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EQUIVALENCE RESULTS FOR OPTIMAL PASS-THROUGH, OPTIMAL INDEXING TO EXCHANGE RATES, AND OPTIMAL CHOICE OF CURRENCY FOR EXPORT PRICING

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Equivalence Results for Optimal Pass-Through, Optimal Indexing to Exchange Rates, and Optimal Choice of Currency for Export Pricing
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ABSTRACT

Firms sometimes write price lists or catalogs for their exports, so they set prices for a period of time and do not adjust prices during that interval in response to changes in their environment. The firm sets the price either in its own currency or the importer's currency. This paper draws a simple link between the choice of currency, and the pricing decision of a firm that changes prices in response to all shocks. Specifically, if the latter firm's price has a lower variance in terms of its own currency than the importer's currency, then the firm with a price list will set the price in its own currency (and otherwise it will set price in the foreign currency.) This relationship is established by consideration of the firm with a price list as a special case of a firm that indexes its export price to the exchange rate.

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Exporting firms frequently have price lists or catalogs for their exported products. The price is set for an interval of time, and does not respond to changes in the environment (such as changes in demand or production costs) during that period. Firms typically set a price either in their own currency or the importer's currency. An extensive literature has investigated the optimal currency of price setting.[1]

A related literature examines the optimal export price. In some of the literature, the firm is assumed to respond to all shocks that might influence its price.[2] Another strand of the literature assumes that export prices are set for a period of time, and examines the factors that influence the price (with the currency of invoicing given, rather than chosen optimally.)[3]

Here we draw a link between the literature on currency of price setting and the literature in which firms can choose their price with knowledge of all shocks. In the latter case, if the variance of the export price in the firm's own currency is less than the variance of the price in the local currency of the importer, we say this firm's price exhibits "producer currency stability (PCS)". If the opposite relationship holds, the firm's export price exhibits "local currency stability (LCS)". Now suppose the firm faces the same environment, but must set a price prior to knowledge of the shocks. The main theorem of this paper is: It is optimal for the firm to set its price in its own currency – "producer currency pricing (PCP)" – under precisely the conditions in which the firm would be PCS if its price responded freely to shocks. The exporter will set price

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1 Baron (1976), Giovannini (1988), Donnenfeld and Zilcha (1991), Friberg (1998), Devereux, Engel, and Storgaard (2004), Bacchetta and van Wincoop (2002, 2003), Corsetti and Pesenti (2004b), and Goldberg and Tille (2004) are examples.

2 Krugman (1987), Dornbusch (1987), Baldwin (1988), Froot and Klemperer (1989), Marston (1990), Goldberg and Knetter (1999), Goldberg and Verboven (2001), Bergin (2003), Goldberg and Campa (2004), and Corsetti and Dedola (2004) are examples.

3 Examples include Feenstra (1989), Feenstra and Kendall (1997), Bacchetta and van Wincoop (2000), Obstfeld and Rogoff (2002), Bergin and Feenstra (2001), and Corsetti and Pesenti (2004a).

in the importer's local currency – "local currency pricing (LCP)" – if and only if the firm would be LCS if its price were freely adjusted.[4]

The proof of this result also draws some interesting links. A firm that chooses between PCP and LCP is a special case of a firm that chooses the optimal index of its export price to the exchange rate. The PCP firm changes its export price (in the importer's currency) one-for-one with the exchange rate, while the LCP's export price (in the importer's currency) does not change at all with the exchange rate. More generally, we consider a firm that indexes the log of its export price to the log of the exchange rate with an affine function. We show that the slope coefficient in this index function is equal to the slope coefficient from regressing the log of the export price on the log of the exchange rate for the firm that adjusts its price freely to all shocks (not just to the exchange rate.) This result is used as a lemma in the proof of the main theorem.[5]

There are perhaps three ways to view the contribution of this paper. First, from a prescriptive standpoint, the main theorem in this paper might simplify the problem of a firm trying to decide between invoicing in its own currency or the importer's currency. The literature that examines theoretically how exchange rate changes should pass-through to export prices can be applied to choosing a currency for pricing. For example, it has been shown that exchange rate pass-through should be low when demand becomes more elastic as the price rises, when substantial costs are incurred in the importer's currency, when the destination market is highly competitive, etc. Under these same conditions, setting the price in the importer's currency will be optimal.

