Prices, Profits and Exchange Rates

by

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Doing research one needs infrastructure. Among the excellent administrative assistants at the department I have had the most to do with Pirjo Furtenbach and Kerstin Niklasson. A big thanks to both of you for all the help over the years. A big thanks also to all the others at the department that I've missed out on above.

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Love matters even more. I am fortunate enough to have been spoiled with disproportionate amounts from both my Family and my wife Magdalena. This was particularly valuable at the times when research mostly resembled an exercise in frustration.

Stockholm in October, 1997
Richard Friberg

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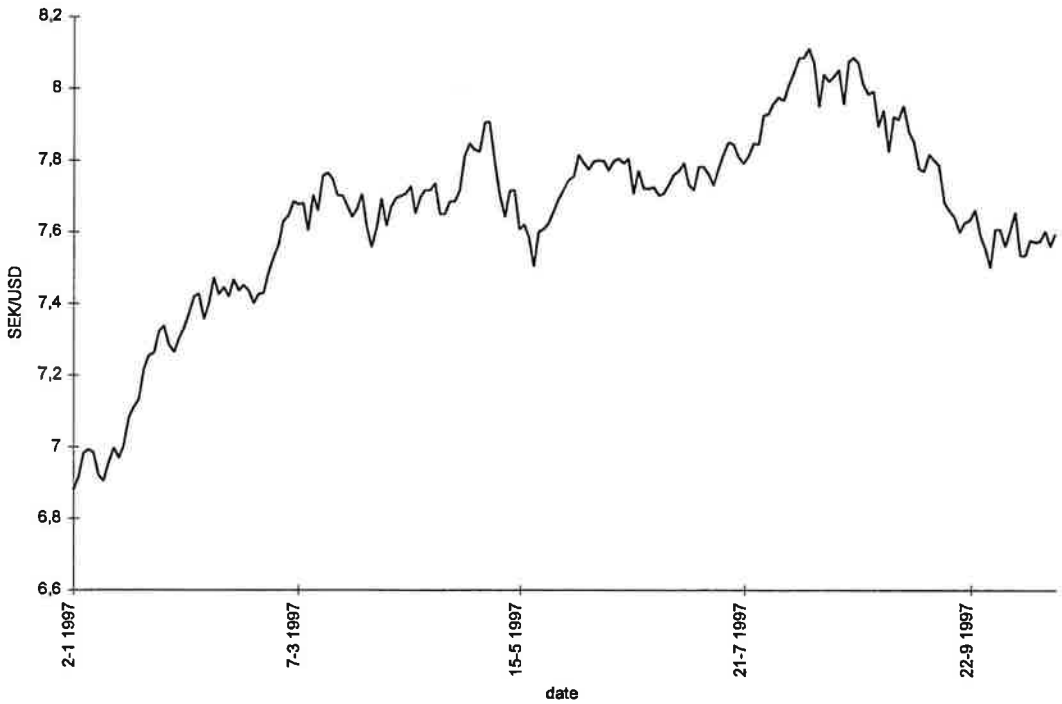
Introduction and summary

This dissertation addresses the effects of changes in exchange rates on prices and profits. It consists of an Introduction followed by Essays 1-5, which are self-contained and include some minor overlaps. This introductory chapter provides an overview of the relevant issues and the results of each Essay. An extensive survey of the overall theme is given in Friberg and Vredin (1997).

The background of the questions under study may be exemplified by Figure 1. It displays the nominal exchange rate between US dollars and Swedish kronor for the period January 2 - October 15, 1997. Both the large day-to-day fluctuations and the longer swings can be regarded as typical of a floating exchange rate.

Figure 1. Nominal exchange rate SEK/USD 1997.



How are such exchange rate changes transmitted to prices of goods and profits of firms? That is the key issue in this dissertation. A closely related question is whether the kind of variability depicted in Figure 1 is harmful in any sense. One need not go further than the discussion about the merits of European Monetary Union to find a lively (not always

academic) debate on this issue. The classical case for a monetary union, or any form of arrangement involving fixed exchange rates (e.g. the Bretton-Woods system) builds partly on the idea that exchange rate variability has detrimental real effects. Not surprisingly, a large empirical literature examines various links between exchange rate variability and the real economy.[1] A very broad characterization of the findings from this literature is that it has been hard to establish any strong links between exchange rate variability and issues such as trade levels, investment, valuation of firms or growth.

If the volatility of the relative price of two currencies appears to matter so little, it is of interest to understand why, particularly since Europe is likely to have a new monetary and exchange rate regime in the near future. Earlier empirical results are of limited value in predicting future patterns if we do not understand the mechanisms that led to the pattern observed in the first place. This applies to e.g. price setting currencies, exchange rate exposure of firms and the transmission of monetary policy. One testament to our as yet limited understanding of the microeconomics of money in international economics is given by Krugman (1993, p. 22):

> "Equally conceivably, the hidden microeconomic benefits of a common currency are so overwhelming in the United States that Europe should follow suit even though the macroeconomic costs would be much greater. We just don't know. It is not that there are conflicts among the estimates. There are simply no estimates at all. At this point you may ask me how I propose to remedy this gap. The short answer is that I don't know. All I can do is assert that if there is one crucial priority in international monetary economics, it is putting some analytical flesh on the microeconomic side of the optimum-currency-area argument."

This thesis consists of five Essays that try to deepen our understanding of some of the mechanisms through which nominal exchange rate changes affect prices of traded goods and profits of firms. That is, we try to increase our understanding of the microeconomic side of international monetary economics. In Essay 1-4 we take a partial equilibrium approach and view the exchange rate as exogenous. A general equilibrium perspective is adopted in Essay 5, where the exchange rate is endogenous.

There are at least two major differences between studying monetary transmission in a closed economy and in an open economy (partly through exchange rates). First, floating exchange

[1] Friberg and Vredin (1997) review the evidence from this literature.

rates are much more volatile than domestic price levels in developed countries. Second, in international trade it matters not only that prices are sticky, but also in which currency they are sticky. This is studied in Essay 1, where a stylized model is used to examine an exporter's choice of price setting currency. The decision whether to set the price in his own currency, that of the importers or a third currency is taken under exchange rate uncertainty. We show that sufficient conditions for import prices to change less than proportionately in response to an exchange rate change (in the absence of uncertainty) are also sufficient conditions for price setting in the importers' currency to yield the highest expected profits (under uncertainty). The intuition behind this result lies in recognizing that both setting the price in the importers' currency and letting import prices change less than the exchange rate are ways of stabilizing demand. The attractiveness of setting price in the importers' currency continues to hold when the exporter has access to forward currency markets. The relative variance of the exporter's currency and the third currency *vis-à-vis* that of the importers determines which of them that dominates the other as price setting currency.

The attractiveness of price setting in the importers' currency is at odds , however, with the standing empirical evidence on currency use in international trade. A number of papers, based mainly on data from the 1960s and 1970s, have established that trade between industrialized countries is mostly denominated in the *exporter's* currency. Essay 1 notes that for Sweden the currency use in trade has changed since the days of Bretton-Woods. This warns against discarding theories of currency use in international trade based on observations from previous institutional setups. For instance, the mechanisms that we study in Essay 1 are irrelevant under a credibly fixed exchange rate.

Whereas Essay 1 concerns the case of an exporter who acts as a monopolist on the foreign market, Essay 2 examines a situation where an exporter faces competition on his foreign market from a producer in a third country. The two firms set prices under exchange rate uncertainty and produce goods that are differentiated. Simple functional forms are assumed. As in Essay 1 setting price in the importer's currency maximizes expected profits for a wide range of parameter values. We also stress the distinction between how an expected exchange rate change affects the import price (exchange rate pass-through) vs. how it affects the percentage change in import price due to a percentage change in the expected exchange rate

(the pass-through elasticity). Specifically, we show that a higher degree of market power for a firm leads to a higher pass-through but to a lower pass-through elasticity. The framework of Essay 2 is quite flexible in that it allows us to discuss a number of issues pertaining to the ways in which exchange rate changes affect prices and profits.

One such issue is the connection between price setting currencies and the effects of an exchange rate surprise on the profits of an exporting firm. Adler and Dumas (1984), spurring a rapidly growing empirical literature, note that that the total effect on the value of a firm from exchange rate surprises (exchange rate exposure) should depend on e.g. the market structure, the currency areas of competitors and the sensitivity of demand to price changes. We make the observation that in the simple world of Essay 2, if both firms set /stabilize prices in the importer's currency, the only uncertainty concerns the rate at which certain profits in the importer's currency should be converted into the exporter's currency. That is, the degree of competition and the origin of the competitor do not matter for the effects of an exchange rate surprise on profits.

A related observation is that in a simple framework as that in Essay 2, a domestic firm would face no exchange rate exposure when its foreign competitors set price in the consumers' currency. This observation provides an approach to understanding the findings of Essay 3 (coauthored with Stefan Nydahl). In this Essay we take up the question of why, in the empirical literature that has followed Adler and Dumas (1984), it has been so difficult to detect any significant effect of exchange rate changes on the stock market valuation of (exporting) firms. Most of the literature has studied the exposure of firms in a relatively closed economy, the United States. It seems reasonable that the average exporting firm in the United States should have less of its revenues related to exports than the average exporting firm in a more open economy, e.g. Sweden. Ideally one would want to study the exchange rate exposure of firms and sectors in many countries. This would be associated with quite extensive data collection, however.

Essay 3 takes the simpler approach of examining exchange rate exposure in a sample of 10 national stock markets during the period 1973-1996. Using monthly data, we find that the stock market in a comparatively more open economy shows a stronger positive relationship

between stock market valuation and depreciation of the exchange rate. This pattern is consistent with relatively greater effects of a change in the exchange rate on exporting activities than on importing activities which, in turn, is consistent with limited exchange rate pass-through/price stability in the importer's currency. If import prices are rigid, the value of an importing firm should not be affected by an exchange rate change. An exporting firm, however, is in a position to convert his stable foreign currency earnings at a more favorable exchange rate when his own currency depreciates.

This dissertation is concerned with price rigidities in international trade and how prices are set when exchange rates fluctuate. Unfortunately, finding good data[2] on prices of traded goods can be quite hard. Finding data on prices and costs (and when they change) for domestic goods can also be hard. In relation to the enormous literature on the reasons for sticky prices and their macroeconomic consequences, only a few studies look at actual transaction prices, and when and how they change. In Essay 4 (coauthored with Marcus Asplund and Rickard Eriksson) we add to the empirical literature on price setting.

We selected a market that is well suited for studying how prices are set when input costs fluctuate, i.e., the gasoline market. The study covers 17 years of daily data on input costs and output prices for one of the largest retail chains on the Swedish gasoline market. We sketch a theoretical model with fixed adjustment costs, the implications of which, at a first glance, fit the data well. Output price remains fixed even though the input price changes. Price adjustment does not take place until input costs have drifted far enough to motivate a price change. Given that the Swedish gasoline retailers are no better than the market at predicting (or do not themselves believe that to be the case) the dollar exchange rate or the Rotterdam spot market price of gasoline, the output price should be adjusted to the static optimum once the benefit of changing the price outweighs the cost of doing so. This does not seem to be the case. Rather, the study suggests that prices move gradually towards the new equilibrium. We employ econometric techniques that take into account that the optimal price is only observed on those days when there is an adjustment (ordered probit sample selection) as well as a

[2] "Good", of course, should be set in relation to the purpose. If the purpose is to establish broad facts about how the prices of traded goods respond to exchange rate changes, then using customs data - applied in most of the exchange rate pass-through literature - should not lead to overly distorted conclusions. Higher quality data are typically required to study the price setting decision in detail, however.

technique that incorporates the deviation from the long-run equilibrium price (error correction).

One of the results that may have a bearing on the issue of exchange rate pass-through in other industries is that limited (short-run) pass-through on the Swedish gasoline market depends both on fixed prices and on partial adjustment once adjustment takes place. We also find that the full adjustment is more drawn out for cost decreases than for cost increases, in this sense prices are more sticky downwards than upwards. However, in the Swedish gasoline market, where price adjustment takes place on average every third week, full adjustment is completed in a couple of months. Another lesson from this Essay is that the conclusion as to which model best describes price setting may be very sensitive to the data, e.g. if one has access to both input and output prices, and to the length of the interval between observations.

In contrast to the previous Essays, a general equilibrium perspective is adopted in Essay 5. When prices are sticky, there is a potential for monetary policy to affect the output and welfare of a country's citizens and perhaps those of other countries as well. This is one of the benefits of remaining outside a monetary union that is normally mentioned. Having access to an independent monetary policy allows the monetary authorities to influence output and consumption in a country (given nominal rigidities) in the face of adverse shocks.[3]

The currency in which prices are sticky should have an impact on the extent to which domestic monetary policy can influence domestic utility. This is one issue considered in Essay 5. The issue that we concentrate on, however, is the international welfare spillover effects. Is an expansionary monetary policy good or bad for neighboring countries? Did the countries that withdrew their monetary policy from the gold standard during the Great Depression of the 1930s depression help others (by stimulating world demand) or hurt others (by "competitive depreciations", gaining market shares at the expense of those still on the gold standard)? The issue is by no means only historical - should the "ins" of an EMU be fearful of independent monetary policy implemented by the "outs"?

[3] For instance, this was the main argument against Sweden joining EMU from the start in the Swedish Government Commission on EMU (Calmfors et al., 1997). Given the high unemployment in Sweden, the economy could fare very badly should it be hit by a negative (country-specific) shock and not have access to an independent monetary policy.

