labor intensity in Japanese industries

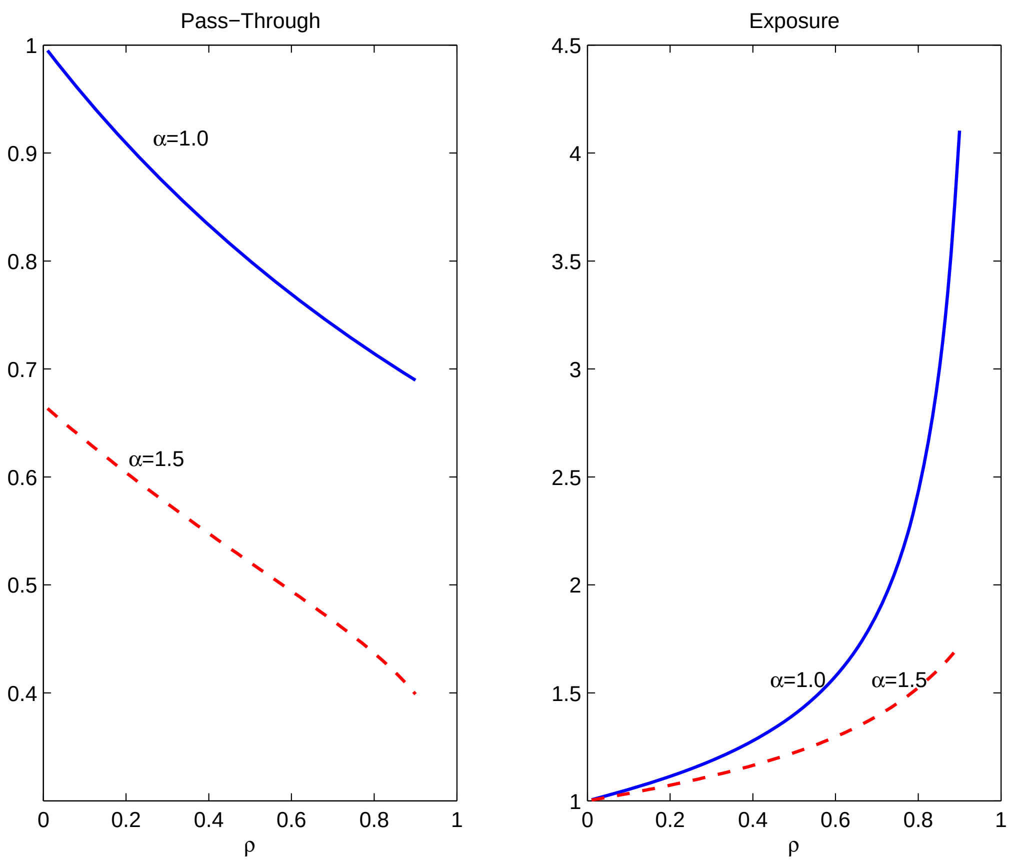
Industry	Pass-Through	Exposure	Labor intensity
Cameras	.471	.687	.17
Construction	.805	.384	.14
Copiers	.284	1.087	.12
Electronic Parts	.244	1.658	.14
Film	.146	1.494	.23
Magnetic Rec. Products	.218	1.433	.09
Measuring Equipment	.750	2.282	.20
Motor Vehicles	.262	.711	.11

Table 2: Partial and simple correlation coefficients

Partial Correlation	
Exposure with Pass-Through	−.1794
Exposure with Labor Intensity	.4155

