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On the Role of Pricing Exports in a Third Currency

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Abstract

The share of Swedish exports that are invoiced in U.S. dollars has doubled comparing a sample from 1968 with figures from 1993. There has been no corresponding increase in Swedish trade with the United States. This serves as motivation for our interest in price setting/invoicing in a third currency. We investigate the role of pricing in the importers', exporter's or a third currency in a simple model with pre-set prices. The firm of study is a risk neutral monopolist exporter who faces a linear demand curve. Expected prices, quantities and profits depend on the price setting currency chosen. Also the curvature of realised profits as a function of exchange rate surprises depends on the price setting currency chosen. In an extension we discuss the role of competition from a third country in a model of Bertrand competition in differentiated goods.

Keywords: invoicing, exchange rate fluctuations, pricing of exports
JEL Classification: F14, F23

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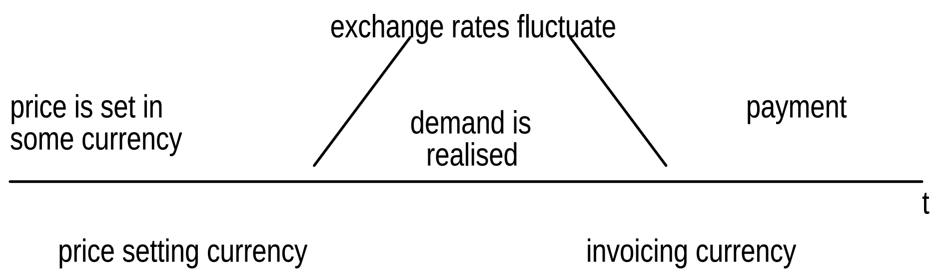
1. Introduction

How prices respond to exchange rate fluctuations has received much attention during the last decade[1]. The related question of how the value and profits of different firms are exposed to exchange rate changes has also received a fair amount of attention[2]. This paper will attempt to provide some insights into the role that the currency that export prices are set in may play for these kinds of problems.

We model a situation where an exporter sets a price in some currency under exchange rate uncertainty. We call this the price setting currency. Demand is realised after exchange rates are known. Typically international trade also involves a lag between the determination of quantity and the actual payment taking place. The currency used for the actual payment is referred to as the invoicing currency. We illustrate the situation in figure 1.

Figure 1



In this paper we will focus on the study of price setting currency. In studying the role of price setting currency when prices are pre-set we follow Baron (1976), Giovannini (1988) and Donnenfeld and Zilcha (1991)[3]. The main contribution is to

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[1] The literature on pricing-to-market and exchange rate pass-through has expanded rapidly. For a survey see Menon (1995).

[2] See for instance Bartov and Bodnar (1994), Jorion (1990), Adler and Dumas (1984).

[3] Baron (1976) and Donnenfeld and Zilcha (1991) study the price setting currency but use the terms price setting and invoicing currency interchangeably.This is somewhat unfortunate as they may differ as noted above. In reality they tend to be the same however according to Giovannini (1988). The

extend previous analysis to include the choice of price setting in a third currency, a currency that is neither that of the importer or the exporter. Another contribution is the explicit modelling of foreign competition.

We know of no systematic evidence on which price setting currencies that are used in international trade. There has been some study of what invoicing currency that is used and as it can be expected that the two often coincide we will discuss this evidence. A seminal empirical contribution was made by Grassman (1973). Grassman studied the currency denomination of Swedish exports and imports using data from 1968. Grassman's main finding was that exporters tended to invoice in their own currency. In Grassman's sample 66% of Swedish exports but only 26% of imports were invoiced in Swedish kronor. Grassman found that 12% of Swedish exports were invoiced in U.S. dollars. The share of exports to the United States as a percentage of total Swedish exports was 8%.

There are some other empirical studies of what invoicing currency that is used in international trade. The ones that we are aware of use data from the 1970's[4]. In most instances they find the same pattern as Grassman does, that exports are mainly denominated in the exporter's currency. This finding, that foreign trade is mainly invoiced in the exporter's currency, is commonly referred to as Grassman's law.

In 1993 the currency distribution of payments for Swedish trade in goods were as shown by table 1[5]. Within parenthesis is indicated the share of Swedish imports and exports from and to the relevant countries (USA, Germany, Rest of World).

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price setting currency relates to the unit of account role of money. The invoicing currency relates to the store of value and medium of exchange role of money.

[4] Page (1977), Van Nieuwkerk (1979). Black (1985) reports data from 1976. See Bilson (1983) for a summary of "stylized facts" and qualifications of Grassman's law.

[5] The data are taken from from the settlement reports of the Swedish Riksbank. All payments through Swedish banks above a threshold of SEK 75,000 (somewhat more than USD 10,000) are reported.

Table 1

Invoicing Currency used in Swedish Trade in Goods 1993[6]

Currency	Imports	Exports
SEK	27.0%	37.1%
USD	25.5% (9.1%)	23.4% (8.4%)
DEM	16.7% (17.9%)	10.7% (14.4%)
OTHER	30.8% (73%)	28.8% (77.2%)

Table 1 indicates that Grassman's law did not hold for Sweden in 1993. We also note that it is not an uncommon practice for firms to invoice in a "third currency", a currency that is neither that of the importer nor that of the exporter. This is established by comparing the share of the U.S. dollar in invoicing with the share of Swedish trade with the United States[7]. Compared with Grassman's sample the share of exports invoiced in dollars has doubled. The most striking observation is the sharp decline in the use of Swedish kronor as invoicing currency between 1968 and 1993.

We note that the evidence presented in table 1 may reflect shifts in "pure" invoicing currencies as well as in currency denomination of intra-firm trade. The evidence nevertheless lead us to an interest in the determinants and implications of the price setting currency. The redrawing of the currency map that a European Monetary Union implies would also make us interested in the role and determinants of price setting currencies.

In this paper we will discuss the role of price setting currency for an exporter when price is set before the exchange rate is known[8]. The exporter commits to sell the

[6] Source: Swedish Riksbank and Statistics Sweden

[7] A questionare study in Elvestedt (1980) also points to a significant role of invoicing in US dollars for Swedish exporters. In the study 67% of responding firms invoiced their exports to non-subsidiaries mainly in Swedish kronor, 24% mainly in US dollars and 10% mainly in local currency.

[8] As a floating exchange rate typically fluctuates literally by the minute it would be prohibitively expensive in most markets to reoptimize offer prices every time the exchange rate changes. The study of pre-set prices will therefore perhaps be more interesting than in a domestic economy setting since exchange rates generally fluctuate much more than inflation does.

demanded quantity at the ex post realised price that importers face[9]. In section 2 we will discuss the previous literature and present some intuition for our results. Section 3 outlines and discusses a simple model with a monopolist exporter faced with a linear demand curve and the choice of setting price in any of three currencies (its' own currency, that of importers' or a third currency). Section 4 introduces a competitor based in the third country. Competition is modelled as Bertrand in differentiated goods. Section 5 concludes and discusses possible extensions.

2. Previous Literature and Discussion

Baron (1976) studies the determination of prices and traded quantities under different pricing practices. He does so for the case of a (residual demand) monopolist exporter with a linear demand function. The monopolist produces in one country and sells in an other country. Baron assumes that prices have to be set before the exchange rate is known. The monopolist has the choice between setting the price in his own currency or in the currency of the importers. Baron shows that expected prices, profits and quantities depend on the choice of price setting currency. Giovannini (1988) generalises Baron's analysis by adding a home market and allowing for general demand and cost functions. Donnenfeld and Zilcha (1991) add a decision on what quantities to produce at the outset of the problem.

Donnenfeld and Zilcha (1991) also note the analogy between the problem at study here and the issue of fixing price or quantity for a firm[10]. The nominal exchange rate is the only source of uncertainty in the studies cited above in this section. Setting a price on the export market in the importers' currency thus implies that demand is certain but that the unit price in the exporter's currency is uncertain. The firm thus sets

[9] Donnenfeld and Zilcha (1991) claim support for that the typical international transaction takes this form: first capacity is decided by the producer, new information arrives about the exchange rate, price is set and finally, after the exchange rate is known, orders from buyers arrive and the goods are shipped.