Obstfeld and Rogoff (1995) have proposed a framework that allows welfare analysis of monetary policy in a two-country setting. They assume that prices are set in the exporter's currency and that the law of one price holds, i.e., that prices of traded goods are equal across markets when expressed in the same currency. Contrary to what is assumed in much of the policy discussion about the relationship between future "ins" and "outs" of EMU, the Obstfeld-Rogoff model produces the result that monetary expansion in one country benefits *both* countries proportionately. It does so by increasing demand in the world economy from an initial level that is suboptimally low due to monopoly pricing.

Essay 5 addresses welfare effects of monetary policy under different assumptions about the currency in which prices are sticky. Sufficient market segmentation and local currency price stability imply that monetary expansion is a beggar-thy-neighbor policy. A monetary expansion in one country forces the other country to work harder, while only getting limited benefits in the form of lower prices on their consumption. With reference to the relationship between future "ins" and "outs" of a European monetary union, we show that increasing market integration and more price setting in the currency of the "ins" work towards creating positive welfare spillovers to "ins" from "out" monetary policy. The implication is that even if expansionary monetary policy by "outs" today is a beggar-thy-neighbor policy, it may not be so in the future. Another implication of this framework is that increasing market integration (prices set in the exporters' currency and the law of one price holding to a greater extent) lowers the degree to which monetary policy in a country can have an impact on domestic utility. This implies that the value of having access to an independent monetary policy decreases as goods markets become more integrated.

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In which currency should exporters set their prices?

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October 15, 1997

Abstract

This paper studies the choice of price setting currency for an exporter faced with the choice of setting price in his own, in the importers' or a third currency under exchange rate uncertainty. We establish that sufficient conditions on demand and cost functions for exchange rate pass-through to be less than unity under certainty, are also sufficient conditions for price setting in the importers' currency to yield the highest expected profit under exchange rate uncertainty. Under the same conditions on demand and cost functions, setting price in the importers' currency maximizes expected utility when risk aversion and forward currency markets are introduced.

Keywords: invoicing, exchange rate fluctuations, pricing of exports.

JEL classification: F14, F23

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1 Introduction

In this paper we study the choice of what currency to set price in from the viewpoint of an exporter. On a micro level the issue is interesting as we may learn much about the connections between the currency denomination of trade on the one hand, and exchange rate pass-through and exchange rate exposure on the other hand. Understanding the micro-foundations for the choice of currency denomination of trade is important for several macro issues. The choice of what currency to use in international trade will affect demand for different currencies and will influence how the trade balance responds to an exchange rate change[1] as long as prices are not fully flexible. One recent article that explores macro-economic implications of pre-set prices in international trade is Betts and Devereux (1996) which studies exchange rate determination and volatility when a share of traded goods have prices that are pre-set in the importer's currency. Another example is Feenstra and Kendall (1997) who study how the price setting currency chosen determines the nature of deviations from Purchasing Power Parity.

The empirical relevance of any pre-set pricing analysis will of course be dependent on how long prices are fixed. As a floating exchange rate fluctuates literally by the minute it could be very costly 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 domestic price levels.

We model a situation where an exporter sets a price in some currency under exchange rate uncertainty. The exporter commits to sell the demanded quantity at the ex post realized price that importers face[2] and has the choice of what currency to set price in. We will call the currency chosen for this the price setting currency. Figure 1 presents a stylized version of an international trade transaction to make clear the focus of this paper. Typically international trade involves a lag between the determination of quantities and the actual payment taking place. The currency used for the trade contract is denoted the invoicing currency and the currency used for the actual payment is referred to as the currency of payment.[3] In theory different currencies could be used for the different

stages but with few known exceptions the same currency is used for all three purposes.

Figure 1 about here

In focusing on one of the roles of trade currency (price setting) while neglecting the other roles, this paper follows the tradition of previous work in the field.[4] Baron (1976), Giovannini (1988) and Donnenfeld and Zilcha (1991) study the pre-set pricing aspect. The shape of demand and cost functions will determine which price setting currency that yields the highest expected profits. Baron (1976) found that, for a demand curve that is linear in price and constant marginal costs, setting price in the importer's currency yields the highest expected profits.

The novelty of this paper is to show that the choice of price setting currency is determined by similar conditions on the demand and cost functions as those that govern exchange rate pass-through (how much import prices change when the exchange rate changes). Specifically, we show that sufficient conditions for exchange rate pass-through to be less than unity (in the absence of uncertainty) are also sufficient conditions for price setting in the importer's currency to yield the highest expected profits under exchange rate uncertainty. The intuition behind this result lies in recognizing that both less-than full exchange rate pass-through and price-setting in the importers' currency are ways of stabilizing demand.

Another contribution is to extend the analysis on pre-set prices to a third currency, a currency that is neither that of the exporter or importer. The issue is empirically important as use of a third currency is common in international trade - an illustration of this is that 50% of world trade is invoiced in US dollars[5] while the United States' share of world trade in manufactured goods is 14%.[6]

We also extend the literature by ranking the choice of price setting currency when there is risk aversion and forward currency markets. The extension is interesting since there is much evidence that firms do indeed use the forward market to hedge exchange rate exposure.[7]

A criticism waged against the literature in the pre-set pricing tradition is that it does not explain the empirical evidence on currency use in international trade. A number of papers have found

that trade in manufactured goods between developed countries is mainly invoiced in the exporter's currency.[8] This finding is often referred to as "Grassman's law" following seminal work by Sven Grassman (1973a,b). Grassman studied the currency denomination of Swedish exports and imports using data from 1968. In Grassman's sample 66% of Swedish exports, but only 26% of imports, were invoiced in Swedish kronor. 12% of exports were invoiced in US dollars in Grassman's sample. By 1995[9] the share of exports invoiced in Swedish kronor had decreased to 43.8% and the share of exports invoiced in US dollars had increased to 18.4%.There had been no corresponding increase in the share of the United States as a Swedish export market (7.9% in 1995).

These observations on Swedish invoicing practices point to the need for newer evidence on invoicing practices. We know of very little survey evidence using data from the 1980s or later.[10] For instance, the figures on Sweden in Page (1981) are taken from Grassman (1973a,b). We should be cautious of discarding theoretical explanations of current or future choice of price setting currency based on evidence from a previous institutional set-up (fixed exchange rates, less developed forward currency markets, exchange restrictions).

Section 2 presents our model and section 3 discusses the choice of price setting currency. In section 3.1 we discuss the choice of price setting currency under risk neutrality. In section 3.2 we discuss the choice of price setting currency under risk aversion and with forward currency markets. Section 4 concludes.

2 The model

The firm of study is an exporter who sells in a single foreign market. The exporter is a monopolist (or more generally we may think of it as a firm whose residual demand curve expressed in the importer's currency is not affected by exchange rate surprises). The exporter has the choice between setting the export price in his own, in the importers' or in a third currency. We assume that the exporter is constrained to produce in his home country. The exporter's objective is to maximize the expected utility of profits in his home currency. *The central assumptions are that the exporter*

has to set price before the exchange rate is known and that demand is a function of the price that importers face after exchange rate uncertainty is resolved. Let e, the stochastic nominal exchange rate denote units of the exporter's currency needed to buy one unit of the importers' currency. A higher value of e thus implies a depreciation of the exporter's currency. Let e^o denote units of third country currency needed to buy one unit of the importers' currency. The exchange rate between the exporter's and the third country's currency is given by the relation e/e^o. Let $E(e) = \overline{e} = 1$ and $E(e^o) = \overline{e}^o = 1$ and assume that e and e^o are uncorrelated, which greatly simplifies calculations.[11] The analysis is partial equilibrium and exchange rates are exogenous. The exporter has access to a forward currency market. The forward rate of e is given by β and the forward rate of $e/e^o = \beta^o$. Assume that international financial markets are efficient such that the forward rate is equal to the expected spot rate. Let h and h^o respectively denote the size of the forward currency contract.

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. Quantity demanded, Q, is a decreasing function of the price that importers face (in their own currency) once the exchange rate is known. Assume that costs are incurred in the exporter's currency and are given by $C(Q)$. Let subindexes denote partial derivatives. U is a Von Neumann-Morgenstern utility function, $U_\Pi > 0$, $U_{\Pi\Pi} < 0$. Let $U(\Pi) = \Pi$ under certainty. Let * denote a price that has been denominated in the importers' currency and ^{o} a price that has been set in the third country currency. When pricing in the exporter's currency no super-index is used. The super-indexes are also used to denote profits under the different pricing strategies. A *hat* is used to denote a variable that has been pre-set at the ex ante optimal level.

2.1 Price is set in the importers' currency

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

$$\max_{p^*,h} EU(\Pi^*) = E\left[U\left(ep^*Q(p^*) - C(Q(p^*)) - h(e-\beta)\right)\right] \tag{1}$$

The associated first order conditions are

$$E\left[U_{\Pi^*}\left((e)\left(p^*Q_{p^*}+Q\right)-C_QQ_{p^*}\right)\right] = 0 \tag{2}$$

$$E\left[U_{\Pi^*}\left(-e+\beta\right)\right] = 0 \tag{3}$$

Rearranging and substituting condition (3) into condition (2) we get

$$\beta\left(p^*Q'+Q\right)=C_QQ_{p^*} \tag{4}$$

We see that the optimal price is not dependent on the shape of the utility function or the stochastic properties of the exchange rate. This is a version of the "separation theorem" that is normally derived in a price taking framework (see e.g. Ethier, 1973 or Kawai and Zilcha, 1986). Exchange rate uncertainty does not influence prices and hence not traded quantities. We also note from (3) that efficient forward markets imply that the exporter will hedge fully, set $h=p^*Q$. This follows by rewriting (3) as

$$\left(E\left[U_{\Pi^*}\right]E\left[-e+\beta\right]+cov\left[U_{\Pi^*},-e\right]\right)=0 \tag{5}$$

When the expected exchange rate equals the forward rate the condition holds only for $cov\left[U_{\Pi^*},-e\right]=0$, which is achieved by full hedging. Profits are linear in exchange rate surprises - hedging does not lower expected profits - and it is therefore optimal for a risk averse exporter to hedge fully.

2.2 Price is set in the exporter's currency

When the price is set in the exporter's currency before the exchange rate is known the firm's maximization problem is given by:

$$\max_p EU\left(\Pi\right)=E\left[U\left(pQ\left(\frac{p}{e}\right)-C\left(Q\left(\frac{p}{e}\right)\right)\right)\right] \tag{6}$$

The associated first order condition is given by

$$E\left[U_{\Pi}\left(pQ_p+Q-C_QQ_p\right)\right]=0 \tag{7}$$

Here risk aversion will affect the optimal price, which will be higher than under risk neutrality. This is discussed in Baron (1976). By setting a higher price the exporter lowers the demand elasticity, thereby reducing the sensitivity of profits to exchange rate surprises. Traded quantities will thus be lower on average and the "separation theorem" does not hold.[12]

2.3 Price is set in the third country currency

When the exporter sets price in the third currency the maximization problem is given by

$$\max_{p^o,h^o} EU(\Pi^o) = E\left[U\left(\frac{e}{e^o}p^oQ\left(\frac{p^o}{e^o}\right) - C\left(Q\left(\frac{p^o}{e^o}\right)\right) - h^o\left(\frac{e}{e^o} - \beta^o\right)\right)\right]$$

The associated first order conditions are given by

$$E\left[U_{\Pi^o}\left(\frac{e}{e^o}\left(p^oQ_{p^o} + Q\right) - C_QQ_{p^o}\right)\right] = 0 \tag{8}$$

$$E\left[U_{\Pi^o}\left(-\frac{e}{e^o} + \beta^o\right)\right] = 0 \tag{9}$$

We are not able to determine the optimal size of the forward contract without further assumptions. We note however that the exporter will not be able to insulate himself fully from risk by using the forward currency market since demand will be affected by surprises in e^o, which implies that the exposure to be hedged is uncertain. As the exporter is not insulated from risk, the curvature of the utility function will influence the optimal price and traded quantities will on average be different than under certainty, the "separation theorem" will not hold.

3 The choice of price setting currency

3.1 Risk neutrality

Which price setting currency that gives the ex ante highest expected utility depends on how profits are affected by exchange rate surprises. We will first compare the choice of setting price in the importers' or exporter's currency under risk neutrality. This gives us a problem of the type analyzed by Baron, Giovannini and Donnenfeld and Zilcha. When **setting price in the importer's currency**

the first order condition is a linear function of the exchange rate, e. The price that is set will be dependent only on the expected value of e. The above implies that

$$E\left(\Pi^*\left(\widehat{p}^*, e\right)\right) = \Pi^*\left(\widehat{p}^*, \overline{e}\right) = \max_{p^*} \Pi^*\left(p^*, \overline{e}\right) \tag{10}$$

Expression (10) tells us that when the exporter sets his price in the importers' currency, the expected profits under a fluctuating exchange rate are equal to realized 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 price is **set in the exporter's currency** profits will typically *not* be a linear function of exchange rate surprises. Which price setting currency that gives the highest expected profits depends on the curvature of profits - if profits when pricing in the home currency are a concave or convex function of exchange rate surprises.