[4] This result is demonstrated using a second-order approximation of the firm's objective function under uncertainty. Friberg (1998) also links the invoicing literature to the price-setting literature. This paper generalizes Friberg's result in a way that is clarified below.

[5] Corsetti and Pesenti (2004a) build a general equilibrium model in which firms index to exchange rates, but the degree of indexation is taken as given. Corsetti and Pesenti (2004b) and Goldberg and Tille (2004) build models in which the degree of indexation is chosen optimally. Tille's note to me linking an earlier version of this paper to Goldberg and Tille (2004) is what led me to the lemma described here. Tille's note shows that the relationship in the lemma holds in the model of Goldberg and Tille (2004).

The second contribution is to clarify the links between the literature on pass-through, and the literature on currency of pricing. Such a clarification might be particularly useful in the context of some macroeconomic models. In a large class of macro models, business cycle behavior is driven by nominal price stickiness. It is the slow adjustment of nominal prices that leads monetary shocks to have real effects in these models, for example. But the behavior of the macroeconomy depends on whether firms are PCP or LCP.[6] Several recent macroeconomic papers have endogenized the currency of pricing in different settings,[7] but the main theorem in this study might help organize these findings.

Third, the main theorem provides a caution in interpreting empirical work on the relationship between exchange rates and prices. The theorem suggests that without further refinement, finding that prices do not respond much to exchange rates is difficult to interpret either as support or contradiction for the notion that nominal prices are "sticky". This warning cuts both ways. Export prices may respond very little to exchange rate changes even when firms are free to adjust their prices continuously. That is, the firms might be LCS, not LCP. Conversely, empirical confirmation of models in which there is LCS could also be interpreted as evidence of LCP. For example, some recent studies have found support for models of firms with freely-adjustable prices in which local distribution services are an important part of the cost of exported goods.[8] The studies conclude that the local-currency stability of the price of these distribution services is a major explanation for local currency stability of export prices. Our theorem says that under these same conditions, if export prices cannot be adjusted in response to shocks, they should be set in the local-currency price. Without a more detailed study of the

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[6] This point has been emphasized especially by Devereux and Engel (2003) and Corsetti and Pesenti (2004a).
[7] In particular, see Devereux, Engel, and Storgaard (2004), Bacchetta and van Wincoop (2002, 2003), Corsetti and Pesenti (2004b), and Goldberg and Tille (2004).
[8] For example, Goldberg and Verboven (2001), Burstein, Neves, and Rebelo (2003), Burstein, Eichenbaum, and Rebelo (2002), and Goldberg and Camap (2004).

adjustment of prices to distinguish the two types of models, the evidence could be consistent with either LCS or LCP.[9]

As Friberg (1998) has pointed out, exporting firms do not reset prices at the same frequency as asset markets reset exchange rates. In some sense, Friberg argues, the models in which prices are set in advance must be the ones that are relevant in determining the effects of exchange rates on export prices. But for macroeconomic models, the relevant distinction is not whether goods prices change as quickly as asset prices, but whether the slow adjustment of goods prices is relevant for understanding the business cycle. While the model presented here is static, it suggests that the same factors that determine pass-through in a sticky-price setting influence pass-through in a flexible-price setting. Then a careful study of the dynamics of price adjustment is needed to determine whether price adjustment is slow enough to play a significant role in macroeconomic adjustment. A snapshot of the pass-through elasticity cannot determine this.

1. Models of Export Pricing

We consider the price setting decision for a monopolistic firm that sells in a single foreign market. First we take the case in which the firm can choose the price for its product with full information about demand, costs, etc. The firm sets a nominal price for its product in order to maximize profits denominated in its own currency. Because prices can respond fully to all information (that is, there is no price stickiness), finding the optimal nominal price and optimal real price are equivalent problems, and it is irrelevant whether the objective function is stated in

[9] Examples of empirical studies that have explicitly allowed for both slow nominal price adjustment and incomplete long-run pass-through are Marston (1990) and Goldberg and Verboven (2005).

real or nominal terms. It is helpful, however, to express these in nominal terms to facilitate comparison later with models in which prices are set without full information on the state.