[10] Weitzman (1974), Klemperer and Meyer (1986).

quantity. Setting a price in the exporter's currency implies that the price that the exporter will receive is certain but that demand will be uncertain since the price that foreign consumers' will face is uncertain. This is the equivalent of setting price. This sums up the relevant literature on price setting/invoicing currency that we are aware of[11]. We will now proceed with a discussion of a simplified model along the lines of Giovannini (1988) to discuss the results reached that are relevant for our analysis and the underlying intuition.

The firm of study is an exporter who sells on a single foreign market. Denote the exporter's home country and currency with x and that of the market country with z. Let e, the nominal exchange rate be expressed as the currency x price of currency z. A higher value of e thus implies a depreciation of the exporter's currency relative to that of the market. The analysis is partial equilibrium and e is exogenous. All agents are risk neutral. *The central assumptions are that the exporter has to set price before the exchange rate is known and that demand is realised after the exchange rate is known.* Let e be stochastic. The exporter has the choice between setting the export price in his own or in the importers' currency. We assume that the exporter is constrained to produce in his home country. The exporter's objective is to maximise the expected value of profits in his home currency. Let the markup and the support of the exchange rate be such that it will always be optimal for the exporter to satisfy ex post demand.

[11] There exists some related theoretical work that studies the invoicing currency alone, as separate from the pre-set pricing aspect that we are interested in. Magee and Rao (1979) propose the result that the currency of invoice should be irrelevant in equilibrium. Bilson (1983) studies the sharing of risk between exporter and importer having assumed away forward markets for currencies. Viaene and de Vries (1992) focus on the bargaining over invoicing currency between an exporter and an importer. In the above models it is assumed that the quantity is exogenously given. In the model of Ahtiala and Orgler (1995) the exporter offers importers a choice between different prices in different currencies at the time of sale. Prices are set optimally and depend on the value of holding the different currencies for agents. Quantity is not exogenously given but there is no study of the pre-set pricing aspect that we focus on in this paper.

Näslund (1983) briefly discusses what currency to keep prices stable in when faced with a devaluation. The issue there is one of a one sided bet- which currency should I keep prices stable in to achieve the greatest possible change in revenues due to a devaluation. The reason for keeping prices stable in one currency is assumed to be some form of bounded rationality. Oxelheim and Wihlborg (1987) study issues of pricing strategies and how firms are affected by exchange rate changes. They report results on interviews with the 20 largest Swedish multinationals in 1983-84 and make a "scenario analysis".

When the firm sets price in the **importers' currency** the firm's maximisation problem is given by

(1) $\max\limits_{p_z} E\left(ep_z q(p_z) - C(q(p_z))\right)$

Evaluating the first order condition of (1) we will note that it is a linear function of the exchange rate. A mean preserving spread of *e* will thus leave expected profits unaffected. The price that is set will be independent of the degree of variance in *e*. Let $\bar{e}$ denote the mean exchange rate, $\hat{p}$ the price that has been fixed at the ex ante optimal level and profit by $\Pi_z(p_z, e)$. Then the above discussion implies that following holds

(2) $E(\Pi_z(p_z, e)) = \Pi_z(\hat{p}_z, \bar{e}) = \Pi_z(p_z, \bar{e})$

Expression (2) tells us that when the exporter sets his price in the importers' currency the expected profits under a fluctuating exchange rate are equal to realised profits with pre-set price when the exchange rate is equal to its' mean. Profits are then equal to optimal ex post profits when the exchange rate is equal to its' mean.

When the price is **set in the exporter's currency** before the exchange rate is known profits will typically *not* be a linear function of exchange rate surprises. The firm's maximisation problem is then given by:

(3) $\max\limits_{p_x} E\left(p_x q(p_x / e) - C(q(p_x / e))\right)$

Which price setting currency that gives the ex ante highest expected profits depends on if profits when pricing in the home currency are a concave or convex function of exchange rate surprises. Concavity of profits in the exchange rate implies that the expected value of profits under a fluctuating exchange rate is lower than realised profits if the exchange rate is equal to its' mean. Intuitively the firm gains less from a depreciation than it looses on an appreciation of equal size. Convexity of profits implies the opposite.

Before turning to the comparison of price setting currencies we note that *ex post* optimal profits must be equal no matter what currency that price is denominated in. That is, *if* prices could be set *after* the exchange rate were known both pricing currencies would yield the same profit. All variables are then known and the exporter can set p_x/e fully by choosing p_x.

(4) $\Pi_z(p_z,\bar{e}) = \Pi_x(p_x,\bar{e})$

After last paragraph's detour we again turn to the study of pre-set prices. If profits are a concave function of surprises in the exchange rate then (2) and (4) combined with the definition of profit maximisation (profits when price is set at an ex post optimal level must be at least as high as profits under pre-set prices) and concavity imply that the following inequality holds:

(5) $E(\Pi_z(p_z,e)) = \Pi_z(\hat{p}_z,\bar{e}) = \Pi_z(p_z,\bar{e}) = \Pi_x(p_x,\bar{e}) \geq \Pi_x(\hat{p}_x,\bar{e}) \geq E(\Pi_x(p_x,e))$

Thus if profits are a concave function of exchange rate surprises when setting price in the exporter's currency, expected profits for the exporter are higher when he sets price in the importers' currency. Letting a sub index denote partial derivatives and suppressing arguments we note that the first and second partial derivative of profits when setting price in the exporter's currency are given by

(6) $\dfrac{\partial \Pi_x}{\partial e} = (\hat{p}_x - c_q)q_e$

(7) $\dfrac{\partial^2 \Pi_x}{\partial e^2} = (\hat{p}_x - c_q)q_{ee} - c_{qq}(q_e)^2$

The first derivative is positive, a lower price for importers will increase demand and lead to higher profits. The function is concave if the second derivative, (7), is negative. We thus conclude that pricing in the exporter's currency will yield lower expected profits the

***** the more negative q_{ee} is (a negative value indicating concavity)

* the larger is c_q the more accentuated is the effect through q_{ee} ($c_q \geq 0$, non-negative marginal costs is a standard assumption)

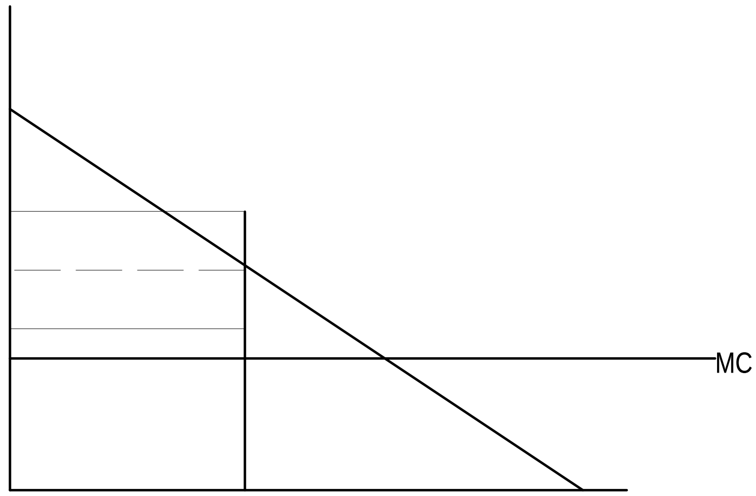
* the larger is $|q_e|$ (the higher the sensitivity of demand to price changes is)

* the larger is c_{qq} ($c_{qq} \geq 0$, convex cost function is a standard assumption)

Given standard assumptions on the cost function (increasing and convex in quantity produced) a sufficient condition for concavity of profits is that the demand function be concave in the exchange rate. This holds for a linear demand function[12]. Note that a demand function that is convex in surprises in *e* is not sufficient to make pricing in the home currency preferred, it has to be convex "enough" to outweigh the effects on costs if the cost function has standard properties. Setting marginal costs constant and letting the demand function be linear gives us the case that Baron (1976) analyses. We will depict this in figures 2 and 3 below. Figure 2 shows how profits will be affected by ex post exchange rate surprises when the firm prices in the importers' currency.