Before turning to the comparison of price setting currencies we note that *if* prices could be set *after* the exchange rate were known, both price setting currencies would yield the same profit. All variables are then known and the exporter can set p/e fully by choosing p.

$$\max_{p^*} \Pi^*\left(p^*, \overline{e}\right) = \max_{p} \Pi\left(p, \overline{e}\right) \tag{11}$$

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 (10) and (11) combined with the definition of profit maximization (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:

$$E\left(\Pi^*\left(\widehat{p}^*, e\right)\right) = \max_{p} \Pi\left(p, \overline{e}\right) \geq \Pi\left(\widehat{p}, \overline{e}\right) \geq E\left(\Pi\left(\widehat{p}, e\right)\right) \tag{12}$$

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. Suppressing arguments we note that the first and second partial derivative of profits with respect to exchange rate surprises when setting price in the exporter's currency are given by

$$\Pi_e = (\widehat{p} - C_Q)\, Q_e \tag{13}$$

$$\Pi_{ee} = (\widehat{p} - C_Q)\, Q_{ee} - C_{QQ}\, (Q_e)^2 \tag{14}$$

The first derivative is positive, a depreciation of the exporter's currency will lead to higher demand and higher profits. The function is concave if the second derivative, (14), is negative.[13] 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 is concave in the exchange rate.

3.1.1 Relationship to the exchange rate pass-through literature

The literature on exchange rate pass-through studies how much import prices change when exchange rates change.[14] Analysis of exchange rate pass-through and the closely related phenomenon of pricing-to-market (market specific markup adjustment when exchange rates change) have typically ignored issues of what currency that prices are set in since it is usually assumed that price is set after the exchange rate is known. The dominating empirical finding in this literature is that of a pass-through elasticity that is less than unity and of "local currency price stability" (see e.g. Knetter, 1993). Import prices change less than the exchange rate does.

Knetter (1992, p.16) notes that the "Choice of invoice currency should depend on the same factors that determine exchange rate pass-through". We will show that this is indeed the case in our framework. Both depend on the curvature of demand and cost functions.

Proposition 1 *Sufficient conditions on the demand and cost functions for the pass-through elasticity to be less than unity (under certainty) are also sufficient conditions for price setting in the importers' currency to yield higher expected profits under exchange rate uncertainty.*

Proof:In appendix 1 it is shown that a sufficient condition for less than full pass-through if $C_{QQ} \geqslant 0$ is that

$$1 > -\frac{Q_{pp}}{Q_p} p \tag{15}$$

Sufficient conditions for setting price in the importers' currency to yield higher expected profits are, from (12) and (14) that $C_{QQ} \geqslant 0$ and $Q_{ee} < 0 \Longleftrightarrow 2 > -\frac{\widehat{p}}{e}\frac{\partial^2 Q/\partial(\widehat{p}/e)^2}{\partial Q/\partial(\widehat{p}/e)}$. Use that $\widehat{p}/e = p$, where p is defined as the price that importers face. We then write $Q_{ee} < 0 \Rightarrow 2 > -\frac{Q_{pp}}{Q_p}p$. ■

The same condition is found in Donnenfeld and Zilcha (1991) but they do not relate it to the exchange rate pass-through literature. Even though limited exchange rate pass-through may depend on issues not directly related to the curvature of demand or cost functions (e.g. market share considerations as in Froot and Klemperer 1989), the common empirical finding of less than full exchange rate pass-through indicates that setting price in the importers' currency often is optimal.

Some intuition for why demand would be concave in exchange rate surprises comes from a comparison with the second order condition for profit maximization under certainty. A necessary condition for profit maximization is that profits are concave in the price, that

$$(p - C_Q)\, Q_{pp} - C_{QQ}\,(Q_p)^2 + 2Q_p e < 0 \tag{16}$$

A sufficient condition for the second order condition to hold if $C_{QQ} \geqslant 0$ is thus that

$$2 > -(p - C_Q)\,\frac{Q_{pp}}{Q_p e} \tag{17}$$

Profit maximization thus implies that demand not be too convex in price, that the sensitivity of demand does not decrease too much as the price is increased. The same mechanism is what is driving the concavity of profits in exchange rate surprises in Proposition 1. Only if demand is sufficiently convex in price will demand increase at a sufficiently increasing rate when the exchange rate depreciates for profits to be convex in exchange rate surprises. The difference between the two stems from that whereas a change in price will affect marginal revenue both through the change in price and the change in demand, an exchange rate change will affect only demand if price is fixed in the exporter's currency.

In the analysis above it was assumed that costs are incurred in the exporter's currency. One could create a set-up where imported inputs priced in a foreign currency would affect how marginal costs were affected by exchange rate surprises. The curvature of marginal costs could also be affected

and thus change the conditions on the demand function under which profits would be concave in exchange rate surprises. The basic flavor of the analysis above would not change however, the curvature of profits in exchange rate surprises would determine the profit maximizing price setting currency.

3.1.2 On the choice of setting price in a third currency

If the exporter sets price in a third currency both demand and the price that the exporter receives will be uncertain. Donnenfeld and Zilcha (1991, p. 1009) note that "Typically it was assumed that exchange rate uncertainty resulted in commodity price uncertainty because prices were quoted in [a third currency]". Commodity price uncertainty in the sense of Oi (1961) implies that profits will be convex in price (exchange rate) fluctuations. Expected profits will thus be an increasing function of price volatility. This, together with the observation that the share of Swedish trade invoiced in dollars has increased, motivates our interest in third currency pricing.

In our framework price setting in the importer's currency will yield higher expected profits than price setting in a third currency under the same conditions on demand and costs as in Proposition 1. The exporter will prefer pricing in a currency with low variance relative to the importers' currency if profits are a concave function of exchange rate surprises that affect demand. The difference relative to commodity price uncertainty is explained by that under the assumptions of Oi (1961) the firm is a price taker and determines quantity after the price (exchange rate) is known. In Oi's framework profits are convex in price fluctuations since when prices are high the firm receives a higher price *and* sells more output. Conversely when prices are low the firm will reduce output and limit the reduction in profits. In our pre-set price framework quantity is demand determined and output is expanded when the price that the exporter receives is low (a depreciation of e^o).

Proposition 2 *Assume that demand and cost functions fulfill sufficient conditions as in Proposition 1. Then; i) setting price in the importer's currency yields highest expected profits; ii) for low enough variance of e^o relative to e, setting price in the third currency will yield higher expected profit than*

setting price in the exporter's currency; iii) for high enough variance of e^o relative to e, setting price in the exporter's currency yields higher expected profits than setting price in the third currency.

Proof in appendix 2. Setting price in the importers' currency yields higher expected profits than price setting in the exporters' or a third currency under sufficient conditions on the demand and cost functions as in Proposition 1. According to this model a Swedish monopolist exporter would want to set price on exports to the Netherlands in Dutch guilders. The ranking of price setting in the exporters' or third currency depends on the relative variance of these currencies. The 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). In the proof we use that when the variance of $e^o = 0$, setting price in the third currency is equivalent to setting price in the importers' currency. The intuition being that there is no difference in expected profits from exports to England between setting prices in Scottish pounds or in English pounds.

3.2 Risk aversion

The optimality of setting price in the importers' currency when profits are concave in ex post exchange rate surprises holds also under risk aversion and efficient forward markets.

Proposition 3 *With $U_\Pi > 0$, $U_{\Pi\Pi} < 0$, and efficient forward currency markets and demand and cost functions that fulfill sufficient conditions as in Proposition1 then: i) setting price in the importers' currency yields higher expected utility than setting price in the exporter's currency. ii) under the assumption that the firm sells an amount $\widehat{h}^o \geqslant 0$ on the forward currency market, setting price in the importers' currency yields higher expected utility than setting price in the third currency.*

Proof in appendix 3. The intuition for Proposition 3 is that by using the forward market and setting price in the importers' currency the exporter fully avoids risk and achieves the same (certain) profits as he would under certainty. Both the price that the exporter receives and the quantity to be exported are certain. Utility is then higher than with concave profits evaluated using a concave

utility function (as is the case with setting price in the exporters' or third country currency). Selling the third currency forward makes profits *more* concave in e^o for a given price. The intuition for profits becoming more concave can be seen by noting that the price that the exporter receives, $(\frac{e}{e^o}\widehat{p}^o)$is convex in surprises in e^o. Selling e^o forward diminishes this effect without alleviating the effect on profits due to the concavity of demand in exchange rate surprises. Note however that selling an amount $\widehat{h}^o$ of the third currency forward lowers the first order effect on profits from an exchange rate surprise. Selling $\widehat{h}^o > 0$ forward thus constitutes a hedge and the assumption is therefore not very restrictive.

Before concluding we will note the 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.[15] 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 the equivalent of what the financial literature has called transaction exposure. A certain revenue in foreign currency whose value in the home currency is uncertain. This exposure is easily hedged since the amount to be hedged is certain. When the exporter sets price in his own currency there is no transaction exposure but as we have seen above that does not mean that total exchange rate exposure is lower. Setting price in the exporter's own currency does not mean that risk is avoided - in fact, in our framework the opposite is true.

4 Concluding remarks

This paper has demonstrated the attractiveness of setting price in the importers' currency in a price setting framework. How can we reconcile this with the common finding in the empirical literature reported in the introduction - that trade between developed countries in manufactured goods is predominantly invoiced in the exporter's currency?

Part of the explanation no doubt rest with the fact that we have neglected transaction cost/medium-

of-exchange and "invoicing"/store-of-value roles of currency. Part of the explanation may be that the empirical evidence stems from older institutional set-ups. The shift away from invoicing in kronor is what our model would predict given that Sweden has a floating exchange rate since November 1992. We note that in our framework the existence of a forward currency market makes price setting in the importers' currency even more attractive. The development of forward markets and spreading understanding of how they work should lead to more goods being priced in the importers' currency.[16] In most developed countries there are also much less exchange restrictions now than during the period when most empirical studies of invoicing currencies were made.[17]

We must of course recognize that the aggregate figures on trade currencies includes both intra-firm transactions (where currency choice should be ruled by other considerations than the ones in this paper) and transactions where nominal rigidities play a very small role, so that the choice of price setting currency is of little consequence. The above points to that more empirical knowledge of current price setting and invoicing practices is desirable. This applies both to surveys of invoicing currency use as well as to careful studies of price setting in different national markets, such as Knetter's (1997) study of the prices of *The Economist.* This paper has emphasized that we should not take for granted that empirical results on price setting from one institutional set-up will hold under another set-up.

Appendix 1

In this appendix we derive sufficient conditions for the pass-through elasticity to be less than unity under certainty. The result is due to Feenstra (1989) and this exposition is a somewhat simplified version of that work. First define $e^* \equiv 1/e$. Under certainty the exporter's maximization problem is given by

$$\max_p pQ(p) - C(Q)e^* \tag{18}$$

the first order condition is

$$Q + Q_p p - C_Q Q_p e^* = 0 \tag{19}$$

Define $\eta = -Q_p p/Q$, the (positive) price elasticity of demand. We rewrite (19) as

$$\text{Marginal Revenue(MR)} \equiv p\left(1-\frac{1}{\eta}\right) = C_Q e^* \tag{20}$$

Total differentiation of (20) yields

$$\left(\left(1-\frac{1}{\eta}\right)+p\frac{\eta_p}{\eta^2}-C_{QQ}Q_p e^*\right)dp - C_Q de^* = 0 \tag{21}$$

Divide by C_Q and e^* and multiply by p to reach

$$\frac{dp}{de^*}\frac{e^*}{p} = \frac{1}{\left(1+\frac{p^2\eta_p}{\eta^2 MR}+\frac{C_{QQ}}{C_Q}Q\eta\right)} \tag{22}$$

(22) is the pass-through elasticity. The percentage change in import price due to a percentage change in the exchange rate (expressed as units of importers' currency needed to buy a unit of the exporter's currency). $\left(\frac{C_{QQ}}{C_Q}Q\right)$ is the elasticity of marginal costs with respect to output, this has the same sign as C_{QQ}. The term $\left(1+\frac{p^2\eta_p}{\eta^2 MR}\right)$ is the elasticity of marginal revenue w.r.t. price, this is $\gtrless 1$ as $\eta_p \gtrless 0$. This establishes that if $C_{QQ} \geqslant 0$ a sufficient condition for $0 < \frac{dp}{de^*}\frac{e^*}{p} < 1$ is that

$$\eta_p > 0 \tag{23}$$

$$-\left(Q_{pp}\frac{p}{Q}+Q_p\frac{1}{Q}\right) > 0 \tag{24}$$

$$-\frac{Q_{pp}}{Q_p}p-1 < 0 \tag{25}$$

$$-\frac{Q_{pp}}{Q_p}p < 1 \tag{26}$$

■

Appendix 2

Proof of Proposition 2:

i) Setting price in the importers' currency yields higher expected profits than setting price in the exporter's currency. This follows from (12) and (14). Now compare price setting in the third currency with price setting in the exporters currency.

$$E\left(\Pi^*\left(\widehat{p}^*, e\right)\right) - E\left(\Pi^o\left(\widehat{p}^o, e, e^o\right)\right) = \tag{27}$$

$$E(e)\,E\left(\widehat{p}^{*}Q(\widehat{p}^{*})-\frac{\widehat{p}^{o}}{e^{o}}Q\left(\frac{\widehat{p}^{o}}{e^{o}}\right)\right)+cov\left(e,\widehat{p}^{*}Q(\widehat{p}^{*})-\frac{\widehat{p}^{o}}{e^{o}}Q\left(\frac{\widehat{p}^{o}}{e^{o}}\right)\right)$$
$$-E\left(C\left(Q\left(\widehat{p}^{*}\right)\right)\right)+E\left(C\left(Q\left(\frac{\widehat{p}^{o}}{e^{o}}\right)\right)\right)$$

e and e^{o} are uncorrelated which implies that the covariance term is 0 (no correlation between e and the difference in revenue measured in the importers' currency under the two price setting practices). Also use that $E(e)=1$ to express (27) as

$$= E\left(\widehat{p}^{*}Q(\widehat{p}^{*})-C\left(Q\left(\widehat{p}^{*}\right)\right)\right)-E\left(\frac{\widehat{p}^{o}}{e^{o}}Q\left(\frac{\widehat{p}^{o}}{e^{o}}\right)-C\left(Q\left(\frac{\widehat{p}^{o}}{e^{o}}\right)\right)\right) \tag{28}$$
$$= \max_{p^{*}}\Pi^{*}(p^{*},\overline{e})-E\left(\frac{\widehat{p}^{o}}{e^{o}}Q\left(\frac{\widehat{p}^{o}}{e^{o}}\right)-C\left(Q\left(\frac{\widehat{p}^{o}}{e^{o}}\right)\right)\right) \tag{29}$$
$$= \max_{p^{o}}\Pi^{o}(p^{o},\overline{e}^{o},\overline{e})-E\left(\frac{\widehat{p}^{o}}{e^{o}}Q\left(\frac{\widehat{p}^{o}}{e^{o}}\right)-C\left(Q\left(\frac{\widehat{p}^{o}}{e^{o}}\right)\right)\right) \tag{30}$$