The firm chooses p^*, the log of the foreign currency price of its export to maximize the twice-differentiable concave profit function $\pi(p^*, \mathbf{x})$. $\mathbf{x}$ is a vector of variables that affect the firm's profits but are exogenous to the firm. This vector might include the exchange rate.

The first-order condition is:

(1) $$\pi_p(p^*, \mathbf{x}) = 0 .$$

Linearize this function around $\mathbf{x} = \bar{\mathbf{x}}$, where $\bar{\mathbf{x}}$ is the mean of $\mathbf{x}$, and $p^* = \tilde{p}^*$, where $\tilde{p}^*$ is the value of p^* that satisfies $\pi_p(\tilde{p}^*, \bar{\mathbf{x}}) = 0$. We get:

(2) $$\pi_{pp}(\tilde{p}^*, \bar{\mathbf{x}}) \cdot (p^* - \tilde{p}^*) + \pi_{px}(\tilde{p}^*, \bar{\mathbf{x}})' \cdot (\mathbf{x} - \bar{\mathbf{x}}) = 0 ,$$

where $\pi_{px}(\tilde{p}^*, \bar{\mathbf{x}})$ is a vector whose *i*th element is $\partial^2 \pi(p^*, \mathbf{x}) / \partial p^* \partial x_i$. Alternatively, equation (2) is the first-order condition for choosing p^* to maximize a second-order approximation (around $\mathbf{x}$ and $\tilde{p}^*$) of the objective function.[10]

Solving (2), we get:

(3) $$\hat{p}^* = \tilde{p}^* - \frac{\pi'_{px}(\tilde{p}^*, \bar{\mathbf{x}})}{\pi_{pp}(\tilde{p}^*, \bar{\mathbf{x}})} \cdot (\mathbf{x} - \bar{\mathbf{x}}) ,$$

where $\hat{p}^*$ is the optimal value of p^* for this firm. The *unconditional pass-through elasticity* – the coefficient in the projection of $\hat{p}^*$ on s (the log of the exchange rate expressed as the home currency price of foreign currency) – satisfies

(4) $$b_{p^*s} = \frac{\pi'_{px}(\tilde{p}^*, \bar{\mathbf{x}})}{\pi_{pp}(\tilde{p}^*, \bar{\mathbf{x}})} \cdot \mathbf{b}_{xs} ,$$

[10] Specifically, the second-order approximation (using $\pi_p(p^*, \mathbf{x}) = 0$) is given by
$$\pi(p^*, \mathbf{x}) \approx \pi(\tilde{p}^*, \bar{\mathbf{x}}) + \pi_x(\tilde{p}^*, \bar{\mathbf{x}})'(\mathbf{x} - \bar{\mathbf{x}}) + .5\left\{\pi_{pp}(\tilde{p}^*, \bar{\mathbf{x}})(p^* - \tilde{p}^*)^2 + (\mathbf{x} - \bar{\mathbf{x}})'\pi_{xx}(\tilde{p}^*, \bar{\mathbf{x}})(\mathbf{x} - \bar{\mathbf{x}}) + 2(p^* - \tilde{p}^*)\pi_{px}(\tilde{p}^*, \bar{\mathbf{x}})'(\mathbf{x} - \bar{\mathbf{x}})\right\}$$

where the *i*th element of the vector $\mathbf{b}_{xs}$ is equal to the coefficient in the projection of x_i on *s*.

Now set aside this case in which the firm can set its price with knowledge of all the components of **x**, and turn to the case in which the firm must set its price without knowledge of any components of **x**. Suppose, though, that the firm can commit to setting *p** as an affine function of *s*: $p^* = p_0 + \beta s$. The firm is assumed to maximize a second-order approximation of the profit function, discounting profits by the factor *D*. The expansion is around $\bar{D}$ (the mean of *D*), and $\bar{\mathbf{x}}$ and $\tilde{p}^*$ defined above:

$$ED\pi(p^*,\mathbf{x}) \approx \bar{D}\pi(\tilde{p}^*,\bar{\mathbf{x}}) + \pi(\tilde{p}^*,\bar{\mathbf{x}})E(D-\bar{D}) + \bar{D}\pi_p(\tilde{p}^*,\bar{\mathbf{x}})E(p^*-\tilde{p}^*) + \bar{D}\pi_x(\tilde{p}^*,\bar{\mathbf{x}})'E(\mathbf{x}-\bar{\mathbf{x}})$$
$$+.5\left\{\bar{D}\pi_{pp}(\tilde{p}^*,\bar{\mathbf{x}})E(p^*-\tilde{p}^*)^2 + \bar{D}E(\mathbf{x}-\bar{\mathbf{x}})'\pi_{xx}(\tilde{p}^*,\bar{\mathbf{x}})(\mathbf{x}-\bar{\mathbf{x}}) + 2\bar{D}E(p^*-\tilde{p}^*)\pi_{px}(\tilde{p}^*,\bar{\mathbf{x}})'(\mathbf{x}-\bar{\mathbf{x}})\right\}$$

$\pi_{xx}(\tilde{p}^*,\bar{\mathbf{x}})$ is a matrix whose *ij*th element is $\partial^2\pi(p^*,\mathbf{x})/\partial x_i \partial x_j$. All of the first order terms in this expansion drop out, because $E(D-\bar{D})=0$, $E(\mathbf{x}-\bar{\mathbf{x}})=0$, and $\pi_p(\tilde{p}^*,\bar{\mathbf{x}})=0$. Simplifying, dropping the constant term, and then dropping $\bar{D}$ which multiplies all remaining terms, we can write the objective as:

(5) $$\pi_{pp}(\tilde{p}^*,\bar{\mathbf{x}})E(p^*-\tilde{p}^*)^2 + E(\mathbf{x}-\bar{\mathbf{x}})'\pi_{xx}(\tilde{p}^*,\bar{\mathbf{x}})(\mathbf{x}-\bar{\mathbf{x}}) + 2E(p^*-\tilde{p}^*)\pi_{px}(\tilde{p}^*,\bar{\mathbf{x}})'(\mathbf{x}-\bar{\mathbf{x}})$$

Notice that the discount factor has completely disappeared from the approximated objective function. This arises from a fairly general assumption about *D* – that it is exogenous for the firm, and so not a function of the firm's price. For example, if the firm is simply maximizing real profits (in terms of purchasing power of the firm's owners), then *D* is the inverse of the consumer price index for the firm's owners. But firm owners might be risk averse, so *D* could be the marginal utility of an increment to profit denominated in the currency of the exporter. In short, this objective for the firm holds under a variety of possible assumptions about the objectives of the firm managers and the structure of asset markets and possibilities for hedging. The assumption that *D* is exogenous to the firm does rule out some possibilities, however. Suppose a single household owns the firm, and the owner-manager discounts profits by marginal utility. The outcome for the firm might directly affect the level of consumption of the owner, and thus the marginal utility. The assumption that *D* is exogenous to the firm would be violated. An exogenous discount factor is more sensible when, for example, there are many owners of the firm, and there are many other sources of income for each owner. Thus our assumption of an exogenous discount factor is violated in the models of Feenstra and Kendall (1997) and the model of risk-averse firm owners in Friberg (1998), who assume in essence that firm owners' only income is from profits (so that the firm maximizes the expected utility of profits.)

Replacing p^* with $p_0 + \beta s$, we find the first-order conditions for choosing p_0 and β, respectively:

$$\pi_{pp}(\tilde{p}^*, \overline{\mathbf{x}}) E(p_0 + \hat{\beta} s - \tilde{p}^*) = 0,$$

$$\pi_{pp}(\tilde{p}^*, \overline{\mathbf{x}}) Es(p_0 + \hat{\beta} s - \tilde{p}^*) + \pi_{px}(\tilde{p}^*, \overline{\mathbf{x}})' Es(\mathbf{x} - \overline{\mathbf{x}}) = 0,$$

where $\hat{\beta}$ is the value of β that maximizes the objective. From the first condition, we have $p_0 = -\hat{\beta}\overline{s} + \tilde{p}^*$. Substitute into the second condition to get:

$$\hat{\beta}\pi_{pp}(\tilde{p}^*, \overline{\mathbf{x}}) Es(s - \overline{s}) + \pi_{px}(\tilde{p}^*, \overline{\mathbf{x}})' Es(\mathbf{x} - \overline{\mathbf{x}}) = 0.$$