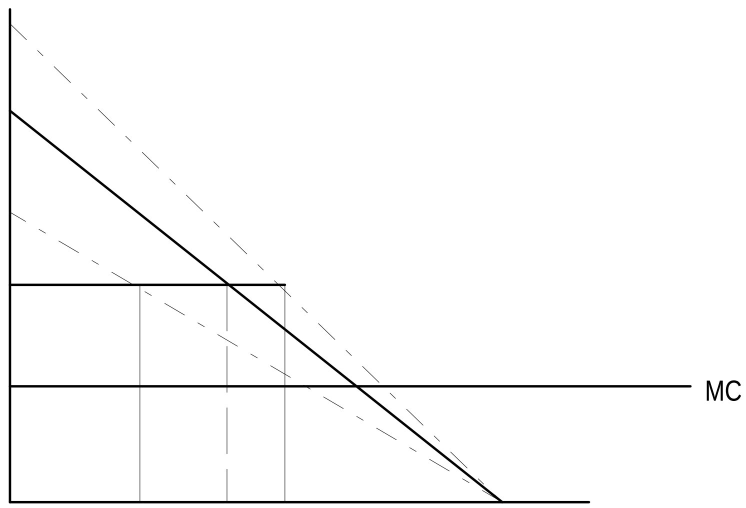
[12] For a constant elasticity demand function with elastic demand it will not hold however. Then demand will be convex in the exchange rate surprises.

Figure 2



We see that demand is not affected by the fluctuating exchange rate. Only the price that the exporter receives fluctuates. A depreciation (higher *e*) raises profits by the area *A* and an appreciation lowers profits by the area *B*. The effect on profits of an exchange rate surprise is of equal size for appreciations and depreciations of equal magnitude. This is an other way saying that profits are linear in the exchange rate. Now turning to the case of pricing in the exporter's currency we study figure 3.

Figure 3



A depreciation shifts the demand curve up and an appreciation shifts it down. It is easily seen in the diagram that the increase in profits due to a depreciation, *C*, is less than the decrease in profits due to an appreciation of equal size, *D*. That is, profit is concave in exchange rate surprises. A positive slope of the marginal cost curve magnifies this effect. Clearly the less sensitive demand is to price changes (lower b, steeper demand curve), the less will quantity and hence profits fluctuate.

We will make a few of observations before turning to our model. If exchange rates are credibly fixed both price setting currencies yield the same expected profit. This clearly has implications for the weight that we can give to empirical observations for pricing and invoicing patterns under the Bretton-Woods period to a situation with a floating exchange rate. We remind ourselves that the empirical evidence cited in the introduction stems from the Bretton-Woods period or shortly thereafter.

There is a close connection between the above analysis and the financial literature on exchange rate exposure. Exchange rate exposure is defined as the current expectation of the sensitivity of the value of the firm to future exchange rate surprises[13]. In the framework presented above the firm's ex ante choice of currency denomination of prices determines how it will be affected by ex post exchange rate surprises. The resulting exposure when pricing in the importers' currency is what the financial literature has called transaction exposure. A certain revenue in foreign currency whose value in the home currency is uncertain.

In the remainder of the paper a linear demand function (in price) and constant marginal costs are assumed in order to keep the analysis tractable. In section 3 we present the special case of monopoly, extending the analysis of Baron (1976) to the study of pricing in a third currency. If an exporter prices in a third currency, a currency that is neither that of the exporter nor of importers', both demand and the price that the exporter receives will be uncertain. If profits in foreign currency are a concave function of the exchange rate that importers' face the exporter is likely to choose the

[13] Adler and Dumas (1984).

currency with the lowest variance relative to the importers' currency. This will be discussed in section 3.

Explicitly adding a competitor from the third country is an extension made in section 4. An example of the kind of situation that we have in mind is the case of a Swedish firm competing on the German market with a U.S. firm. We note that if both firms set their prices in German marks both the relative price and the market share will be unaffected by exchange rate surprises. If the U.S. competitor sets his price in U.S. dollars, demand for the Swedish firm's exports as a function of exchange rates will be uncertain no matter what currency that the Swedish exporter sets his price in. If the Swedish exporter prices in U.S. dollars as well the relative price and the market share will be certain. The size of market demand will however be uncertain.

3. A Simple Extension with Three Currencies

The assumptions made in section 2 are still valid with the following modifications. There are now three countries, x, y and z. x, y, and z are also used to denote the respective currencies. Country z is the sole market for the product that is produced by a monopolist in country x. Demand q for the product is given by the demand function

(8) $q = Q - bp^*$

Q denotes exogenous demand and p^* denotes the price in importers' (country z) currency. Let e^* denote the exchange rate between country y and z. It is expressed as units of y currency needed to buy one unit of z currency. The exchange rate between y and x is given by the relation e/e^*. A simplifying assumption is that e and e^* are uncorrelated. We can then use the property that $E(ee^*)=E(e)E(e^*)$ which greatly simplifies calculations. Implicitly, we assume that exchange rate changes are due to expectations of monetary policy changes in x and z only and that these are uncorrelated. Assume that the firm's marginal costs is fix in the home currency.

The maximisation problem facing the firm depends on what currency that price is set in. In this risk neutral set up the firm will set price in the currency that maximises expected profits. The maximisation problems are respectively:

i) Pricing in the home currency, x:

(9) $\max\limits_{p_x} E\left[\left(p_x - c\right)\left(Q - \frac{b}{e} p_x\right)\right]$

ii) Pricing in the importers' currency, z:

(10) $\max\limits_{p_z} E\left[(ep_z - c)\left(Q - bp_z\right)\right]$

iii) Pricing in the "third country" currency, y:

(11) $\max\limits_{p_y} E\left[\left(\left(\frac{e}{e*}\right)p_y - c\right)\left(Q - \frac{b}{e*} p_y\right)\right]$

Solve for the optimal price in respective currency and denote these by $\hat{p}_k$. These are given in equation (12)-(14). The index $k=x, y, z$ denotes the currency in which prices are set. Note that the optimal prices in equation (12)-(14) are determined before the realisations of exchange rates.

The optimal prices are then in the respective currency:

i) optimal price in home currency (x)

(12) $\hat{p}_x = \frac{1}{2bE(1/e)}\left(Q + cbE(1/e)\right)$

ii) optimal price in the importers' currency (z)

(13) $\hat{p}_z = \frac{1}{2b}\left(Q + \frac{cb}{E(e)}\right)$

iii) optimal price in the "third country currency" (y)

(14) $\hat{p}_y = \frac{E(1/e*)}{E\left(1/(e*)^2\right)} \frac{1}{2b}\left(Q + \frac{cb}{E(e)}\right)$

Expected prices that importers' and the exporter face will depend on the price setting currency chosen. The results are discussed in appendix 1. We use Jensen's inequality and the definition of variance to determine the sign of comparisons.