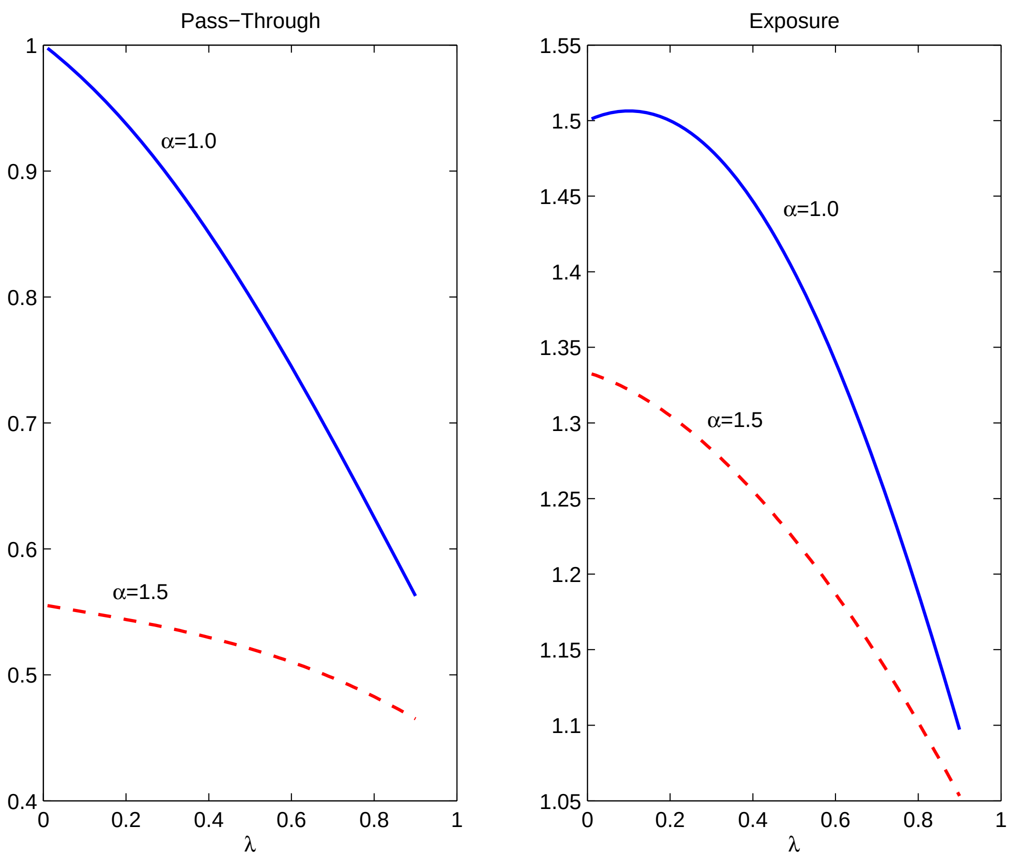
Simple Correlation Coefficients	Exposure	Pass-Through	Labor Intensity
Exposure	1.0000		
Pass-Through	−0.0873	1.0000	
Labor Intensity	0.3894	.1922	1.0000

Figure 1: Pass-through and exposure for different degrees of substitutability



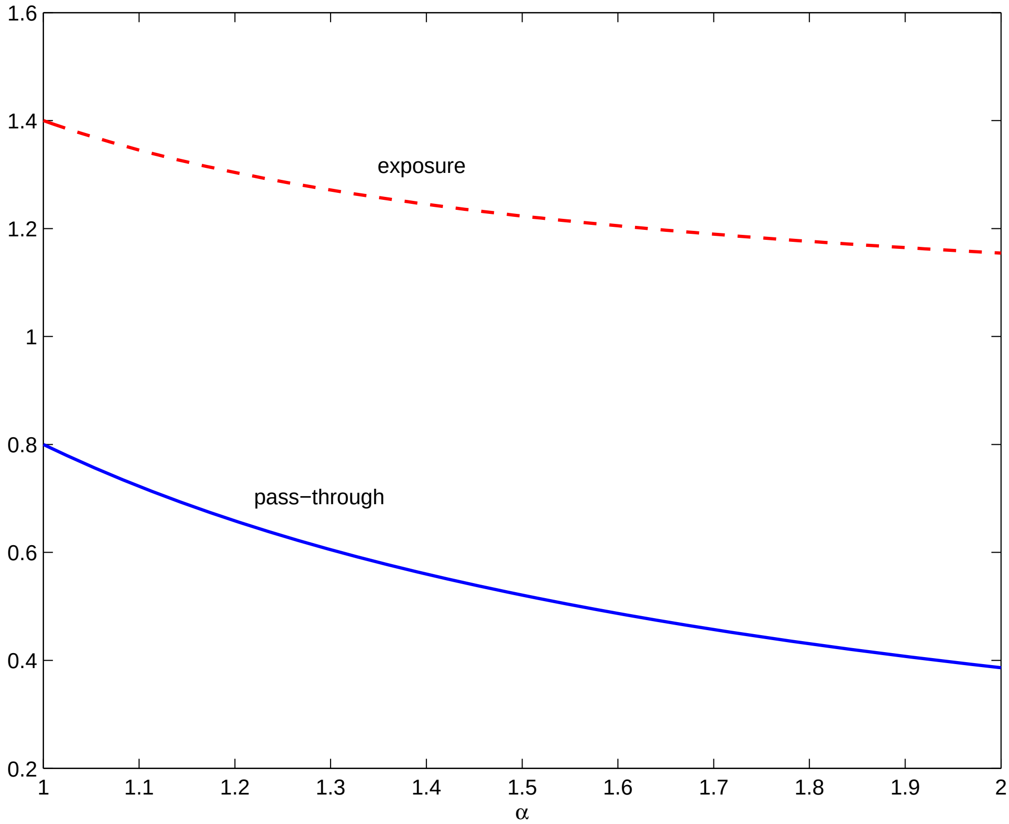
Note: The figure plots pass-through and exposure as functions of ρ, holding the market share constant at $\lambda = 0.5$.

Figure 2: Pass-through and exposure for different market shares



Note: The figure plots pass-through and exposure as functions of λ, holding product substitutability constant at $\rho = 0.5$.

Figure 3: Pass-through and exposure as functions of the convexity of costs



Note: The figure plots pass-through and exposure as functions of the convexity of costs, α, holding ρ and λ constant at $\rho = 0.5$ and $\lambda = 0.5$.