Solving for $\hat{\beta}$, we find

$$\hat{\beta} = \frac{\pi'_{px}(\tilde{p}^*, \overline{\mathbf{x}})}{\pi_{pp}(\tilde{p}^*, \overline{\mathbf{x}})} \cdot \frac{\mathrm{cov}(s, \mathbf{x})}{\mathrm{var}(s)}. \tag{6}$$

Comparison of equations (4) and (6) immediately gives us:

Lemma The unconditional pass-through elasticity when prices are set flexibly, b_{p^*s}, equals the exchange-rate elasticity of the import price index, $\hat{\beta}$.

Intuitively, a firm that can commit to set the log of the price as a linear function of the log of the exchange rate operates exactly like a firm that can observe the exchange rate when setting its price. If that firm can observe only *s*, and not other elements of **x**, then it will form its optimal linear forecast of $\hat{p}^*$ by taking the projection of $\hat{p}^*$ on *s*. So the indexing firm in essence is a flexible-price firm that must set $\hat{p}^*$ as a linear function of *s* and nothing else.

We can now consider the more realistic case of a firm that must set a price for export either in its own currency, or the currency of the importer. This firm can be thought of as choosing an index function, $p_0 + \beta s$, but with only two choices of β, 0 or -1. If $\beta = 0$, the export price is constant in the foreign currency, so the firm is local-currency pricing (LCP). If $\beta = -1$, the price is constant in the producer's currency, so the firm is producer-currency pricing (PCP).

The main theorem draws a link between the choice facing this firm, and the firm that can set price with full knowledge of **x**. For the full-knowledge firm, we say there is local-currency price stability (LCS) when the variance of the price in the importer's currency is less than the variance in the producer's currency: $\text{var}(p^*) < \text{var}(p^* + s)$. In the opposite situation, there is producer-currency price stability (PCS).

Theorem: When a firm must set its price in advance and choose between LCP or PCP, it chooses LCP under exactly the same conditions in which the firm that prices with full information has LCS pricing. Likewise, the firm that sets price in advance chooses PCP if and only if the full-information firm chooses PCS pricing.

Proof: The objective function of the firm that sets price in advance is continuous in β. Because the function is quadratic, it is symmetric around its unique maximum point, $\hat{\beta}$, given in equation (6). Because the quadratic function is continuous, strictly concave and symmetric, the value of the objective function is higher for $\beta = 0$ than for $\beta = -1$ (so LCP is preferred) when $\hat{\beta} > -0.5$, and PCP is preferred when $\hat{\beta} < -0.5$.

But if $\hat{\beta} > -0.5$, then from the Lemma, $b_{ps} > -0.5$. This implies $Cov(\hat{p}^*, s) + 0.5 \cdot Var(s) > 0$. Add $0.5 \cdot Var(\hat{p}^*)$ to each side of this inequality, and we get $0.5 \cdot Var(\hat{p}^*) + Cov(\hat{p}^*, s) + 0.5 \cdot Var(s) > Var(\hat{p}^*)$, which is equivalent to $Var(\hat{p}^* + s) > Var(\hat{p}^*)$, the condition for LCS. ■

An alternative interpretation of the theorem, which is evident from the proof, is that the invoicing firm will choose LCP when the unconditional pass-through elasticity is less than one-half for the full-information price-setter. So, the firm that sets its price in advance will choose zero pass-through exactly in the case in which the firm that sets prices freely allows only low unconditional pass-through. Conversely, the pricing-in-advance firm chooses PCP, and hence a pass-through elasticity of one, under the same conditions that the full-information firm chooses high unconditional pass-through (elasticity greater than one-half.)