We turn directly to the question of expected profits. Let Π_k denote profits under the respective price setting currency. Use the expressions for optimal prices in (12)-(14) and plug them in to the respective expressions for expected profits that are given in (9)-(11). After some algebra and using the relation between expected prices we reach expressions for expected profits under the different price setting currencies.

$$\begin{aligned}
E(\Pi_x) &= Q\hat{p}_x - E(1/e)b(\hat{p}_x)^2 + E(1/e)cb\hat{p}_x - cQ \\
&= \frac{1}{4bE(1/e)}\left(Q - cbE(1/e)\right)^2 \\
E(\Pi_z) &= E(e)Q\hat{p}_z - E(e)b(\hat{p}_z)^2 + cb\hat{p}_z - cQ \\
&= \frac{E(e)}{4b}\left(Q - \frac{cb}{E(e)}\right)^2 \\
E(\Pi_y) &= \left(1 - \frac{\mathrm{var}(1/e*)}{E\left(1/(e*)^2\right)}\right)\left(E(e)Q\hat{p}_z - E(e)b\hat{p}_z^2 + cb\hat{p}_z\right) - cQ \\
&= \left(1 - \left(\frac{\mathrm{var}(1/e*)}{E\left(1/(e*)^2\right)}\right)\right)\frac{E(e)}{4b}\left(Q - \frac{cb}{E(e)}\right)^2 - \frac{\mathrm{var}(1/e*)}{E\left(1/(e*)^2\right)}cQ
\end{aligned}$$

Proposition 1:

i) $E(\Pi_z)>E(\Pi_x)$

ii) $E(\Pi_z)>E(\Pi_y)$

iii) $E(\Pi_y)>E(\Pi_x)$ if $\frac{\mathrm{var}(1/e*)}{E(1/(e*)^2)}$ is sufficiently small[14]

Proof:

i) $E(\Pi_z) - E(\Pi_x) = \frac{1}{4b}\left[\left(E(e)\left(Q - \frac{cb}{E(e)}\right)^2\right) - \frac{\left(Q - cbE(1/e)\right)^2}{E(1/e)}\right]$

[14] the inequality holds if $\frac{\mathrm{var}(1/e*)}{E(1/(e*)^2)} < \frac{E(\Pi_z) - E(\Pi_x)}{E(\Pi_z) + cQ}$

Jensen's inequality implies that $E(1/e) > \frac{1}{E(e)} \Rightarrow E(e) > \frac{1}{E(1/e)}$, using this we note that we have that $E(e)(Q\text{-}cb/E(e))^2\text{-}(Q\text{-}cbE(1/e))^2/E(1/e) > E(e)(Q\text{-}cb/E(e))^2\text{-} E(e)(Q\text{-}cbE(1/e))^2 > E(e)(Q\text{-}cb/E(e))^2 - E(e)(Q\text{-}cb/E(e))^2 = 0$.

ii) $E(\Pi_z)>E(\Pi_y)$ since $E(\Pi_z) - E(\Pi_y) = \frac{\mathrm{var}(1/e^*)}{E(1/(e^*)^2)}\left(E(\Pi_z) + cQ\right)$

iii) $E(\Pi_y)\text{-}E(\Pi_x) = E(\Pi_z) - E(\Pi_x) - \frac{\mathrm{var}(1/e^*)}{E(1/(e^*)^2)}\left(E(\Pi_z) + cQ\right)$. From i) we have that $E(\Pi_z)>E(\Pi_x)$. Hence $E(\Pi_y)>E(\Pi_x)$ if $\frac{\mathrm{var}(1/e^*)}{E(1/(e^*)^2)}$ is sufficiently small.

The comparison in i) follows from Jensen's inequality. The key to understanding that result is that when invoicing in the importers currency profits are a linear function of exchange rates , when invoicing in the home currency realised profits are a concave function of exchange rates. This result is due to Baron (1976). The second and third result are new. We conclude that setting price in the importers' currency yields the highest expected profits. Price setting in a third currency will be preferred to price setting in the exporter's home currency if the variance of e^* is moderate relative to the variance of e[15]. This supports our intuition that in the case when demand is concave in exchange rate surprises the exporter will want to set his price in some currency with low variance relative to the market. According to this model a Swedish monopolist exporter would prefer to set price on exports to the Netherlands in German marks over setting price in Swedish kronor (the Dutch guilder being tied to the German mark). Reassuringly we note from the proof of ii) that when the variance of $1/e^*= 0$ invoicing in the third currency is equivalent to invoicing in the importers' currency. The intuition there being that there is no difference in expected

[15] The variance of e enters through the difference between $E(\Pi_x)$ and $E(\Pi_z)$. See footnote 14.

profits from exports to England between setting prices in Scottish pounds or in English pounds.

Regarding the issue of exchange rate exposure it is easily checked that profit is linear when price is set in the importers' currency and concave when set in the exporter's currency along the lines discussed in section 2 and depicted in figure 2 and 3[16].

We focus on exchange rate exposure when prices are set in the **third currency**. Just as when invoicing in the importers' currency profits are linear in *e*. We will now discuss the effect of shocks in e^*. A surprise depreciation in e^* lowers both the price that the firm receives and that which customers face. Thus, when prices for the firm are low output is expanded.

Realised profits are given by

$$\Pi_y = \left(\frac{e}{e^*}\hat{p}_y - c\right)\left(Q - \frac{b}{e^*}\hat{p}_y\right).$$

The partial derivative of realised profits with respect to exchange rate surprises in e^* is given by

$$(15)\ \frac{\partial \Pi_y}{\partial e^*} = -\frac{e}{(e^*)^2}\hat{p}_y\left(Q - \frac{b}{e^*}\hat{p}_y\right) + \left(\frac{e}{e^*}\hat{p}_y - c\right)\frac{b}{(e^*)^2}\hat{p}_y$$

The first term is the negative effect on profits of a surprise depreciation of e^* that stems from the lower price that the exporting firm receives. The second effect is the positive effect on profits that higher quantities induce. We can rewrite (15) as

[16] Note that for small changes in *e* we would actually get the same effects on profits without assuming pre-set prices. The envelope theorem implies that for a marginal change in *e* the only effect on Π would be the direct effect since the price is already set at the optimal level. Since we have assumed pre-set prices we will also be interested in the curvature of profits.

(16) $$\frac{\partial \Pi_y}{\partial e*} = \frac{\hat{p}_y}{(e*)^2}\left(\frac{2b\hat{p}_y e}{e*} - Qe - cb\right)$$

The sign of (16) is determined by the sign of the last expression within parentheses, this is negative if

(17) $$\frac{\hat{p}_y}{e*} < \frac{1}{2b}\left(Q + \frac{cb}{e}\right)$$

Expression (17) thus implies that the partial derivative of profits with respect to e* is negative if the price is lower than the ex post optimal price in the importers' currency. Condition (17) holds in expectation since we know from equation (14) and appendix 1 that

(18) $$E(1/e*)\hat{p}_y = \left(1 - \frac{\mathrm{var}(1/e*)}{E\left(1/(e*)^2\right)}\right)\frac{1}{2b}\left(Q + \frac{cb}{E(e)}\right)$$

Thus, in expectation, realised profits are a decreasing function of surprises in *e**. The curvature of realised profits is given by the combined effect of the concavity of demand in surprises in *e** and the convexity of the price that the exporter receives[17]. The second partial is given by

(19) $$\frac{\partial^2 \Pi_y}{\partial (e*)^2} = \frac{2\hat{p}_y}{(e*)^3}\left(eQ + cb\right) - \frac{6\left(\hat{p}_y\right)^2 be}{(e*)^4}$$

The sign of (19) is positive if

[17] The concavity of demand is analogous to the case of invoicing in the exporter's currency. Convexity of the firms price in surprises in *e** is easily established by twice differentiating $\frac{e\hat{p}_y}{e*}$ with respect to *e**.

(20) $\frac{1}{3b}\left(Q+\frac{cb}{e}\right)>\frac{\hat{p}_y}{e*}$

We are interested in the curvature of realised profits in surprises in *e**. We evaluate this at the *e=E(e)* and remember that

(21) $\hat{p}_z=\frac{1}{2b}\left(Q+\frac{cb}{E(e)}\right)$

Using this we can rewrite (20) as

(22) $e*>\frac{\hat{p}_y}{(2/3)\hat{p}_z}=\frac{3E(1/e*)}{2E(1/(e*)^2)}$

Condition (20) implies that for large enough surprises in *e** realised profits will be a locally convex function of surprises in *e**, otherwise it will be concave. Note that in our model the possibility of local convexity of profits for large surprises in e* is not the same as the well established result that the profits of a price taker are convex in fluctuating prices[18]. In the standard case the convexity derives from the fact that when prices are high firms' receive a higher price *and* sell more output. Conversely when prices are low they will reduce output and limit the reduction in profits. In our framework the firm is not a price taker, the local convexity of profits is a result of prices for the firm being affected more than demand by sufficiently large exchange rate surprises.