Expression (30) will be positive if profits when setting price in the third currency (measured in the importers' currency) are concave in e^{o} $\Leftrightarrow$ if

$$\frac{2}{e^{o2}}\left(\frac{\widehat{p}^{o}}{e^{o}}Q-\widehat{p}^{o}Q_{e^{o}}\right)+\left(\frac{\widehat{p}^{o}}{e^{o}}-C_{Q}\right)Q_{e^{o}e^{o}}-C_{QQ}\left(Q_{e^{o}}\right)^{2}<0 \tag{31}$$

The last two terms in (31) are the equivalent of (14) and the sum of these two is negative following Proposition 1 . We can rewrite the first term as $2\frac{\widehat{p}^{o}}{e^{o3}}Q+2\frac{\widehat{p}^{o2}}{e^{o4}}Q_{\widehat{p}^{o}}$. This is positive if $1-\frac{\eta}{e^{o}}$ is positive, where $\eta=-Q_{\widehat{p}^{o}}\frac{\widehat{p}^{o}}{Q}$ is defined as the (positive) price elasticity of demand evaluated at the ex ante optimal price. This implies that the first term will be negative in expectation since the exporter would not set price where demand is inelastic. Thus for $Q_{e^{o}e^{o}}<0$ and convex marginal costs the second derivative will be negative, establishing that $E\left(\Pi^{*}\left(\widehat{p}^{*},e\right)\right)>E\left(\Pi^{o}\left(\widehat{p}^{o},e^{o},e\right)\right)$. ■

ii) From (12) and (14) and monetary neutrality we know that

$E\left(\Pi^{*}\left(\widehat{p}^{*},e\right)\right)=E\left(\Pi^{o}\left(\widehat{p}^{o},\overline{e}^{o},e\right)\right)>E\left(\Pi\left(\widehat{p},e\right)\right)$. If the variance of $e^{o}=0$, setting price in the importers' and third currency imply equal expected profits. The inequality is strict implying that

$E\left(\Pi^{*}\left(\widehat{p}^{*},e\right)\right)>E\left(\Pi^{o}\left(\widehat{p}^{o},e^{o},e\right)\right)>E\left(\Pi\left(\widehat{p},e\right)\right)$ for small enough variance of e^{o} relative to the variance of e. ■

iii) From i) and monetary neutrality we know that

$E\left(\Pi^{*}\left(\widehat{p}^{*},e\right)\right)=E\left(\Pi\left(\widehat{p},\overline{e}\right)\right)>E\left(\Pi^{o}\left(\widehat{p}^{o},e^{o},\overline{e}\right)\right)$. If the variance of $e=0$ setting price in the

importers' and exporter's currency imply equal expected profits. The inequality is strict implying that

$E\left(\Pi^{*}\left(\widehat{p}^{*}, e\right)\right) > E\left(\Pi\left(\widehat{p}, e\right)\right) > E\left(\Pi^{o}\left(\widehat{p}^{o}, e^{o}, e\right)\right)$for small enough variance of e relative to the variance of e^{o}. ■

Appendix 3

Proof of Proposition 3:

i) Show that the following chain of inequalities hold to establish that expected utility when setting price in importers' currency is higher than expected utility when setting price in the exporter's currency

$$E\left(U\left(\Pi^{*}\left(\widehat{p}^{*}, \widehat{h}, e\right)\right)\right) \geq U\left(\Pi^{*}\left(\widehat{p}^{*}, h = p^{*}Q\right)\right) \tag{32}$$

$$= \max_{p^{*}} \Pi^{*}\left(p^{*}, \overline{e}\right) \tag{33}$$

$$= \max_{p} \Pi\left(p, \overline{e}\right) \tag{34}$$

$$> E\left(U\left(\Pi\left(\widehat{p}, e\right)\right)\right) \tag{35}$$

Expected utility when pricing in the importers' currency when using the forward market optimally is at least as high as utility with full hedging (as seen in 2.1 the two are equal in our setup). When hedging fully profits are non-stochastic, use this and the assumption that $U(\Pi) = \Pi$ under certainty to establish (33). Profit when hedging fully is equal to profits with optimally set price (ex post) when the exchange rate is equal to its mean. Monetary neutrality establishes (34). Under conditions on demand and costs as in Proposition 1 profits are concave in exchange rate fluctuations when price is pre-set in the exporter's currency. The utility function is assumed to be concave and increasing in profit. We can then use the result that if $f(x)$ is concave and $F(z)$ is concave and increasing, then $F(f(x))$ is concave to establish the proposition. ■

ii) Show that the following chain of inequalities holds to establish that expected utility when setting price in the importers' currency is higher than when setting price in the third currency.

$$E\left(U\left(\Pi^{*}\left(\widehat{p}^{*}, e, \widehat{h}\right)\right)\right) \geq U\left(\Pi^{*}\left(\widehat{p}^{*}, h = p^{*}Q\right)\right) \tag{36}$$

$$= \max_{p^*} \Pi^* (p^*, \overline{e}) \tag{37}$$

$$= \max_{p^o} \Pi^o (p^o, \overline{e}^o, \overline{e}) \tag{38}$$

$$> E\left(U\left(\Pi^o\left(\widehat{p}^o, e^o, e, \widehat{h}^o\right)\right)\right) \tag{39}$$

The equality in (38) is analogous to (34).

As discussed in section 2.3 we were not able to determine the optimal hedge when the firm sets price in the third currency. We will instead analyze how an hedge affects the behavior of ex post realized profits. We noted that the exposure to be hedged is uncertain since quantities and hence revenues are uncertain. Assume that the exporter has sold an amount $\widehat{h^o}$ on the forward currency market. Expected profits will then be given by

$$\begin{aligned} & E\left(\frac{e}{e^o}\widehat{p}^o Q\left(\frac{\widehat{p}^o}{e^o}\right) - C\left(Q\left(\frac{\widehat{p}^o}{e^o}\right)\right) - \widehat{h}^o\left(\frac{e}{e^o} - \beta^o\right)\right) \\ = \; & E(e)\left(\frac{\widehat{p}^o}{e^o}Q\left(\frac{\widehat{p}^o}{e^o}\right) - \frac{\widehat{h}^o}{e^o}\right) + cov\left(e, \frac{\widehat{p}^o}{e^o}Q\left(\frac{\widehat{p}^o}{e^o}\right) - \frac{\widehat{h}^o}{e^o}\right) - E\left(C\left(Q\left(\frac{\widehat{p}^o}{e^o}\right)\right) + \widehat{h}^o\beta^o\right) \end{aligned} \tag{40}$$

e and e^o are uncorrelated which implies that the covariance term is 0 (no correlation between e and revenue measured in the importers' currency). Also use that $E(e) = 1$ to express (40) as

$$E\left(\frac{\widehat{p}^o}{e^o}Q\left(\frac{\widehat{p}^o}{e^o}\right) - C\left(Q\left(\frac{\widehat{p}^o}{e^o}\right)\right) - \widehat{h}^o\left(\frac{1}{e^o} - \beta^o\right)\right) \tag{41}$$

If (41) is concave in surprises in e^o the inequality (39) holds. The second partial derivative of (41) w.r.t. e^o is given by

$$\frac{2}{e^{o2}}\left(\frac{\widehat{p}^o}{e^o}Q - \widehat{p}^o Q_{e^o}\right) + \left(\frac{\widehat{p}^o}{e^o} - C_Q\right)Q_{e^o e^o} - C_{QQ}\left(Q_{e^o}\right)^2 - \frac{2}{e^{o3}}\widehat{h}^o \tag{42}$$

The sum of the first three terms are negative in analogy with Proposition 2. $\widehat{h}^o \geqslant 0$ by assumption which establishes that expected profits are concave in exchange rate surprises. The utility function is assumed to be concave and increasing in profit. We can then use the theorem that if $f(x)$ is concave and $F(z)$ is concave and increasing, then $F(f(x))$ is concave to establish the Proposition. ■

Footnotes

[1] See e.g. Magee (1974).

[2] Donnenfeld and Zilcha (1991) claim 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.

[3] These roles also correspond to the different roles of money - price setting relates to the unit of account function, invoicing relates to the store of value function and the currency of payment fulfills the medium of exchange function.

[4] 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, e.g. Magee and Rao (1979), Bilson (1983) and Viaene and de Vries (1992). There has also been some work focusing on the currency of payment (medium of exchange) role of money. See Krugman (1980) and Rey (1996).

[5] The Economist (1996).

[6] US exports and imports as share of world exports and imports 1994. For services the US share is somewhat higher. Source: World Trade Organization.

[7] See for instance the Wharton/CIBC Wood Gundy (1995) study of derivatives usage by U.S. non-financial corporations. Of the responding firms that do use derivatives, 91% hedge anticipated foreign exchange transactions within one year or less ("sometimes" or "frequently"). Forward/future currency contracts are reported as the most commonly used instrument for this purpose.

[8] See e.g. Page (1981) and Carse and Wood (1979). See Bilson (1983) for a summary of "stylized facts".

[9] The data are taken from the settlement reports of Sveriges Riksbank (the Swedish Central Bank). All payments through Swedish banks above a threshold of SEK 75,000 (about USD 10,000) are reported. Friberg and Vredin (forthcoming) give a more detailed account of the currency use in Swedish foreign trade.

[10] Black (1991) is one exception. He reports data on Germany, France, Italy and Japan from 1987.

[11] It would clearly be preferable to relax this assumption. For now we note that the higher the positive correlation between e and e^o in our model, the less difference will there be between pricing in the exporter's and the third currency.

[12] This builds on an implicit assumption that the exporter does not hedge the demand risk by buying forward contracts in his own currency. For the specific demand function used in Feenstra and Kendall (1997) it is possible to achieve a perfect hedge and the separation theorem will hold. We do not include hedging when price setting in the exporter's currency for simplicity and since we observe relatively little short selling of currencies that are not matched by any flows in that currency (see e.g. Wharton/CIBC Wood Gundy 1995).

[13] Note that for small changes in e we would 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 profits would be the direct effect since the price is already set at the optimal level.

[14] See for instance Feenstra (1989) or Menon (1995) for a survey.

[15] Adler and Dumas (1984).

[16] Grassman (1973b, p. 70) points to the difficulties of using the forward currency market at the time: "The market for forward exchange is relatively thin and tends, moreover to disappear in acute currency crises, i.e. when it is most needed...they are considered technically complicated and that firms have only a limited knowledge of the foreign exchange market...all forward transactions require the permission of the Bank of Sweden, and this may also have restricted the scope of forward transactions in Sweden".

[17] See Carse and Wood (1979) for a discussion of far-reaching exchange restrictions in Great Britain at the time of their survey.

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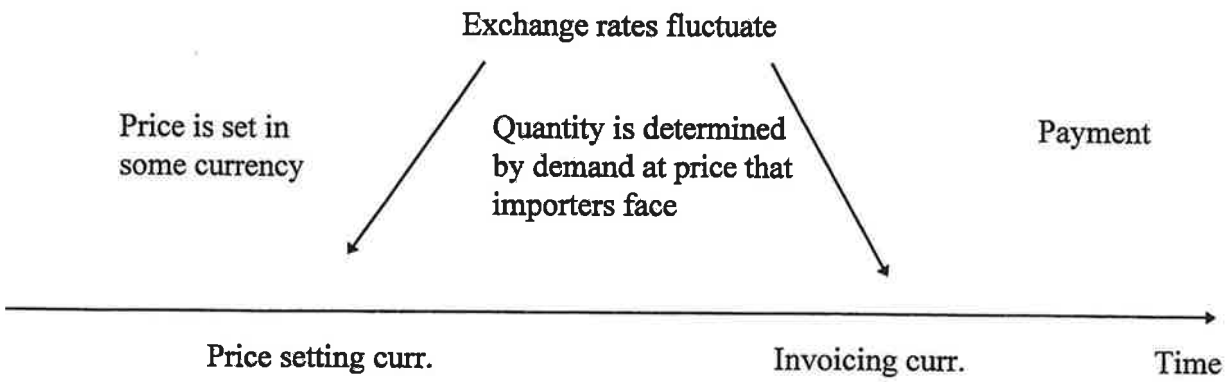

Fig. 1. A stylized international trade transaction

Prices, profits and exchange rate uncertainty: The case of Bertrand competition in differentiated goods

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Abstract

This paper studies a simple duopoly model of price competition under exchange rate uncertainty with pre-set prices and differentiated goods. Competitors come from different countries and compete in a foreign market. We study the effect of the price setting currency chosen on expected prices, profits and exchange rate exposure as well as equilibrium choice of price setting currency. Implications of limited exchange rate pass-through for exchange rate exposure are discussed. The exchange rate pass-through elasticity is shown to be increasing in own-price effects. Parallels are drawn to the literature on strategic trade policy.