2. Discussion

As an example,[11] consider a firm that faces a demand curve, $Y^D = G(P^* / Z)N$. P^* is the foreign currency price of the firm's product, Z is a price index of products that are substitutes for our firm's product, and N represents other factors that shift demand. We assume that the product

[11] This example is worked out in great detail in an earlier draft of this paper, Engel (2003).

is produced using two variable inputs: one local and one foreign. The local input might be labor used to produce the product, and the foreign input might be foreign labor used to distribute the product, or to assemble imported intermediate goods into final products. The cost function takes the form: $C(Y)\cdot H(W_1, SW_2^*)$, $C' > 0$. C'' may be positive or negative.[12] Y refers to output for the firm. We assume $H(.,.)$ is homogeneous of degree 1. W_1, is the home-currency nominal unit factor costs for the home input. W_2^* is the cost of the foreign-currency price of the foreign input. S is the home currency cost of foreign currency.

Application of equation (3) in this case gives us:

$$p^* = \frac{\varepsilon + \delta\gamma(\gamma-1)}{\Delta} z + \frac{\delta(\gamma-1)}{\Delta} n + \frac{\omega(\gamma-1)}{\Delta}(w_1 - s) + \frac{(1-\omega)(\gamma-1)}{\Delta} w_2^*,$$

where lower case letters are the logs of their upper-case counterparts. Here, we have $\gamma \equiv -P^* G' / Z\, G$ (the elasticity of demand for the product), $\varepsilon \equiv P^* \gamma' / Z\gamma$ (the elasticity of the elasticity of demand), $\delta \equiv C'' Y / C'$ (a measure of concavity or convexity of the cost function), $\omega \equiv H_1 W_1 / H$ (factor 1's share of costs), and $\Delta \equiv \gamma - 1 + \varepsilon + \delta\gamma(\gamma-1)$.[13]

We have from this equation that b_{p^*s} is given by:

$$b_{p^*s} = \frac{\varepsilon + \delta\gamma(\gamma-1)}{\Delta} b_{zs} + \frac{\delta(\gamma-1)}{\Delta} b_{ns} + \frac{\omega(\gamma-1)}{\Delta} b_{w_1 s} + \frac{(1-\omega)(\gamma-1)}{\Delta} b_{w_2^* s} - \frac{\omega(\gamma-1)}{\Delta}.$$

It follows that PCP is optimal when

(7) $$[\varepsilon + \delta\gamma(\gamma-1)] b_{zs} + \delta(\gamma-1) b_{ns} + \omega(\gamma-1) b_{w_1 s} + (1-\omega)(\gamma-1) b_{w_2^* s} < \frac{(2\omega-1)(\gamma-1) - \varepsilon - \delta\gamma(\gamma-1)}{2}$$

This example can be related to some of the literature on optimal currency of pricing:

[12] There is a second-order conditions for a maximum to be satisfied (see below).
[13] $\Delta > 0$ by the second-order condition for profit maximization.

The necessary and sufficient condition derived in Devereux, Engel, and Storgaard (2004) for PCP pricing is a special case of this condition when $\varepsilon = 0$ (so demand is constant elasticity), $\delta = 0$ (so the cost function is linear in output), $\omega = 1$ (so only local inputs are used), and $\gamma > 1$. In that case, the condition reduces to $b_{w_1 s} < \frac{1}{2}$ (which corresponds to their Proposition 1.)

The necessary and sufficient condition for PCP pricing in the so-called "old-style" partial equilibrium model of Bacchetta and van Wincoop (2002) is also a special case, when the exchange rate is the only stochastic variable, $\varepsilon = 0$, $\omega = 1$, and $\gamma > 1$. In that case, equation (7) becomes $\delta\gamma < 1$ (which corresponds to their Theorem 1.) The condition for PCP pricing in Bachetta and van Wincoop's more general model can also be interpreted as a special case of equation (7). That model allows for the price of competing goods to covary with the exchange rate – that is, $b_{zs} \neq 0$, but still maintains $\varepsilon = 0$, $\omega = 1$, and $\gamma > 1$. Under these assumptions, equation (7) reduces to $\delta\gamma(1 + 2b_{zs}) < 1$.