[18] Varian (1992), p 43, Oi (1961).

4. Competition from the Third Country

Competition based in a third country offers one plausible explanation to why a firm would set prices in that currency. We will therefore discuss an extension of our previous model that includes a competitor based in *y*. The closest precursor is Fisher (1989). He studies the case of Bertrand competition in homogenous goods in a two country model. Each firm sets price in its own currency in Fischer's model[19].

In section we 4.1 we study the case were the exporter from *y* sets price in his own currency, *y*. In section 4.2 we will discuss the case were the exporter from *y* prices in the importer's currency,*z*.

4.1 *y* Firm Prices in his own Currency

The same assumptions as in section 3 apply with the following addition; the country *x* firm faces competition in the *z* market from a producer based in *y*. The *y* producer is also risk neutral and maximises expected profits in his own currency. Competition is modelled as Bertrand in differentiated goods. The same assumptions as to timing of events apply as in section 3. We will be refering to the country *x* exporter as the home firm. Each firm faces the following demand function:

$$q_i = Q - bp_i^* + \gamma \; p_j^*$$

q_i denotes demand for the product of firm $i = x,y$. Q is exogenous demand, p_i^* is the own price and p_j^* is the price of the competitor. Both are in terms of the *z* currency, the currency of importers. Marginal costs are fix in each producer's domestic currency and denoted by c_x and c_y respectively. Let p_k denote the currency that the

[19] Fisher is the only article that we are aware of that studies competition with pre-set prices under exchange rate uncertainty. Other related studies are Owen and Perrakis (1988), Luehrman (1990) and Marston (1996) who all study quantity competition.

home firm prices in and let P_y^k denote the price of the competitor from *y*. *k=x, y, z* denotes the currency in which the home firm sets its price. The maximisation problems for the home firm are then respectively:

i) Pricing in his home currency, *x*:

$$(23)\quad \max_{p_x} E\left[\left(p_x - c_x\right)\left(Q - \frac{b}{e}p_x + \frac{\gamma}{e*}P_y^x\right)\right]$$

ii) Pricing in the importers' currency,*z*:

$$(24)\quad \max_{p_z} E\left[(ep_z - c_x)\left(Q - bp_z + \frac{\gamma}{e*}P_y^z\right)\right]$$

iii) Pricing in the competitor's, "third country" currency,*y*:

$$(25)\quad \max_{p_y} E\left[\left(\left(\frac{e}{e*}\right)p_y - c_x\right)\left(Q - \frac{b}{e*}p_y + \frac{\gamma}{e*}P_y^y\right)\right]$$

Solving for the first order conditions of the home firm yields us the reaction functions. As usual for Bertrand competition they are increasing in the competitor's price when goods are substitutes. Equilibrium prices are found by solving the relevant maximisation problem of the competitor[20] and substituting his optimal price into the home firms first order condition. Solve for the optimal price for the home firm and denote it by $\hat{p}_k$ These are given in equations (26)-(28). To shorten notation let *A* be defined as $A = \frac{2b}{\left(4b^2 - \gamma^2\right)}$.

The equilibrium prices in the respective currencies are then:

i) optimal price in home currency (*x*)

$$(26)\quad \hat{p}_x = A\left[\left(Q\left(1 + \frac{\gamma}{2b}\right) + \frac{\gamma}{2}c_y E(1/e*)\right)\frac{1}{E(1/e)} + c_x b\right]$$

ii) optimal price in the importers' currency (*z*)

$$(27)\quad \hat{p}_z = A\left[Q\left(1 + \frac{\gamma}{2b}\right) + \frac{\gamma}{2}c_y E(1/e*) + \frac{c_x b}{E(e)}\right]$$

iii) optimal price in the "third country currency" (*y*)

[20] These are given in appendix 2.

$$(28)\ \ \hat{p}_y = A\left[Q\left(\frac{E(1/e^*)}{E(1/(e^*)^2)} + \frac{\gamma}{2bE(1/e^*)}\right) + \frac{\gamma}{2}c_y + c_x b\frac{E(1/e^*)}{E(e)E(1/(e^*)^2)}\right]$$

4.1.2 Prices and Profit

We note that setting $\gamma = 0$ in (26)-(28) yields expressions (12)-(14), those that we found under monopoly. We assume that $b > \frac{|\gamma|}{2}$. That is, the own-price effect on demand is large enough relative to the cross-price effect on demand for prices to be well defined.

We first note that under *certainty* the optimal price, measured in common currency, is independent of the price setting currency. Computing optimal prices as in (23)-(25) under certainty and comparing prices in the importers' currency, we then have that

$$\frac{\hat{p}_x}{e} = \frac{\hat{p}_y}{e^*} = \hat{p}_z = A\left[Q\left(1 + \frac{\gamma}{2b}\right) + \frac{\gamma c_y}{2e^*} + \frac{c_x b}{e}\right]$$

In this simple framework the price setting currency can only influence any real variables when prices are set before exchange rates are known. It is the standard property of monetary neutrality in a somewhat specific dress. Note that the price setting currency will be neutral even if domestic monetary policy is not neutral. Loosely speaking, think of a monetary expansion in *x* that leads to a depreciation of the *x* currency. This lowers the cost of producing in *x* (relative to the market) if *c*, nominal costs, do not adjust fully. This cost advantage will be present no matter what currency that prices are set in.

We will now turn to the expected prices that are faced by agents. When prices are pre-set expected prices will depend on the price setting currency that is chosen. We first study the expected prices to be paid by importers' on imports from*x*

Proposition 2: $\hat{p}_x E(1/e) > \hat{p}_z > \hat{p}_y E(1/e^*)$

Proof: In appendix 3

The expected price to be paid by importers' is highest when the product is priced in the exporters' currency and lowest when it is priced in the third country currency. The reverse side of the coin is the expected prices that the home country exporter receives.

Proposition 3: i) $E(e)\hat{p}_z > \hat{p}_x$

ii) $E(e)\hat{p}_z > E(e)E(1/e^*)\hat{p}_y$

iii) $E(e)E(1/e^*)\hat{p}_y > \hat{p}_x$ if $\dfrac{\mathrm{var}(1/e^*)}{E(1/(e^*)^2)}$ is sufficiently small.

Proof: In appendix 4

We now focus on the expected price of imports from *y* that importers in *z* meet.

Proposition 4: $E(1/e^*)\left[\hat{P}_y^x > \hat{P}_y^z > \hat{P}_y^y\right]$ if goods are substitutes

Proof: in appendix 5

The expected prices for imports from *y* depend on the price setting currency chosen by our home firm. Expected import prices from *y* follow the same ordering as do the expected import prices from the home firm. The reason for this being that firms' reaction functions are positive when goods are substitutes. If the home firm charges a higher price it shifts the demand curve outwards for *y* and it is optimal for the country *y* firm to raise his price as well. In our model the prices that importers' face are lowest when both firms set price in *y*.

Expressions for expected profits tend to become complicated and hard to sign. We will therefore calculate expected profits under some different parameter values.

Table 2 reports some of these results[21]. We study expected profits under two different levels of exchange rate variability. In the calculations the expected value is 1 for both exchange rates. In the case that we call L (low) there are equal probabilities of a 5 percent depreciation or appreciation. In the case that we call H (high) there are equal probabilities of a 20 percent depreciation or appreciation. The levels of exchange rate variability were chosen high to highlight the difference in expected profits.

table 2 here

We see from table 2 that the results reached in section 3 as to the ordering of expected profits seem to carry over to the case with a third-country competitor. We focus on the expected profits for the home country firm. For a wide range of values the highest expected profits for the home firm are reached when he sets price in the importers' currency. Only when the variability of e^* is high relative to that of e does pricing in his own currency result in higher expected profits than pricing in the competitor's currency, *y*. The stronger γ, cross-price effects, the more attractive does pricing in currency *y* become. We refer to the last section of appendix 6 for a discussion. For very strong cross-price effects pricing in *y* actually gives the highest expected profits. The importance of this should not be overstated, it is the case only when $\gamma >> b$, when cross-price effects are much stronger than own-price effects. A standard assumption is that own-price effects are stronger than cross-price effects. We also see that the choice of price setting currency by the home firm affects expected profits by the *y* firm. They are highest when the home firm sets price in his own currency. Higher expected market prices from the home firm allow the *y* firm to quote a higher optimal price as shown in proposition 4, the higher expected price resulting in higher expected profits.