Keywords: pricing of exports, exchange rate pass-through, exchange rate exposure.

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1 Introduction

This paper studies exchange rate pass-through[1], exposure[2] and price setting currencies under exchange rate uncertainty. It is motivated by what we perceive as potentially important issues that have received little or no formal attention in the literature on exchange rate pass-through and exposure. How does the price setting currency of a firm's competitor affect the firm's exchange rate exposure? What are connections between exchange rate pass-through and exposure? What is the effect on an exporter's profits from an expected depreciation of its currency? Of an unexpected? What are the effects of market power on pass-through when there is competition?

The effects of exchange rate variability on prices and profits will be dependent on the market structure and the form of competition. Several authors have noted that Bertrand competition in differentiated goods is a form of competition that should be empirically relevant for issues of prices and exchange rates.[3] In this paper we study Bertrand competition in differentiated goods with pre-set prices under exchange rate uncertainty.[4] The assumption of price competition allows us to study issues of e.g. price setting currencies. This could for obvious reasons not be done if we model firms as setting quantity. We study a duopoly where firms are of different nationalities and compete in a single, foreign, market.[5] Firms have to set price in one of three currencies (their own, that of

[1]How import prices of traded goods respond to exchange rate changes. See Menon (1995) for a survey.

[2]Exchange rate exposure is defined as the sensitivity of the value of a firm to exchange rate surprises, see e.g. Adler and Dumas (1984).

[3]Krugman (1987, p. 62) states about the study of exchange rates and prices "A more realistic model, then, would be one in which firms produce differentiated products and probably engage in Bertrand competition". Gottfries (1994), in an empirical study of Swedish export pricing, interprets his findings as supporting the view that (p.23-25) "A natural interpretation of the results is that prices are set a few quarters in advance...This supports the view that, in the short run, firms set prices rather than quantities. The mode of competition is Bertrand, and demand is very inelastic in the short run"

[4]The assumption of pre-set price should not be controversial - given that a floating exchange rate fluctuates literally by the minute it would be prohibitively expensive in many markets to reoptimize offer prices every time the exchange rate changes.

[5]By having a three country model we are able to discuss issues of price setting in a "third currency" and exchange

the importer or a that of the competitor) under exchange rate uncertainty. After the exchange rate is known, the importer decides desired quantities at the prices that he faces.

There has been some study of quantity competition under exchange rate uncertainty,[6] but we are only aware of one article that studies price competition under exchange rate uncertainty, Fischer (1989).[7] Fischer studies the case of Bertrand competition in homogenous goods in a two country model. In Fischer's framework each firm sets price in his own currency before the exchange rate is known. After the realization of exchange rates world demand is allocated. Firms' marginal costs are constant in their domestic currency and they face no capacity constraints. Fischer's focus is on how the number of competitors in the different markets affect exchange rate pass-through. He finds that foreign monopoly tends to decrease expected pass-through into import prices relative to what the case would be if there were several foreign firms. A foreign monopolist will increase profit margins, measured in his own currency, when the exchange rate is expected to move in a favorable direction for him.

In section 2 we develop our simple model with demand functions that are linear in price and marginal costs that are constant in each exporter's domestic currency. The functional forms are attractive as they yield manageable expressions and match the common empirical finding of less than full pass-through.[8]

Section 3 studies how the choice of price setting currency affects expected prices, expected profits and exchange rate exposure when there are no changes in the expected values of exchange rates. The analysis bears a strong connection to the analysis of choice of price setting currency for a residual demand monopolist found in e.g. Baron (1976) and Friberg (1998).[9] Section 3.3 studies the

rate exposure to movements in the currency of foreign competition.

[6] Owen and Perrakis (1988), Luehrman (1990) and Marston (1996).

[7] Feenstra and Kendall (1997) is another exception but with a very different focus, see section 4.

[8] 40 out of the 46 empirical studies surveyed in Menon (1995) report estimated pass-through elasticities that are less than unity.

[9] Typically in international trade the same currency is used for all stages of a transaction. For price setting, as store of value when there is trade credit (invoicing currency), and as medium-of-exchange for the actual payment. The

equilibrium choice of price setting currencies for the numerical cases that we study in section 3.1 and 3.2. Price setting in the importer's currency is the dominant strategy for both firms when cross-price effects are low. With higher cross-price effects there are no dominant strategies. However, the sole Nash equilibrium is for both firms to set price in the importer's currency (except for unreasonably strong cross-price effects, then there are three Nash equilibria, the three cases where both firms set price in the same currency). Section 3.4 studies the issue of exchange rate exposure. We note that when both firms set price in the importer's currency the exchange rate exposure is simply (certain) revenue in foreign currency.

In section 4 we focus on the effects of an expected exchange rate change (of one exporter´s currency) on prices and profits. Exchange rate pass-through (in absolute value) is seen to depend positively on the market power - a firm that has more market power (lower own-price effect on demand) will pass-through more of an expected exchange rate change onto import prices. We also show that pass-through depends negatively on the variance of the exchange rate. The worse the quality of the signal (expected exchange rate change), the less will the exporter respond to it (less pass-through). The effect of market power and substitutability of goods on the pass-through *elasticity,* is the opposite of their effect on exchange rate pass-through. A higher own-price effect leads an exporter to pass-through less of an expected exchange rate change onto import price. However, a higher own-price effect also implies a lower price, so that the percentage change in import price will be higher.

In 4.1 we discuss the effect of expected exchange rate changes on expected and realized profits. We draw connections to the literature on strategic trade policy.[10] Take the case of an expected

choice of what currency to use in trade transactions will be influenced by all three factors. Traditionally trade between developed countries has been denominated in the exporter's currency. For the country where we have access to recent evidence, Sweden, this pattern seems to be changing. Grassman (1973) reported that 66% of Swedish exports were invoiced in Swedish kronor. By 1995 the share invoiced in kronor had decreased to 44%. See Friberg and Vredin (1997) for further discussion.

[10]See e.g. Brander (1996).

appreciation. Each firm would like to charge a higher price, if only it could make such a "promise" credible (price increases raise profits of both firms in this set-up). An expected appreciation of one exporter's currency allows that firm to credibly commit to a higher price. If the appreciation does not materialize this positive effect from higher prices is the only effect on profits. That is, it would fulfill a role very much like that of an export tax in strategic trade policy.

2 The model

There are three countries in the analysis, x, y and z. Country z is the single market where goods are sold. The importing firm passes through price changes fully and immediately to consumer prices (alternatively we may think of the foreign firms selling directly to the final users).We focus on a country x firm that faces competition on the z market from a firm from country y (also called the third country). Demand functions are given by:

$$q(x) = Q - bp^* + \gamma P^* \tag{1}$$

$$q(y) = Q - bP^* + \gamma p^* \tag{2}$$

$q(i)$denotes demand for the product of firm $i = x, y$. Q is exogenous demand, p^* is the price of the good from x and P^* is the price of the good from y. Both are in terms of the z currency, the currency of importers. Assume that $b, \gamma > 0$. *The central assumptions are that firms have to set price before exchange rates are known and that consumers choose quantity demanded after the exchange rates are known.* Each firm has the choice between setting the export price in his own, in the importers' or in the third country currency. Let p^*denote a price that has been set in the importer's currency (z) and p^o a price that has been set in the country y currency. The super-indexes are also used to denote profits under the different pricing strategies. When pricing in the x currency no super-index is used. The price of the competing firm is taken as given (in the currency in which it is set).We assume that each firm is constrained to produce in his home country. Marginal costs are fixed in each producer's domestic currency and denoted by c for the x firm and C for the y firm.

Each firm's objective is to maximize expected profits in his home currency.

Let e, the stochastic nominal exchange rate denote units of the country x currency needed to buy one unit of the importers' currency, z. A higher value of e thus implies a depreciation of the country x firm's currency relative to currency z. Let e^o denote units of country y currency needed to buy one unit of the importer's currency. The exchange rate between x and y is given by the relation e/e^o. Assuming that e and e^o are uncorrelated, we can use the property that $E(ee^o) = E(e)E(e^o)$ which greatly simplifies calculations. Implicitly, we assume that exchange rate changes are due to expectations of monetary policy changes in country x and y only and that these are uncorrelated. The analysis is partial equilibrium and exchange rates are exogenous. Let the markup and the support of the exchange rate be such that the ex post markup is always positive. As markups are positive it will be profitable for firms to accommodate ex post demand.

3 Prices and profits with unchanged expected value of exchange rates

In this section we will study expected prices and profits under different choices of price setting currencies. In 3.1 we study the choices of the firm from x when the firm from y sets price in his own currency. In 3.2 we study the choices faced by the firm from x when the firm from y sets price in the importer's currency. Section 3.3 uses expected profits from 3.1 and 3.2 (and expected profits for the case where each firm sets price in the competitor's currency) to analyze the equilibrium choice of price setting currency. Section 3.4 discusses exchange rate exposure, the sensitivity of ex post profits to exchange rate surprises.

3.1 Third country firm sets price in his own currency

Let P, $P^{(o)}$, $P^{(*)}$ denote the price of the competitor from the third country, when the firm from x sets price in his own, country y and country z currency respectively. The maximization problems

for the x firm are then respectively:

i) pricing in his home currency, x:

$$\max_{p} E\left[(p-c)\left(Q-\frac{b}{e}p+\frac{\gamma}{e^o}P\right)\right] \tag{3}$$

ii) pricing in the importer's currency, z:

$$\max_{p^*} E\left[(ep^*-c)\left(Q-bp^*+\frac{\gamma}{e^o}P^{(*)}\right)\right] \tag{4}$$

iii) pricing in the competitor's, third country currency, y:

$$\max_{p^0} E\left[\left(\frac{e}{e^o}p^o-c\right)\left(Q-\frac{b}{e^o}p^o+\frac{\gamma}{e^o}P^{(o)}\right)\right] \tag{5}$$

Solving for the first order conditions of the firm from x 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 maximization problem of the competitor[11] and substituting his optimal price into the home firms first order condition. Solve for the optimal prices for the x firm and denote these by $\widehat{p}$. These are given in equations (6)-(8). To shorten notation let A be defined as $A=\frac{2b}{(4b^2-\gamma^2)}$. 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. The equilibrium prices in the respective currencies are then:

i) optimal price in home currency, x:

$$\widehat{p}=A\left[\left(Q\left(1+\frac{\gamma}{2b}\right)+\frac{\gamma}{2}CE\left(1/e^o\right)\right)\frac{1}{E\left(1/e\right)}+cb\right] \tag{6}$$

ii) optimal price in the importer's currency, z:

$$\widehat{p}^*=A\left[Q\left(1+\frac{\gamma}{2b}\right)+\frac{\gamma}{2}CE\left(1/e^o\right)+\frac{cb}{E\left(e\right)}\right] \tag{7}$$

[11] These are given in appendix 1.

iii) optimal price in the competitor's, third country currency, y:

$$\widehat{p}^{o} = A\left[Q\left(\frac{E\left(1/e^{o}\right)}{E\left(1/\left(e^{o}\right)^{2}\right)} + \frac{\gamma}{2bE\left(1/e^{o}\right)}\right) + \frac{\gamma}{2}C + cb\frac{E\left(1/e^{o}\right)}{E\left(e\right)E\left(1/\left(e^{o}\right)^{2}\right)}\right] \tag{8}$$

3.1.1 Expected prices and profits

We turn first to expected prices that are faced by the importer and by the exporters. When prices are pre-set expected prices will depend on the price setting currency that is chosen. We use Jensen's inequality and the definition of variance to determine the signs of comparisons. We first study the expected prices to be paid by the importer on imports from x

Proposition 1 *Expected import price of goods from x is highest when price is set in the x currency and lowest when price is set in the same currency as that of competition, y: $\widehat{p}E\left(1/e\right) > \widehat{p}^{*} > \widehat{p}^{o}E\left(1/e^{o}\right)$*

Proof: In appendix 2

The expected price to be paid by the importer is highest when the product is priced in the x currency and lowest when the firms from both countries set price in the third country currency (y). The reverse side of the coin is the expected prices that the country x exporter receives.

Proposition 2 *Expected price to be received by the x firm is highest when the x firm sets price in the importer's currency. i)$E\left(e\right)\widehat{p}^{*} > \widehat{p}$ ii)$E\left(e\right)\widehat{p}^{*} > E\left(e\right)E\left(1/e^{o}\right)\widehat{p}^{o}$ iii)$E\left(e\right)E\left(1/e^{o}\right)\widehat{p}^{o} > \widehat{p}$ if $\frac{var(1/e^{o})}{E\left(1/(e^{o})^{2}\right)}$ is sufficiently small.*

Proof: In appendix 3

We now focus on the expected price of imports from y that the importer in z meets.

Proposition 3 *Expected import price of goods from y is highest when the price of x goods is set in the x currency and lowest when price is set in the y currency: $E\left(1/e^{o}\right)\left[\widehat{P} > \widehat{P}^{(*)} > \widehat{P}^{(o)}\right]$*

Proof: in appendix 4

The expected prices for imports from y depend on the price setting currency chosen by the country x firm. Expected import prices from y follow the same ordering as do the expected import prices from the x firm. The reason for this being that firms' reaction functions are positive when goods are substitutes. If the x 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 expected prices that the importer faces are lowest when both firms set price in y.