Bacchetta and van Wincoop (2003) consider a model in which there are two stages of production: exporters sell intermediate goods to final producers, who in turn sell to consumers. If the final producers are LCP, then the exporting firm's problem is a special case of the one considered here in which the only stochastic variable is the exchange rate, $\varepsilon = 0$, $\omega = 1$, and $\gamma > 1$. (The input for exporters is the wage in the exporting country, and *Z* is the price of final goods. *Z* is nonstochastic when final goods producers follow LCP.) The condition for the exporter to price in its own currency is then the special case of equation (7) given by $\delta_I \gamma_I < 1$ (as in their Theorem 1), where δ_I measures the curvature of the exporting firm's production function and γ_I is the elasticity of demand faced by exporters. If the exporters are PCP, then the final goods producers also have a problem that is the same special case. The input price is the price of the export good which is priced in the exporter's currency (so $\omega = 1$), and only the exchange rate is stochastic. The condition for LCP pricing is a special case of equation (7): $\delta_F \gamma_F > 1$ (as in their Theorem 2), but now δ_F relates to the final goods producers' technology, and γ_F is the elasticity of demand of final goods consumers. Bacchetta and van Wincoop then conclude there is a Nash equilibrium in which exporters play PCP and final goods producers play LCP if $\delta_I \gamma_I < 1$ and $\delta_F \gamma_F > 1$.

Giovannini (1988) finds that the condition for PCP pricing in a partial equilibrium model is that the profit function is convex in exchange rates. His model is the special case in which the exchange rate is the only random variable (so the entire left-hand side of the inequality in equation (7) is zero) and $\omega = 1$. In that case, the condition for PCP pricing reduces to $(1-\delta\gamma)(\gamma-1)-\varepsilon > 0$, which is precisely the condition that the profit function is convex in the exchanger rate.

Friberg (1998), like this paper, compares pass-through under flexible prices to conditions for PCP vs. LCP when nominal prices are set in advance. He, like Giovannini (1988), considers the special case in which the exchange rate is the only random variable and $\omega = 1$. In this case, in the flexible price model, we have $-b_{p^*s} = \dfrac{\gamma-1}{\gamma-1+\varepsilon+\delta\gamma(\gamma-1)}$. Since Friberg assumes $\gamma > 1$ and $\delta > 0$, a sufficient condition for the pass-through coefficient ($-b_{p^*s}$) to be less than one is $\varepsilon > 0$. An even stronger condition is $\varepsilon > \gamma$. Turning to the sticky-price models, under Friberg's assumptions, the condition for firms to choose LCP pricing is $(1-\delta\gamma)(\gamma-1)-\varepsilon < 0$. This condition is met when $\varepsilon > \gamma$. This is Friberg's theorem: that when $\delta > 0$ (and in the confines of his set-up in which the exchange rate is the only random variable and $\omega = 1$), then a sufficient condition for both LCP pricing and a pass-through coefficient less than one is $\varepsilon > \gamma$. Friberg does not fully characterize the conditions for LCP vs. PCP pricing (even in his set-up), and so does not arrive at our theorem: a necessary and sufficient condition for LCP pricing is that the pass-through coefficient be less than ½.

Finally, note the role of distribution costs incurred in the importing country. If prices are set with full information about the exogenous variables affecting profits, then when distribution costs are a large share of total costs (when $1-\omega$ is close to one) there will be a large elasticity of p^* with respect to w_2^*. If wages are very stable (have low variance and therefore a low covariance with the exchange rate) and ω is close to zero, then the import price will tend to be stabilized in the importer's currency. That is the result noted by, for example, Goldberg and Verboven (2001); Burstein, Neves, and Rebelo (2003); Burstein, Eichenbaum, and Rebelo (2002); and, Goldberg and Campa (2004). That result says that if distribution costs are significant, and those costs are relatively stable in the importer's currency, then the apparent pass-through of the exchange rate to the final goods price will be low.

But under these same conditions, LCP will be optimal. That is, when distribution costs are a large share of total costs, and when the wage in the importing cost is stable, it is optimal for the exporting firm to set the price in the consumer's currency.