[21] In the calculations Q=6, $c_x=c_y=1, b=2$.

4.1.3 Exchange Rate Exposure

Relative to the monopoly model a richer picture of exchange rate exposure emerges. As in the monopoly case the home firm chooses how it will be affected by exchange rate surprises by its' choice of price setting currency. Here it should be noted that demand is uncertain no matter what currency that the home firm sets prices in.

The exchange rate exposure of the home firm is given by

$$(29)\quad d\Pi\left(\hat{p}_k, e, e*\right) = \frac{\partial\Pi\left(\hat{p}_k, e, e*\right)}{\partial e} de + \frac{\partial\Pi\left(\hat{p}_k, e, e*\right)}{\partial e*} de*$$

In appendix 6 expressions for the partial derivatives of the home firm's profit function are given. A surprise depreciation of the home currency, *e*, has a positive effect on the home firm's profits no matter what currency that prices are set in. If the firm sets price in his own or in the competitor's currency the effect is simply a conversion effect, demand is not affected.

Study now the case of how changes in the competitor's currency affect the home firms' profits. Disregard first the case of pricing in the competitor's currency. A depreciation of the competitor's currency has a negative effect on cash flows if the goods are substitutes, $\gamma>0$, and positive if they are complements, $\gamma<0$. If the goods of our competitor become cheaper our profits are affected negatively if the goods are substitutes.

When the home firm sets price in the competitor's currency there are three effects on the home firm's profits from a depreciation of *e**. The price that the home firm receives is lower. Demand is affected positively by the lower price that customers meet on the home firm's goods and negatively (if the goods are substitutes) by the lower price of the competitor's good.

Another property of the framework that follows from the assumptions of duopoly and three countries may be worth noting. The response of corporate cash flows to a depreciation of the home currency relative to that of the firms' market is dependent on if it is *x* that depreciates or *z* that appreciates. Focus on the case where goods are substitutes. The effects are clearly larger in the first case - in that case our goods not only become cheaper in the foreign market, they also become cheaper relative to the competition. If the importers' currency appreciates against both the other currencies our goods become cheaper, but so do the goods of our foreign competitor. The largest boost to home firm profits are of course given if the home currency depreciates relative to the market and the competitor's currency appreciates against that of the market.

4.2 *y* Firm Prices in Importers' Currency

We will only briefly study this case. The maximisation problems of firms are analogous to those in section 4.1 with straightforward changes of where the exchange rates enter the problem. They are not reported here. The exchange rate exposure for the *x* firm is similar to the monopoly case in the sense that by setting price in the importers' currency it will achieve certain demand. The price of the competitors' goods on the import market is known. In table 3 the expected profits are calculated using the same parameter values as in table 2.

table 3 here

Just as in the monopoly case we see that when the firm from *x* prices in the importers' currency expected profits are unaffected by the variance of exchange rates. We also note that expected profits are always highest when the home firm prices in the importers' currency[22].

[22] Profits when pricing in *y* do not increase as rapidly as under other pricing practices when γ is increased. This is because exchange rate terms enter optimal prices in such a way that price does not "explode" to the same extent as under the other price setting currencies when γ is increased. We have no intuition for this result at present.

Comparing with table 2 we see that for the home firm it generally led to higher expected profits when the firm from *y* priced in his own currency. We also note that pricing in his own currency is not optimal for the *y* firm. Only if the home firm prices in *y* does the *y* firm achieve higher expected profits by pricing in its own currency.

5. Conclusions and Extensions

This paper is a first attempt at formally studying the role of pre-set prices in a three country framework. It was motivated by the observation that the use of U.S. dollars as invoicing currency for Swedish exports had doubled and that the use of Swedish kronor for the same purpose had declined sharply. This was established by comparing a sample from 1968 with figures from 1993.

The shift away from invoicing in Swedish kronor is something that we would expect based on the models that we have studied in section 3 and 4 (given that for some reason price setting and invoicing currencies often are the same). Exchange rate variability is much higher today than during the Bretton-Woods period. Higher exchange rate variability makes price setting in the exporters' currency less attractive.

Our model predicts that price setting in a third currency would be preferred to setting price in the exporter's currency if the variance of the third currency vis-à-vis that of consumers' is sufficiently low relative to the variability of the exporter's currency vis-à-vis consumers' currency. Calibrations suggest that the stronger cross-price effects are, the more attractive does pricing in a third currency become if the foreign competitor prices in his own currency. Traditionally U.S. exports have largely been invoiced in U.S. dollars. We also noted that in our model pricing in the same currency as the competitor resulted in a certain market share, which might be a motivation for pricing in a third currency.

There are clearly many aspects of the choice of invoicing (price setting) currency that are not present in the above framework. A frequent explanation is simply to refer to traditions within the industry. Another observation is that primary commodities are often priced in U.S. dollars. Magee and Rao (1980) propose that the reason for this being that with continuous changes in prices it is more economical to transmit price information in a single currency, U.S. dollars. Neither of these offers a satisfactory explanation to why the use of U.S. dollars as invoicing currency has increased for Sweden.

We will now briefly discuss a number of possible extensions and discuss their likely effect on the choice of price setting (invoicing)currency in a framework such as the above.

A particularly simple extension would be to include transaction costs for exchanging currency. This would make invoicing in the exporter's home currency more attractive for the exporter[23]. This offers one potential explanation for why exports tended to be invoiced in the exporter's currency during theBretton-Woods period when lower exchange rate variability led to less demand uncertainty as a function of exchange rates. Letting different foreign currencies have different transactions costs would also affect the choice of invoicing currency.

A feature of international trade in differentiated goods seems to be a low sensitivity of demand to price changes in the short run[24]. This would imply that the change in profits due to an exchange rate surprise would be small, even when pricing in another currency than that of importers'. Transaction costs for exchanging currency and fluctuating exchange rates could thus conceivably combine to make pricing in the exporter's currency preferred even if profits then are a concave function of exchange rate surprises. The empirical prediction would be that the lower the sensitivity of demand to price changes the more likely is an exporter to set price in his own currency.

For the case when demand is sufficiently insensitive to price changes to be inelastic we need some explanation for why the exporter did not raise his prices in the

[23] This of course only relates to the invoicing currency. A firm could set price in the importers' currency and use his own currency for invoicing, thus avoiding transaction costs.

[24] See for instance Gottfries (1994) for a discussion of this point with an application to Swedish exports.

first place. One avenue would be to include some dynamic considerations. One form of dynamic linkages is to let customer's have costs for changing suppliers. In the international context the implications of this has been investigated by Froot and Klemperer (1989) and in several papers by Nils Gottfries. One of the results of this kind of models is that it is costly to regain lost market shares. Adding such concerns to our framework could imply that one motivation for pricing in the same currency as competitors is a desire to avoid surprise losses of market shares.

Another way of studying low responses of quantities demanded to exchange rate surprises would be to let importers' follow some form of Ss rule, only changing quantity demanded when the price that they face reaches some threshold. In general explicit modeling of the importers' might yield interesting insights. There may be perceived advantages for importers' of firms pricing in the same currency. Say for instance that importers' want to avoid risk by using the forward currency market. If all competitors price in the same currency the importer does not ex ante have to decide from which firm he will buy goods[25].