Expressions for expected profits tend to become complicated and hard to sign[12]. We will therefore calculate expected profits under some different parameter values. Table 1 reports some of these results[13]. 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 1 about here

We focus on the expected profits for the country x firm. For a wide range of values the highest expected profits for the x firm are reached when he sets price in the importer's currency. The reason for this is analogous to the monopoly case studied by e.g. Baron (1976) and Friberg (1998). When price is set in the importer's currency demand is unaffected by surprises in e. Profits will be a linear function of exchange rate surprises in e - expected profits are not affected (this is seen by twice differentiating equation (40) in appendix 5 with respect to e). If price is set in the x currency, profits are a concave function of exchange rate surprises in e since a demand function that is linear in price then is concave in exchange rate surprises (seen by twice differentiating equation (37) in

[12]In Friberg (1996) explicit expressions are calculated and ranked for the case where $\gamma = 0$, the monopoly case. Price setting in the importer's currency yields the highest expected profits for a monopolist facing a linear demand function and having constant marginal costs..

[13]In the calculations $Q = 6, c = C = 1, b = 2$.

appendix 5 with respect to e). Concavity of profits in e imply that the expected value of profits will be affected negatively by the variance of e.

The concavity of profits in e can be contrasted to Fischer's (1989, p. 130) discussion of the convexity of the profit function in the price noise. Focus on the simplest case in Fischer's model, one firm from each country. Fluctuating exchange rates and homogenous goods imply that a firm has a positive probability of capturing the whole foreign market, while there is also a probability that he will sell nothing on the foreign market. Profits will be convex in exchange rate fluctuations. In Fischer's model expected profits are increasing in the volatility of the exchange rate. In our model goods are differentiated and quantity is demand determined - the shape of demand and cost functions will determine convexity or concavity of profits in exchange rate fluctuations.

The stronger cross-price effects (γ), the more attractive does pricing in currency y become. We can get some intuition for why this could be the case by noting the analog between the issue that we study here and the issue of choosing price or quantity as strategic variable under uncertainty. Klemperer and Meyer (1986) note that the cost of choosing a strategic variable is the cost of deviating from the optimal ex post point on the residual demand curve. The stronger cross-price effects are, the stronger will the effect of surprises in e^o be on the ex post demand curve that the x firm faces. A depreciation of the y currency lowers the price of the y good that the importer faces, this shifts the ex post demand curve for x goods downwards. By setting his price in the y currency as well, the x firm will achieve the same adjustment of his price to the importer.[14] In our model price setting in the y currency yield the highest expected profits 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. The example still gives us valuable intuition for why a firm would want to set price in the same currency as competition when cross-price effects are strong.

[14]Why shouldn't the x firm always price in the y currency then? Note (equation (43) in appendix 5) that demand will be concave in e^o through the own-price effect. This tends to lower expected profits.

We also see that the choice of price setting currency by the x firm affects expected profits by the y firm. They are highest when the x firm sets price in his own currency. Higher expected market prices from the x firm allow the y firm to quote a higher optimal price as shown in proposition 3, the higher expected price resulting in higher expected profits[15].

3.2 Third country firm sets price in importer's currency

We will only briefly study this case. The maximization problems of firms are analogous to those in section 3.1 with straightforward changes of where the exchange rates enter the problem. They are not reported here. In table 2 the expected profits are calculated using the same parameter values as in table 1.

Table 2 about here

We see that when the firm from x prices in the importer's currency expected profits are unaffected by the variance of exchange rates. We also note that expected profits are always highest when the x firm prices in the importer's currency. This is the same result as Baron (1976) found. He showed that, when demand is linear in price and marginal costs are constant (and the residual demand curve unaffected by exchange rate surprises), price setting in the importer's currency maximizes expected profits.

Comparing with table 1 we see that for the x firm it generally led to higher expected profits when the firm from y priced in the y currency. We also note that price setting in his own currency is not optimal for the y firm.[16] The next section studies the equilibrium choice of price setting currencies.

[15]Our results are derived under the assumption that e and e^o are uncorrelated. Introducing correlation between the different exchange rates in our model would make it more realistic, but also more complicated. We note for now that the higher the correlation between e and e^o, the less difference will there be between pricing in an exporter's own currency compared to pricing in the competitors currency. If there is perfect correlation between e and e^o expected prices and profits are unaffected by if the x firm sets price in x or in y.

[16]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

3.3 Equilibrium choice of price setting currencies

To construct a complete pay-off matrix with expected profits (for the numerical values considered in 3.1 and 3.2) under the possible combinations of price setting currencies we need to calculate expected profits for the case when both firm sets price in the competitor's currency. Using this and expected profits from tables 1 and 2 we construct table 3 which gives the pay-off matrix for the case when the variability of e is L, that of e^o is H and the cross-price effect is 1. The first number in each box is the expected profits of the firm from y and the second the expected profits of the firm from x. For instance the upper left-hand corner says that the expected profit of the firm from y is 5.538 when both firms set price in the x currency. The expected profit of the x firm is then 5.5250. It is easily verified that it is the dominant strategy for both firms to set price in the importer's currency. We do not report the other pay-off matrixes here since they are easily constructed from tables 1 and 2 (the "missing" case where firms' set price in each others' currencies is always dominated). Price setting in the importer's currency is the dominant strategy for both firms when the strength of cross-price effect, γ, equals 1 for all the cases that we considered in tables 1 and 2.

Table 3 about here

As the strength of the cross-price effect is increased to 2 there is no dominant strategy. The only Nash equilibrium is however for both firms to set price in the importer's currency (the same holds for the case when $\gamma = 3$). For the unlikely case that $\gamma = 3.9$ we have three Nash equilibria, for both firms to set price in x, both firms pricing in z and both firms pricing in y.

3.4 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[17]. The price setting currencies of both firms' will affect how

under the other price setting currencies when γ is increased. We have no intuition for this result at present.

[17] Adler and Dumas (1984).

the x firm is affected by exchange rate surprises. The exchange rate exposure of the x firm is given by

$$d\pi\left(\widehat{p}, e, e^{o}\right) = \frac{\partial \pi\left(\widehat{p}, e, e^{o}\right)}{\partial e} de + \frac{\partial \pi\left(\widehat{p}, e, e^{o}\right)}{\partial e^{o}} de^{o} \tag{9}$$

This section studies the exchange rate exposure of the x firm both for the case when the competitor sets price in his own currency (section 3.4.1) and when the competitor sets price in the importer's currency, (section 3.4.2).

3.4.1 Third country firm sets price in his own currency

Appendix 5 reports expressions for the partial derivatives of the x firm's profit function with respect to exchange rates when the y competitor sets price in his own currency (y). Here it should be noted that demand is uncertain no matter what currency the x firm sets prices in. A surprise depreciation of the x firm's home currency against currency z, (a higher value of e), has a positive effect on the x firm's profits no matter what currency that prices are set in.

When the x firm sets price in the competitor's currency, the effects on the x firm's profits from a depreciation of the y currency stem both from price and demand effects. The price that the x firm receives is lower. Demand is affected positively by the lower price that customers meet on the x firm's goods and negatively by the lower price of the competitor's good.

Another property of the framework that follows from the assumption of competition based in a third country may be worth noting. The response of a corporate cash flow, to a depreciation of the x currency relative to that of the firm's market, is dependent on if it is x that depreciates, or if it is z that appreciates against both the other currencies. 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 importer's currency appreciates against both the other currencies our goods become cheaper, but so do the goods of our foreign competitor. The largest boost to an exporter's profits is of course given if his own currency depreciates relative to the market and the competitor's currency appreciates against that of the market.

3.4.2 Third country firm sets price in the importer's currency

We will focus on the exchange rate exposure of the x firm when he sets price in the importer's currency as well. The realized ex post profits of the x firm are then given by

$$\pi^* = (e\widehat{p}^* - c)\left(Q - b\widehat{p}^* + \gamma\widehat{P}^*\right) \tag{10}$$

We note that the exchange rate exposure in this case is simply given by (the certain) revenues in foreign currency. ($\frac{\partial \pi^*}{\partial e} = \widehat{p}^*\left(Q - b\widehat{p}^* + \gamma\widehat{P}^*\right)$; $\frac{\partial \pi^*}{\partial e^o} = 0$). Demand is unaffected by exchange rate surprises, the only uncertainty concerns the exchange rate at which the x firm will translate its foreign revenue into domestic currency. The exchange rate exposure of the firm will be the equivalent of the transaction exposure[18].

Now for a moment interpret price setting in the importer's currency to simply mean that firms tend to keep import prices stable in the importer's currency. This then means that pricing-to-market/less than full exchange rate pass-through tends to limit exchange rate exposure to transaction exposure. Demand elasticities, strength and origin of competition and other market structure variables will be of little importance for the exchange rate exposure of a firm if all firms keep import prices stable. This relationship between price stability in the importer's currency and exchange rate exposure stresses the role of exchange rate pass-through for exchange rate exposure. Our discussion may give some intuition for why many firms seem to focus so much on the management of transaction exposure as opposed to the resources that they devote to the management of total economic exposure to exchange rates[19] (which incorporates competitive effects, see e.g. Sercu and Uppal,

[18]Transaction exposure arises on assets that are denominated in foreign currency and whose value in the exporter's currency is uncertain. See e.g. Sercu and Uppal (1995). It normally relates to past contractual undertakings, but, just as in our case, it measures the exposure of a certain foreign currency revenue.

Marston (1996) in his study of quantity competition under exchange rate uncertainty makes a similar finding - that under many forms of quantity competition the exchange rate exposure is simply proportional to revenues in foreign currency. That result is driven by the envelope theorem, quantities are determined by the exchange rate - by the first order condition for profit maximization the effect of a change in quantity on profit is 0.

[19]See e.g. Belk and Glaum (1990).

1995).

4 Changes in expected exchange rates

We will now study the behavior of prices and profits when the expected value of exchange rates change. The theoretical literature on exchange rate-pass through has found the degree of pass-through to depend on how the demand elasticity changes along the demand curve (i.e. the curvature of the demand curve). If the demand elasticity increases as the price rises there will be incomplete pass-through. There has been little study of price competition with differentiated goods [20], uncertainty[21] or competition from third countries. Attention to how industry characteristics influences pass-through has focused on concentration ratios and the relative numbers of competitors from different countries.

In our simple framework we investigate how the strength of own-price and cross-price effects affect pass-through. We stress the distinction between how own- and crossprice effects affect pass-through $\left(\frac{d\widehat{p^*}}{dE(e)}\right)$vs. how they affect the pass-through elasticity $\left(\frac{d\widehat{p^*}}{dE(e)}\frac{E(e)}{\widehat{p^*}}\right)$. The distinction is important as much of the empirical work on exchange rate pass-through (surveyed in Menon 1995) studies pass-through elasticities, whereas discussions and hypotheses about how market structure and market power affect pass-through behavior often relate to pass-through.

To keep the issue as simple as possible assume in this section that both firms set price in the importer's currency (which also was the dominant strategy for the most realistic cases in 3.3). This means that pass-through measures the actual price change in response to an expected exchange rate

[20] Feenstra, Gagnon and Knetter (1996) and Baniak and Phlips (1995) are two exceptions.

[21] Fischer (1989) is the only exception. Some papers, e.g. Feenstra (1989), include uncertainty but study a certainty equivalent structure and carry out the analysis under the assumption that the ex post realised exchange rate is equal to the ex ante expected exchange rate. Feenstra and Kendall (1997) introduce risk aversion, forward markets and study price setting in both the importer's and exporter's currency. The focus is quite different from the present paper. Their model predicts that firms' hedging should lead to PPP holding on forward rather than spot exchange rates.

change[22]. The x firm's maximization problem is given by

$$\max_{p^*} E\left[(ep^* - c)\left(Q - bp^* + \gamma P^*\right)\right] \tag{11}$$

and that of the country y firm by

$$\max_{P^*} E\left[(e^o P^* - C)\left(Q - bP^* + \gamma p^*\right)\right] \tag{12}$$

The corresponding first order conditions are given by

$$E(e)\,Q - E(e)\,2bp^* + \gamma E(e)\,P^* + cb = 0 \tag{13}$$

$$E(e^o)\,Q - E(e^o)\,2bP^* + \gamma E(e^o)\,p^* + Cb = 0 \tag{14}$$

Totally differentiate (14) and (13), let $dE(e^o) = 0$ to solve for pass-through (alternatively solve for the equilibrium price and differentiate this with respect to $E(e)$.

Proposition 4 *Exchange rate pass-through* , $\frac{d\widehat{p}^*}{dE(e)}\Big|_{dE(e^o)=0}$, *is always negative. The absolute value of the pass-through is decreasing in the own-price effect, increasing in the cross-price effect and decreasing in the variance of the exchange rate when the exchange rate is distributed log-normally with mean μ and standard deviation σ.*

Proof: Pass-through is given by

$$\frac{d\widehat{p}^*}{dE(e)}\Big|_{dE(e^o)=0} = \frac{\partial \widehat{p}^*}{\partial E(e)} = -\frac{2b^2c}{(4b^2-\gamma^2)E(e)^2} < 0 \tag{15}$$

All terms in (15) are positive which establishes that pass-through is negative. Define $PT \equiv \left|\frac{\partial \widehat{p}^*}{\partial E(e)}\right|$. The absolute value of pass-through is decreasing in b since

$$sign\left(\frac{\partial PT}{\partial b}\right) = sign\left(-4bc\gamma^2 E(e)^2\right) < 0 \tag{16}$$

[22]Note that pass-through here is differently defined than what is usually the case. We study the change in import prices due to a *depreciation of the exporter's* currency. This is negative, a depreciation leads the exporter to lower his price to consumers. Often pass-through is defined as the percentage change in import prices due to a percentage *depreciation of the importers* currency ($1/e$ in or model) in which case it is positive.

and increasing in cross-price effects since

$$\frac{\partial PT}{\partial \gamma} = \frac{2b^2c}{(4b^2-\gamma^2)^2E(e)^2}2\gamma > 0 \tag{17}$$

PT is decreasing in the volatility of the exchange rate when e is distributed log-normally with mean μ and standard deviation σ, since

$$\frac{\partial PT}{\partial \sigma^2} = -\frac{4b^2c\sigma}{(4b^2-\gamma^2)\left(exp\left(\mu+\frac{1}{2}\sigma^2\right)\right)^2} < 0 \tag{18}$$

■

A firm that has lower mark-ups (higher b, lower γ) passes through less of the expected exchange rate change (that is, the absolute value of pass-through is lower). The more that demand decreases when a firm raises its price, the less does a firm want to pass through an exchange rate change. That an increase in the noisiness of the exchange rate leads to less response of the pre-set price is also intuitively appealing. The worse the quality of the signal (higher variance of the exchange rate), the less will the pre-set price respond to the signal. This could be one way in which lower exchange rate variability could improve the effectiveness of the "price signal".