To elaborate on this condition, consider the case in which the production function is CES, so that $H(W_1, SW_2^*) = (\lambda W_1^{1-\alpha} + (1-\lambda)(SW_2^*)^{1-\alpha})^{\frac{1}{1-\alpha}}$. Then we have

$$1-\omega = \frac{(1-\lambda)(SW_2^*)^{1-\alpha}}{\lambda W_1^{1-\alpha} + (1-\lambda)(SW_2^*)^{1-\alpha}}.$$

In the Cobb-Douglas case $(\alpha = 1)$, we have $1-\omega = 1-\lambda$. In that case, the unconditional pass-through is lower the larger the share $1-\lambda$ of foreign inputs into the production process. That is also the case, as the theorem states, in which LCP is more likely. When foreign and domestic inputs are combined in fixed proportions (as in the model of Burstein, Eichenbaum and Rebelo (2002) in which labor in the importing country is used to distribute the good), we find $1-\omega = \frac{(1-\lambda)SW_2^*}{\lambda W_1 + (1-\lambda)SW_2^*}$. Under flexible prices, pass-through will be low when the cost of distribution services is high and $1-\lambda$ is large, but again those are also the circumstances in which the exporter that invoices prefers LCP.

Equation (7) is a general statement of a standard model of pass-through in the international trade literature, and suggests empirically testable propositions. Pass-through should be high when equation (7) is satisfied, and low otherwise. But empirical evidence of this link – that, for example, pass-through is low when the distribution share is high, or when demand becomes more elastic at higher prices ($\varepsilon > 0$) – does not distinguish whether the flexible-nominal-price model or the sticky-nominal-price approach is appropriate for macroeconomic modeling. The theorem of this paper shows that both types of models imply high pass-through when the condition of equation (7) is met, and low pass-through when it is not. The work cited above finding a link between high distribution shares and low pass-through, or the studies cited in Goldberg and Knetter (1997) uncovering a link between variable elasticity of demand and pass-through,[14] do not help us draw inferences about the applicability of flex-price vs. sticky-price models of import pricing.

It is worth noting a few precautions in interpreting these results. First, all of the discussion above pertains to the behavior or a single firm taking the economy as given. Some of the papers mentioned cast the firm in a general equilibrium context, but condition (7) takes the vector of regression coefficients, $\mathbf{b}_{xs}$, as given to the firm. In general equilibrium, these are

[14] For example Aw (1993), and Goldberg and Knetter (1998) find such links.

endogenous. A related point is that the response of aggregate prices to the change in the exchange rate is not determined by this condition.

Second, these results are derived for a second-order approximation to the profit function. In some instances, third or fourth moments may not be small.

An obvious limit to the model presented here is that it is static. There is no claim that the equivalence between the conditions for LCS and LCP (or PCS and PCP) carry through to a dynamic model.

The question of whether nominal prices should be modeled as sticky in a macroeconomic model is clearly a dynamic question. There are very few markets in which goods prices change instantly, as they do in asset markets. But the question that is relevant for macroeconomic modeling is whether prices adjust infrequently enough that slow-price adjustment becomes an important determinant of business-cycle behavior. There is no consensus of how infrequently prices must adjust before they can be labeled “sticky”.

One of the most contentious debates in macroeconomics is whether price stickiness is an important feature of the macroeconomy that can explain, for instance, the persistence of output or unemployment over the business cycle. In the open-economy context, some studies have asked how infrequent price adjustment must be if slow nominal price adjustment is to explain the persistence of deviations from purchasing power parity. Chari, Kehoe, and McGrattan (2002) demonstrate in one sticky-price model that even when prices are set by firms only annually, the persistence of the real exchange rate cannot be matched. In their data, the first-autocorrelation of HP-filtered quarterly real exchange rates for OECD economies is around 0.8, but their model produces an autocorrelation of only about 0.6. But Bergin and Feenstra (2001) have somewhat more success in matching real exchange rate persistence in a model with translog preferences that assumes prices are reset once per year. Benigno (2004) finds, on the other hand, that real exchange rate persistence can be explained in a model with even more frequent price adjustment, depending on the interest-rate rule applied by the monetary authorities.

The intuition of the result of this paper is that firms prefer to invoice in the importer's currency when their optimal price (if they could observe all factors affecting the pricing decision when they set the price) is stable in the importer's currency. But whether the local-currency price stability that we observe is consistent with a degree of sluggishness that is relevant for macroeconomic modeling would require testing a fully dynamic model of price setting that can identify the speed of adjustment.[15]

[15] Marston (1990), Goldberg and Verboven (2005), Choudhri, Faruqee, and Hakura (2003), and Devereux and Yetman (2004) are examples of models that attempt to measure the speed of adjustment of prices using micro-based models.

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