Another possible extension is to include imported inputs whose prices are set in a foreign currency. Relating to section 2 the cost function could then be written C(q(p),e) and C(q(p/e),e) respectively. The first and second derivatives would be affected by $-c_e$ and $-c_{ee}$ respectively. The change in profits due to an exchange rate surprise would be lower than in the case where there was no direct effect on marginal costs from the exchange rate. The basic flavour of the analysis presented above would not change. The convexity or concavity of profit with respect to exchange rate surprises would determine the profit maximising price setting currency.

The previous analysis builds on the assumption that prices are pre-set. As noted by Giovannini (1988) the response of prices to exchange rate changes are likely to be a combination of the effect of pre-set prices in some currency and of price adjustment. Using a framework like the above for studying issues of exchange rate

[25] I thank Patrik Säfvenblad for this suggestion.

pass-through might yield interesting insights. For now we note that the common finding of "local currency price stability" (see e.g. Knetter, 1993) in the literature on exchange rate pass-through fits in nicely with our results.

Risk aversion and forward markets would be two natural extensions. As noted by Baron (1976) risk aversion will favour pricing in the importer's currency as long as profits not are "too" convex in exchange rate surprises. We note that as long as quantities are certain (as for the monopolist setting price in the importer's currency in section 2 and 3) the exporter can fully insulate himself from risk by using the forward market.

Our perhaps most unrealistic assumption is that of exchange rates being uncorrelated. It would clearly be preferable to relax this assumption. For now we note that the higher the positive correlation between e and e^* in our model the less difference will there be between pricing in the exporter's and the third currency.

Lastly we also note that more empirical knowledge of current price setting and invoicing currency practices is desireable. If nothing else this paper has pointed to that we can not take for granted that empirical results on price setting from one exchange rate regime will hold under another regime.

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Appendix 1

Study first the expected prices to be paid by importers'.
Proposition: $E(1/e)\hat{p}_x > \hat{p}_z > E(1/e^*)\hat{p}_y$
Proof:
i) compare $\hat{p}_x E(1/e)$ and $\hat{p}_z$

$$\hat{p}_x E(1/e) - \hat{p}_z = \frac{c}{2}\left[E(1/e) - \frac{1}{E(e)}\right]$$

1/*e* is convex in *e* =>/Jensen's inequality,*E(1/e)>1/E(e)*/=> $\hat{p}_x E(1/e) > \hat{p}_z$

In the following proof we will use the definition of variance.

var(*X)=E(X*2*)-E(X)*2 => $\frac{E(X)^2}{E(X^2)} - 1 = -\frac{\mathrm{var}(X)}{E(X^2)}$

ii) compare $\hat{p}_y E(1/e^*)$ and $\hat{p}_z$.

$$\hat{p}_y E(1/e^*) - \hat{p}_z = \frac{1}{2b}\left(\frac{E(1/e^*)^2}{E(1/(e^*)^2)} - 1\right)\left(Q + \frac{cb}{E(e)}\right)$$

Using the definition of variance we write this as

$$-\frac{\mathrm{var}(1/e^*)}{E(1/(e^*)^2)}\frac{1}{2b}\left(Q + \frac{cb}{E(e)}\right) < 0 \Rightarrow \hat{p}_z > E(1/e^*)\hat{p}_y$$

Now study instead the expected prices to be received by the exporter:

Proposition: i) $E(e)\hat{p}_z > \hat{p}_x$

ii) $E(e)\hat{p}_z > E(e)E(1/e^*)\hat{p}_y$

iii) $E(e)E(1/e^*)\hat{p}_y > \hat{p}_x$ if $\frac{\mathrm{var}(1/e^*)}{E(1/(e^*)^2)}$ is sufficiently small[26]

Proof:
i) compare $\hat{p}_x$ and $\hat{p}_z E(e)$

$$\hat{p}_x - \hat{p}_z E(e) = \frac{Q}{2b}\left(\frac{1}{E(1/e)} - E(e)\right)$$

Jensen's inequality implies that the second term isnegative=> $\hat{p}_x < \hat{p}_z E(e)$

ii) Compare $E(e)E(1/e^*)\hat{p}_y$ and $\hat{p}_z E(e)$

$$E(e)E(1/e^*)\hat{p}_y - \hat{p}_z E(e) = \left(\frac{E(1/e^*)^2}{E(1/(e^*)^2)} - 1\right)\frac{E(e)}{2b}\left(Q + \frac{cb}{E(e)}\right)$$

[26] The inequality holds if $\frac{\mathrm{var}(1/e^*)}{E(1/(e^*)^2)} < \frac{E(e)\hat{p}_z - \hat{p}_x}{E(e)\hat{p}_z}$

Using the definition of variance we write this as

$$-\frac{\mathrm{var}(1/e^*)}{E(1/(e^*)^2)}\frac{E(e)}{2b}\left(Q+\frac{cb}{E(e)}\right)<0 \Rightarrow E(e)E\left(\frac{1}{e^*}\right)\hat{p}_y < E(e)\hat{p}_z$$

iii) Compare $E(e)E(1/e^*)\hat{p}_y$ and $\hat{p}_x$

$$E(e)E(1/e^*)\hat{p}_y - \hat{p}_x = \frac{1}{2b}\left(Q\left(\left(1-\frac{\mathrm{var}(1/e^*)}{E(1/(e^*)^2)}\right)E(e)-\frac{1}{E(1/e)}\right)-\frac{\mathrm{var}(1/e^*)}{E(1/(e^*)^2)}cb\right)$$

Jensen's inequality implies that the first term is positive if $\frac{\mathrm{var}(1/e^*)}{E(1/(e^*)^2)}$ is sufficiently small => $E(e)E(1/e^*)\hat{p}_y > \hat{p}_x$ for suffiently small $\frac{\mathrm{var}(1/e^*)}{E(1/(e^*)^2)}$.

Lastly study expected quantities sold under the different pricing practices.

Expected quantities are given by the following three expressions

$$E(q_y) = Q - b\hat{p}_y E(1/e^*)$$
$$E(q_x) = Q - b\hat{p}_x E(1/e)$$
$$q_z = Q - b\hat{p}_z$$

Using these expressions and the results from the first proposition in this appendix it is straightforward to show that $E(q_y)>q_z>E(q_x)$.

Appendix 2

Maximisation problems of the foreign competitor (country *y* firm), when the country *x* firm sets its price in currency *x*, *z* and *y* respectively.

$$\max_{P_y^x} E\left[\left(P_y^x - c_y\right)\left(Q-\frac{b}{e^*}P_y^x+\frac{\gamma}{e}p_x\right)\right]$$
$$\max_{P_y^z} E\left[\left(P_y^z - c_y\right)\left(Q-\frac{b}{e^*}P_y^z+\gamma p_z\right)\right]$$
$$\max_{P_y^y} E\left[\left(P_y^y - c_y\right)\left(Q-\frac{b}{e^*}P_y^y+\frac{\gamma}{e^*}p_y\right)\right]$$

Appendix 3

Comparison of expected prices for imports from *x*.

i) compare $\hat{p}_x E(1/e)$ and $\hat{p}_z$.

$$\hat{p}_x E(1/e) - \hat{p}_z = Ac_x b\left[E(1/e)-\frac{1}{E(e)}\right]$$

Jensen's inequality implies that the second term ispositive=> $\hat{p}_x E(1/e) > \hat{p}_z$

ii) Compare $\hat{p}_y E(1/e^*)$ and $\hat{p}_z$

$$\hat{p}_y E(1/e^*) - \hat{p}_z = \left(\frac{E(1/e^*)^2}{E\left(1/(e^*)^2\right)} - 1 \right)\left(Q + \frac{c_x b}{E(e)} \right).$$

Using the definition of variance we write

this as $- \dfrac{\operatorname{var}(1/e^*)}{E\left(1/(e^*)^2\right)}\left(Q + \dfrac{c_x b}{E(e)} \right) < 0.$

Appendix 4

Comparison of expected prices to be received by the country x exporter.

i) compare $\hat{p}_x$ and $\hat{p}_z E(e)$

$$\hat{p}_x - \hat{p}_z E(e) = A\left(\frac{1}{E(1/e)} - E(e) \right)\left(Q\left(1 + \frac{\gamma}{2b}\right) + \frac{\gamma}{2} c_y E(1/e^*) \right)$$