We now turn to a discussion of exchange rate pass-through elasticities, the issue is important as most of the empirical work in the area studies pass-through elasticities and not pass-through itself. Effects on the equilibrium pass-through elasticity of changing b and γ are then the opposite of the effect of changing those parameters on pass-through.

Proposition 5 *The exchange rate pass-through elasticity, $\frac{\partial \widehat{p}^*}{\partial E(e)}\frac{E(e)}{\widehat{p}^*}$, is always negative and less than unity in absolute value. The absolute value of the pass-through elasticity is decreasing in the cross-price effect, increasing in the own-price effect and decreasing in the variance of the exchange rate process when the exchange rate is distributed log-normally with mean μ and standard deviation σ.*

Proof: The pass-through elasticity is given by

$$\frac{\partial \widehat{p}^*}{\partial E(e)}\frac{E(e)}{\widehat{p}^*} = -\frac{cb}{E(e)\left(Q\left(1+\frac{\gamma}{2b}\right)+\frac{\gamma}{2E(e^o)}C\right)+cb} < 0 \tag{19}$$

All terms in (19) are positive which establishes that the pass-through elasticity is negative. It is also immediately clear from (19) that the pass-through elasticity will be between 0 and -1. Define $\theta = \left|\frac{\partial \widehat{p^*}}{\partial E(e)} \frac{E(e)}{\widehat{p^*}}\right|$ and $G = Q\left(1 + \frac{\gamma}{2b}\right) + \frac{\gamma}{2E(e^o)}C$. The absolute value of the pass-through elasticity is increasing in b since

$$\frac{\partial \theta}{\partial b} = \frac{c\left(E(e)\,Q\left(1+\frac{\gamma}{b}\right) + \frac{\gamma}{2}\frac{C}{E(e^o)}\right)}{\left(E(e)\,G + cb\right)^2} > 0 \tag{20}$$

and decreasing in γ since

$$\frac{\partial \theta}{\partial \gamma} = -\frac{cb}{\left(E(e)\,G + cb\right)^2}\left(\frac{Q}{2b} + \frac{C}{2E(e^o)}\right)E(e) < 0 \tag{21}$$

θ is decreasing in the volatility of the exchange rate, when e is distributed log-normally with mean μ and standard deviation σ, since

$$\frac{\partial \theta}{\partial \sigma^2} = -\frac{cb}{\left(exp(\mu + \frac{\sigma^2}{2})G + cb\right)^2} G\sigma exp\left(\mu + \frac{\sigma^2}{2}\right) < 0 \tag{22}$$

■

The simplest way to understand what the difference in pass-through and pass-through elasticities stems from is to discuss the effects of increasing b, the own-price effect. The change in import price, due to an expected exchange rate change, is larger the lower b is (as showed in proposition 4). But a lower b implies a higher price so that the *percentage* change in import price, due to a percentage change in the expected exchange rate, is lower the lower b is. A particular case in point is the case where $\gamma = 0$, monopoly. It is then well known that pass-through then is independent of b (see e.g. Feenstra, Gagnon and Knetter 1996). Since the change in import price is not dependent on b, but the level of the price itself is (lower b implies a higher price), the percentage change in import price will be dependent on b.

In the analysis above we have kept $dE(e^o) = 0$. We should also note however that more generally the price that the country x firm charges is affected not only by the expected exchange rate between currency x and the importer's currency, but also by the exchange rate between the importer's currency and the country y currency. $\frac{\partial \widehat{p^*}}{\partial E(e^o)} = -A\left(\frac{\gamma}{2E(e^o)^2}C\right) < 0$. If the y currency is expected to depreciate the x firm exporter will decrease his price. An expected depreciation of the y firm's

home currency leads him to charge a lower price on the z market - it is then optimal for the firm from x to lower his price as well.

4.1 Effect on profits from an expected depreciation

Solving for the optimal prices from (13) and (14) and plugging them into the respective maximization problems gives the expected profits of the two competitors.

$$E(\pi^*) = (E(e)\widehat{p}^* - c)\left(Q - b\widehat{p}^* + \gamma\widehat{P}^*\right) \tag{23}$$

$$E(\Pi^*) = \left(E(e^o)\widehat{P}^* - C\right)\left(Q - b\widehat{P}^* + \gamma\widehat{p}^*\right) \tag{24}$$

To shorten notation define $\widehat{q}(x) \equiv \left(Q - b\widehat{p}^* + \gamma\widehat{P}^*\right)$. Totally differentiating expected profits yields

$$dE(\pi^*) = \widehat{p}^*\widehat{q}(x)dE(e) + \frac{\partial E(\pi^*)}{\partial p^*}dp^* + \frac{\partial E(\pi^*)}{\partial P^*}dP^* + \frac{\partial E(\pi^*)}{\partial E(e^o)}dE(e^o) \tag{25}$$

Use first order conditions (13) and (14), let $dE(e^o) = 0$, to express (25) as

$$\frac{dE(\pi^*)}{dE(e)} = \widehat{p}^*\widehat{q}(x) - (E(e)\widehat{p}^* - c)\gamma A\left(\frac{\gamma}{2E(e)^2}c\right) \tag{26}$$

The first term is positive, a depreciation of the country x currency will make the x firm's total foreign currency revenues more worth in its own currency. The second effect is negative, an expected depreciation lowers the price that competition charges. This leads to lower demand for the country x exporter's goods which lowers profits. The first order condition, (13), implies that the direct effect on expected profits from changing his own price is 0 for the firm from x. There is thus no direct effect on expected profits from the lower price charged by the country x firm. We depict firms' reaction functions in figure 1 below. An expected depreciation of the x currency shifts the x firm's reaction function inwards, both firms lower their prices.

figure 1 about here

We also note another implication of (26) - an expected depreciation that does not materialize affects realized profits negatively. The expected depreciation lowers the prices of both firms as in

figure 1 which leads to lower profits. In the case where the depreciation does not happen this will be the only effect on realized profits (for small surprises the only effect on profits will be through the lower price that competition charges, for larger surprises there will also be a negative effect on profits from the lower price that the x firm himself charges, $\frac{\partial \pi^*}{\partial p^*} = 0$ will then not hold). We have what might be called a "problem due to a Peso problem"[23]. We also note that an expected appreciation that does not materialize benefits both firms. The intuition being the same as that behind the result that the optimal strategic trade policy under Bertrand competition is an export tax[24]. The firm from x would like to charge a higher price than the Bertrand level, if only it could commit to it. An export tax makes the higher price credible. Here an expected appreciation serves the same role. In the case where the appreciation does happen, the positive effect on profits for the x firm is outweighed by the negative translation effect.

5 Conclusions

Even though the model presented in this paper relies on a very simple structure it allowed us to study issues that have received little attention previously.. Choice of price setting currency when there is competition from a third country, connections between price setting currencies and economic exposure, and effects of expected exchange rate changes on profits. We demonstrated the attractiveness of setting price in the importer's currency for both firms. That pricing in the same currency as competition becomes more attractive the stronger cross-price effects are may help explain behavior such as the invoicing patterns shown by Swedish forestry firm Södra Skogsägarna. Exports of softwood pulp to European countries is invoiced in dollars. The majority of competition in softwood pulp is based in North America. Hardwood pulp on the other hand is invoiced in

[23] A Peso problem normally relates to a future discrete shift in policy that does not materialize during the period studied. The expected value of the exchange rate may therefore be different from the observed average value over a long period. See e.g. Lewis (1996).

[24] See e.g. Brander (1996).

Ecu and the majority of competition comes from Spain and Portugal. The choice of price setting and invoicing currency thus seems ruled by concerns as to the competitive structure rather than medium-of-exchange or store-of-value roles of currency.

We have also stressed that depending on if we study pass-through or the pass-through elasticity, we should expect different effects from market power and substitutability. The effect of substitutability on pass-through elasticities is the opposite in our Bertrand framework than what is hypothesized in e.g. Menon (1996). This stresses the need for formal models underlying empirical studies of pass-through - we should not expect structural variables to have the same effect on pass-through irrespective of the form of competition. Under the assumption that the exchange rate is distributed log-normally we showed that pass-through was lower the more volatile the exchange rate was. This is a result of the same flavor as Krugman's (1989, p.54) finding (in a "sunk cost" model) that, "the exchange rate has so little effect in part because it fluctuates so much".

Finally, as discussed in the introduction, it is surprising that there has been so little study of price competition under exchange rate uncertainty - there are many ways in which it should be fruitful to extend the present work. One extension is to include several competitors and study how the country distribution of competitors affects pass-through. Extending the analysis to include two markets would enable us to discuss Pricing-to-Market issues. Using more general functional forms and allowing for futures markets and risk aversion are examples of extensions that should be interesting, though at a price of probably making analysis more involved.

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Appendix 1

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

$$\max_{P} E\left[(P-C)\left(Q-\frac{b}{e^o}P+\frac{\gamma}{e}p\right)\right] \tag{27}$$

$$\max_{P^{(*)}} E\left[\left(P^{(*)}-C\right)\left(Q-\frac{b}{e^o}P^{(*)}+\gamma p^*\right)\right] \tag{28}$$

$$\max_{P^{(o)}} E\left[\left(P^{(o)}-C\right)\left(Q-\frac{b}{e^o}P^{(o)}+\frac{\gamma}{e^o}p^o\right)\right] \tag{29}$$

Appendix 2

Comparison of expected prices for imports from x.

i) compare $\widehat{p}E(1/e)$ and $\widehat{p}^*$

$$\widehat{p}E(1/e)-\widehat{p}^* = Acb\left(E(1/e)-\frac{1}{E(e)}\right) \tag{30}$$

Jensen's inequality implies that the second term is positive$\Rightarrow$ $\widehat{p}E(1/e) > \widehat{p}^*$.

ii) Compare $\widehat{p}^o E(1/e^o)$ and $\widehat{p}^*$

$$\widehat{p}^o E(1/e^o)-\widehat{p}^* = \left(\frac{E(1/e^o)^2}{E\left(1/(e^o)^2\right)}-1\right)\left(Q+\frac{cb}{E(e)}\right) \tag{31}$$

Using the definition of variance, $var(x) = E(x^2)-E(x)^2$,we write this is as $-\frac{var(1/e^o)}{E\left(1/(e^o)^2\right)}\left(Q+\frac{cb}{E(e)}\right) < 0$. This establishes proposition 1. ■

Appendix 3

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

i) Compare $\widehat{p}$ and $\widehat{p}^* E(e)$.

$$\widehat{p}-\widehat{p}^* E(e) = A\left(\frac{1}{E(1/e)}-E(e)\right)\left(Q\left(1+\frac{\gamma}{2b}\right)+\frac{\gamma}{2}CE(1/e^o)\right) \tag{32}$$

Jensen's inequality$\Rightarrow$ $\widehat{p}-\widehat{p}^* E(e) < 0$.

ii) Compare $E(e)E(1/e^o)\widehat{p}^o$ and $E(e)\widehat{p}^*$.

$$E(e)E(1/e^o)\widehat{p}^o - E(e)\widehat{p}^* = -E(e)A\frac{var(1/e^o)}{E\left(1/(e^o)^2\right)}\left(Q+\frac{cb}{E(e)}\right) < 0. \tag{33}$$

iii) Compare $E(e)\,E(1/e^o)\,\widehat{p}^o$ and $\widehat{p}$.

$$E(e)\,E(1/e^o)\,\widehat{p}^o - \widehat{p} = \left(E(e) - \frac{1}{E(1/e)}\right) Q\left(1+\frac{\gamma}{2b}\right) - \frac{var(1/e^o)}{E\left(1/(e^o)^2\right)}\left(E(e)\,Q + cb\right) \tag{34}$$

Jensen's inequality implies that the first term is positive. The second is negative. For high enough variance in e^o the whole expression will be negative. This establishes proposition 2. ■

Appendix 4:

Optimal equilibrium price for the firm from y are found by using the first order conditions from (3)-(5) into the first order conditions from appendix 1.

i) Compare $\widehat{P}$ and $\widehat{P}^{(*)}$.

$$\widehat{P} - \widehat{P}^{(*)} = \frac{b\gamma}{(4b^2-\gamma^2)\,E(1/e^o)}c\left(E(1/e) - \frac{1}{E(e)}\right) \tag{35}$$

Jensen's inequality$\Rightarrow \widehat{P} > \widehat{P}^{(*)}$

ii) Compare $\widehat{P}^{(o)}$ and $\widehat{P}$.