Jensens inequality $\Rightarrow \hat{p}_x - \hat{p}_z E(e) < 0$

ii) Compare $E(e)E(1/e^*)\hat{p}_y$ and $\hat{p}_z E(e)$

$$E(e)E(1/e^*)\hat{p}_y - \hat{p}_z E(e) = -E(e) A \frac{\operatorname{var}(1/e^*)}{E\left(1/(e^*)^2\right)}\left(Q + \frac{c_x b}{E(e)} \right) < 0$$

iii) Compare $E(e)E(1/e^*)\hat{p}_y$ and $\hat{p}_x$

$$E(e)E(1/e^*)\hat{p}_y - \hat{p}_x = \left(E(e) - \frac{1}{E(1/e)} \right) Q\left(1 + \frac{\gamma}{2b}\right) - \frac{\operatorname{var}(1/e^*)}{E\left(1/(e^*)^2\right)}\left(E(e)Q + c_x b \right)$$

Jensens inequality implies that the first term is positive. The second is negative. For high enough variance in e^* the whole expression will be negative.

Appendix 5:

Optimal equilibrium price for the firm from y are found by using the first order conditions from (23)-(25) into the first order conditions from appendix 2.

Proof of Proposition 5

i) compare $\hat{P}_y^x$ and $\hat{P}_y^z$

$$\hat{P}_y^x - \hat{P}_y^z = \frac{b\gamma}{(4b^2 - \gamma^2) E(1/e^*)} c_x \left(E(1/e) - \frac{1}{E(e)} \right)$$

Jensen's inequality $\Rightarrow \hat{P}_y^x - \hat{P}_y^z > 0$

ii) compare $\hat{P}_y^y$ and $\hat{P}_y^x$.

$$\hat{P}_y^y - \hat{P}_y^z = -\frac{b\gamma}{(4b^2-\gamma^2)E(1/e^*)}\left(Q+c_x b\right)\frac{\text{var}(1/e^*)}{E\left(1/(e^*)^2\right)} < 0$$

We see that $\begin{array}{l}\hat{P}_y^x > \hat{P}_y^z > \hat{P}_y^y \text{ if } 2b > \gamma > 0 \\ \hat{P}_y^y > \hat{P}_y^z > \hat{P}_y^x \text{ if } 0 > \gamma > \text{-2b}\end{array}$

Appendix 6

i) Price set in the home currency, *x*

$$\Pi_x = \left(\hat{p}_x - c_x\right)\left(Q - \frac{b}{e}\hat{p}_x + \frac{\gamma}{e^*}\hat{P}_y^x\right)$$

$$\frac{\partial \Pi_x}{\partial e} = (\hat{p}_x - c_x)\frac{b}{e^2}\hat{p}_x > 0, \quad \frac{\partial^2 \Pi_x}{\partial e^2} = -2(\hat{p}_x - c_x)\frac{b}{e^3}\hat{p}_x < 0$$

$$\frac{\partial \Pi_x}{\partial e^*} = -(\hat{p}_x - c_x)\frac{\gamma}{e^{*2}}\hat{P}_y^x < 0, \quad \frac{\partial^2 \Pi_x}{\partial e^{*2}} = 2(\hat{p}_x - c_x)\frac{\gamma}{e^{*3}}\hat{P}_y^x > 0 \text{ iff} \gamma > 0$$

Profits are concave in surprises in *e* and convex in surprises in *e** when goods are substitutes. When goods are complements profits are concave in surprises in *e**.

ii) Price set in the importer's currency,*z*

$$\Pi_z = (e\hat{p}_z - c_x)\left(Q - b\hat{p}_z + \frac{\gamma}{e^*}\hat{P}_y^z\right)$$

$$\frac{\partial \Pi_z}{\partial e} = \hat{p}_z\left(Q - b\hat{p}_z + \frac{\gamma}{e^*}\hat{P}_y^z\right) > 0, \quad \frac{\partial^2 \Pi_z}{\partial e^2} = 0$$

$$\frac{\partial \Pi_z}{\partial e^*} = -\left(e\hat{p}_z - c_x\right)\frac{\gamma}{e^{*2}}\hat{P}_y^z < 0, \quad \frac{\partial^2 \Pi_z}{\partial e^{*2}} = 2\left(e\hat{p}_z - c_x\right)\frac{\gamma}{e^{*3}}\hat{P}_y^z > 0 \text{ iff } \gamma>0$$

Profits are linear in surprises in e and convex in surprises in *e** when goods are substitutes. When goods are complements profits are concave in surprises in *e**.

iii) Price set in the competitor's currency,*y*

$$\Pi_y = \left(\frac{e}{e^*}\hat{p}_y - c_x\right)\left(Q - \frac{b}{e^*}\hat{p}_y + \frac{\gamma}{e^*}\hat{P}_y^y\right)$$

$$\frac{\partial \Pi_y}{\partial e} = \frac{\hat{p}_y}{e^*}\left(Q - \frac{b}{e^*}\hat{p}_y + \frac{\gamma}{e^*}\hat{P}_y^y\right) > 0, \quad \frac{\partial^2 \Pi_y}{\partial e^2} = 0$$

$$\frac{\partial \Pi_y}{\partial e^*} = -\frac{e}{e^{*2}}\hat{p}_y q_y + \frac{1}{e^{*2}}\left(\frac{e}{e^*}\hat{p}_y - c_x\right)\left(b\hat{p}_y - \gamma\hat{P}_y^y\right)$$

Studying the case where goods are compliments there is a negative effect of a surprise depreciation in *e** on profits by the lowering of the price that the home firm receives, this is the first term. There is a positive effect by the induced effect on demand, this is higher the higher my mark-up is and the stronger the own price effect. We now turn to the curvature of profits.

$$\frac{\partial^2 \Pi_y}{\partial e^{*2}} = \frac{2e}{e^{*3}} \hat{p}_y q_y + \frac{2}{e^{*3}} \left(b\hat{p}_y - \gamma \hat{P}_y^y \right) \left(c_x - \frac{2e}{e^*} \hat{p}_y \right)$$

The last term is negative. We thus see that the stronger cross-price effects are, the higher that $\gamma \hat{P}_y^y$ is relative to $b\hat{p}_y$, the more likely is the whole expression to become positive. Under monopoly the curvature was given by the combined effect of convexity in the price that the exporter receives (the first term) and the concavity of demand. In the case with a foreign competitor this effect is moderated since the cross-price effect on demand is convex. Thus, pricing in the third currency gets more attractive the stronger that cross-price effects are.

table 2

Variability of			Expected profits for firm from: x when pricing in			y when x prices in		
e	e*	γ	x(exp)	z(imp)	y(3d)	x	z	y
H	H	1	5.24	5.39	5.28	5.24	5.21	5.08
H	L	1	5.21	5.56	5.54	5.57	5.53	5.26
L	H	1	5.57	5.59	5.27	5.21	5.21	5.08
L	L	1	5.54	5.56	5.54	5.54	5.53	5.52
H	H	2	17.28	18.17	17.90	17.28	17.12	16.54
H	H	3	95.2	99	98.75	95.2	94.24	90.72
H	H	3.9	12225	12612	12619	12224	12098	11640

table 3

Variability of			Expected profits for firm from: x when pricing in			y when x prices in		
e	e*	γ	x(exp)	z(imp)	y(3d)	x	z	y
H	H	1	5.53	5.55	4.86	5.56	5.55	4.94
H	L	1	5.21	5.55	5.51	5.59	5.55	5.51
L	H	1	5.53	5.55	4.86	5.56	5.55	4.94
L	L	1	5.53	5.55	5.51	5.56	5.55	5.51
H	H	2	17.12	18	15.01	18.17	18	14.38
H	H	3	94.24	98	67.6	99	98	62.8
H	H	3.9	12098	12482	1107	12612	12482	1023