$$\widehat{P}^{(o)} - \widehat{P}^{(*)} = -\frac{b\gamma}{(4b^2-\gamma^2)\,E(1/e^o)}(Q+cb)\,\frac{var(1/e^o)}{E\left(1/(e^o)^2\right)} \tag{36}$$

We see that $\widehat{P} > \widehat{P}^{(*)} > \widehat{P}^o$. This establishes proposition 3. ■

Appendix 5

i) Price set in the home currency, x:

$$\pi = (\widehat{p}-c)\left(Q - \frac{b}{e}\widehat{p} + \frac{\gamma}{e^o}\widehat{P}\right) \tag{37}$$

$$\frac{\partial\pi}{\partial e} = (\widehat{p}-c)\,\frac{b}{e^2}\widehat{p} > 0 \tag{38}$$

$$\frac{\partial\pi}{\partial e^o} = -(\widehat{p}-c)\,\frac{\gamma}{e^{o2}}\widehat{P} < 0 \tag{39}$$

ii) Price set in the importers' currency, z

$$\pi^* = (e\widehat{p}^* - c)\left(Q - b\widehat{p}^* + \frac{\gamma}{e^o}\widehat{P}^{(*)}\right) \tag{40}$$

$$\frac{\partial\pi^*}{\partial e} = \widehat{p}^*\left(Q - b\widehat{p}^* + \frac{\gamma}{e^o}\widehat{P}^{(*)}\right) > 0 \tag{41}$$

$$\frac{\partial\pi^*}{\partial e^o} = -(e\widehat{p}^* - c)\,\frac{\gamma}{e^{o2}}\widehat{P}^{(*)} < 0 \tag{42}$$

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

$$\pi^o = \left(\frac{e}{e^o}\widehat{p}^o - c\right)\left(Q - \frac{b}{e^o}\widehat{p}^o + \frac{\gamma}{e^o}\widehat{P}^{(o)}\right) \tag{43}$$

$$\frac{\partial \pi^o}{\partial e} = \frac{\widehat{p}^o}{e^o}\left(Q - \frac{b}{e^o}\widehat{p}^o + \frac{\gamma}{e^o}\widehat{P}^{(o)}\right) > 0 \tag{44}$$

$$\frac{\partial \pi^o}{\partial e^o} = -\frac{e}{e^{o2}}\widehat{p}^o\left(Q - \frac{b}{e^o}\widehat{p}^o + \frac{\gamma}{e^o}\widehat{P}^{(o)}\right) + \frac{1}{e^{o2}}\left(\frac{e}{e^o}\widehat{p}^o - c\right)\left(b\widehat{p}^o - \gamma\widehat{P}^{(o)}\right) \tag{45}$$

Table 1: Expected profits when y firm sets price in the y currency

Variability of exchange rates:		Cross-price effect	Expected profits of firm from x when he sets price in (and the y firm prices in y):			Expected profits of firm from y when he sets price in y and the x firm sets price in:		
e	e^0	γ	x	z	y	x	z	y
H	H	1	5.245	5.593	5.286	5.245	5.210	5.081
H	L	1	5.212	5.558	5.538	5.571	5.534	5.5251
L	H	1	5.571	5.593	5.286	5.212	5.210	5.081
L	L	1	5.536	5.558	5.538	5.536	5.534	5.5251
H	H	2	17.28	18.17	17.87	17.28	17.12	16.54
H	H	3	95.20	99.01	98.75	95.20	94.24	90.72
H	H	3.9	12224	12612	12619	12224	12098	11640

Table 2: Expected profits when y firm sets price in the z currency

Variability of exchange rates		Cross-price effects	Expected profits of firm from x when he sets price in (and the y firm sets price in z):			Expected profits of firm from y when he sets price in z and the x firm sets price in:		
e	e^o	γ	x	z	y	x	z	y
H	H	1	5.210	5.555	4.924	5.593	5.555	5.097
H	L	1	5.210	5.555	5.514	5.593	5.555	5.5253
L	H	1	5.534	5.555	4.924	5.558	5.555	5.097
L	L	1	5.534	5.555	5.514	5.558	5.555	5.5253
H	H	2	17.12	18.00	15.65	18.17	18.00	15.38
H	H	3	94.24	98.00	74.80	99.00	98.00	72.12
H	H	3.9	12098	12482	1872	12612	12482	1798

Table 3: Equilibrium choice of price setting currencies

		Expected profits for firm from x when setting price in					
		x		z		y	
Expected profits for firm from y when setting price in	x	5.538	5.5250	5.514	5.5253	0.982	1.138
	z	5.558	5.534	5.555	5.555	5.097	4.924
	y	5.212	5.571	5.210	5.593	5.081	5.286

Expected profits are calculated for the case where variability of e is L, variability of e^0 is H, and c=C=γ=1, Q=6, b=2.

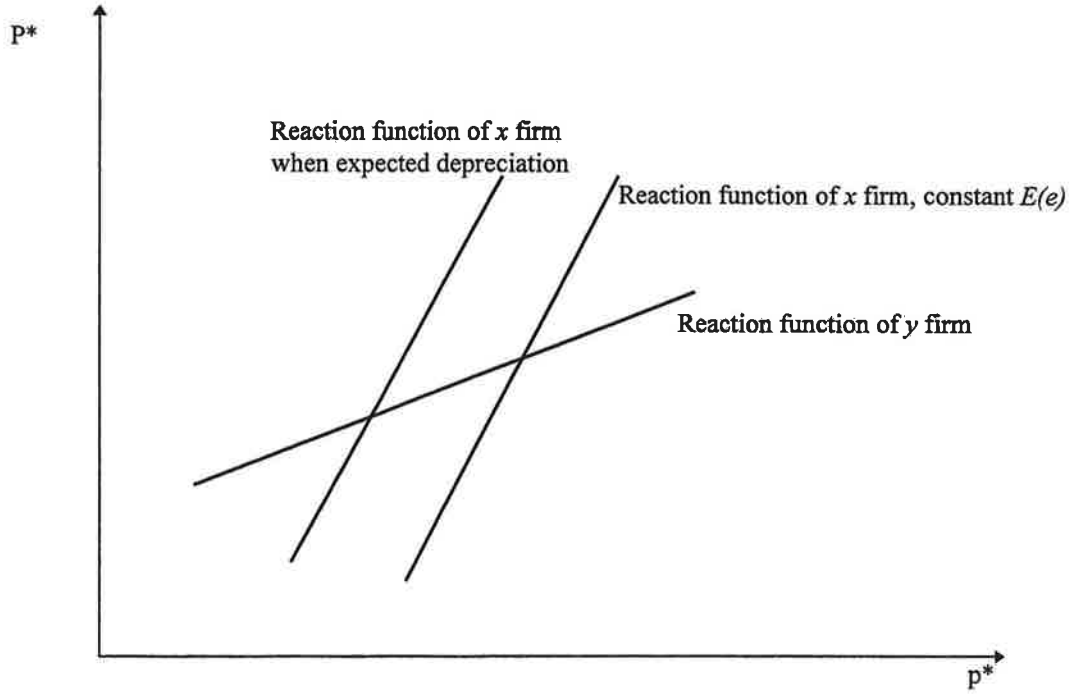

Fig.1. Effects on prices from an expected depreciation of currency *x*.

Openness and the Exchange Rate Exposure of National Stock Markets - a Note *

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Abstract: This paper examines the relationship between the valuation of the stock market and an effective exchange rate. We use monthly data on 10 industrialized countries for the period 1973-1996. We find that the more open the economy, the stronger is the (positive) relationship between return on the stock market and the exchange rate. The pattern that we find is consistent with the well documented findings of less than full pass-through of exchange rates into import prices.

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Is the relationship between stock market value and the exchange rate (exchange rate exposure) stronger in a more open economy than in a more closed economy? Our interest in this issue was spurred by the very limited evidence of a statistically significant relationship between exchange rates and market valuation of firms (see e.g. Jorion, 1990, Bodnar and Gentry, 1993, Bartov and Bodnar, 1994). Many observers have found this lack of significance surprising[1]. However, most of the empirical work cited above uses data from a relatively closed economy, the United States. Potentially this could account for the limited stock price responses to exchange rate surprises. In their study on the exchange rate exposure of a sample of British firms, Donnelly and Sheehy (1996, p. 163) point out that "Our analysis has found a contemporaneous relationship between the exchange rate and a portfolio of export-intensive companies. We attribute the difference between our findings and those of U.S. research to the fact that the U.K. is a far more open economy than that of the U.S. and that our sample firms are more export intensive than those used in prior U.S. based research."

Conventional wisdom says that (the firms in) a more open economy should be affected stronger by changes in the exchange rate than that of a more closed economy as long as money is not neutral. In a more open country a larger share of the average firm's transactions should be related to exchange rate changes, through exports, imports or competition from foreign firms. One possible research strategy for studying this issue is to study the dispersion of exchange rate exposure between the same industries based in different countries. The task that we set for ourselves in this paper is more humble in the sense that we examine the exchange rate exposure of national stock markets. The advantage of our strategy is that we are able to expand the number of markets studied at a low cost. By studying the stock market index we also implicitly study how importing and import-competing firms are affected by

[1] Chow, Lee and Solt (1997, p. 105) for instance state that "More puzzling is that analyses thus far have failed to substantiate a statistically significant relationship [between firm value and exchange rates]"

exchange rate surprises - this is in contrast to the literature on exchange rate exposure that has focused on exporting firms.

The relationship between the valuation of the stock market and an effective exchange rate for 10 industrialized countries is examined. Monthly data for the period 1973-1996 are used. We establish a significant positive relationship between exchange rate exposure on the stock market and openness.

In section I we discuss related literature. Section II presents our empirical analysis and section III contains a discussion of our findings. We claim that if firms tend to keep prices stable in the importer's currency (less than full exchange rate pass-through) this should lead to the kind of pattern that we observe. Section IV concludes and makes suggestions for further research.

I. Exchange rate exposure

In the literature on exchange rate exposure it is common practice to divide exposure into economic and accounting exposure. Accounting exposure is concerned with the effect of exchange rate surprises on the accounting value of assets and liabilities. Economic exposure for a firm measures the extent to which a firm's value, defined as the expected value of future cash flows, changes with the exchange rate. This is a much more general and relevant measure of exchange rate exposure than accounting measures, but also more complex. It is hard to identify all, or even a small part of, the individual components of economic exposure[2]. A simple approach has however been suggested by Adler and Dumas (1984). They show that the economic exposure for a firm is equal to the slope coefficient(s) from a regression of the change in the firm's value as the dependent variable and changes in exchange rates as the

[2] Theoretical work exploring the link between exchange rate exposure and industrial organization issues is extremely scarce. Marston (1996) and Friberg (1997) are two exceptions.

regressor(s). This approach has been used in several empirical studies (e.g. Jorion, 1990 and Bartov and Bodnar, 1994).

It is quite plausible that firms' exchange rate exposure differs between countries. Companies in more open countries might on average be more sensitive to international conditions than companies in a large, less open economy. Therefore the lack of studies presenting and comparing results for different countries is somewhat surprising. One step in this direction is made by Bodnar and Gentry (1993). They study industries in Canada, Japan and the United States and find (weak) support for the hypothesis that the value of industries in more open economies (Canada, Japan) are more influenced by exchange rate changes than in a more closed economy (the US).

Of course exchange rate exposure can not be interpreted as the effect of purely exogenous movements in the exchange rate on the value of a firm. The estimate of exchange rate exposure may reflect that exchange rates and stock prices are driven by the same shocks. This is all the more relevant if one studies the exchange rate exposure of an entire stock market as opposed to studying the exposure of an individual firm. Ibrahimi, Oxelheim and Wihlborg (1995) study how stock market returns are affected by macroeconomic shocks in Japan, U.S. and Sweden for the period 1970-1987. When they regress real stock market return on anticipated and unanticipated changes in monetary variables (exchange rate, money supply, short-term interest rates), the coefficient on the exchange rate turns out insignificant. They take this to signify that exchange rates are not an independent source of risk or that exchange rate risk is diversified in national stock markets. One may also recognize that developments in the stock market may influence monetary policy and interest rates. This would perhaps lead one to prefer a VAR analysis, to see how e.g. interest rates, equity returns and inflation respond to money supply shocks. Lastrapes (1996) is an example of that methodology.

We choose in this paper to stay close to the tradition in the exchange rate exposure literature, that of including the exchange rate as the only independent variable in our main analysis. This

makes comparison easy with the findings from the exchange rate exposure literature. As a robustness check we also run regressions that include interest rates and return on a world market portfolio as explanatory variables, as well as regress real stock market return on real exchange rates.

II . The exchange rate exposure of national stock indexes

To measure national stock market's exposure to exchange rate fluctuations we follow Adler and Dumas (1984) and estimate the following equations,

$$(1) \qquad R_{i,t} = \beta_{0,i} + \beta_{1,i}\Delta S_{i,t} + \varepsilon_{i,t}, \qquad i = 1,.....N. \quad t = 1,.....T.$$

For market i at time t $R_{i,t}$ is the return on the national stock market (percentage change in the stock index), $\Delta S_{i,t}$ is the percentage change in a country specific, trade weighted, exchange rate index and $\varepsilon_{i,t}$ is an error term. The return on the respective national stock market is based on stock market data from Morgan-Stanley that are comparable across countries. The data that we use are described in appendix 1. The trade weighted exchange rate index is calculated for each country using IMF's Multilateral Exchange Rate Model (MERM) weights[3]. A positive change in the index indicates a depreciation, so for a country with a heavily export-oriented industry one would expect a positive sign of $\beta_{1,i}$. Equation (1) was estimated for 10 industrialized countries with Ordinary Least Squares (OLS) regression. Monthly data for the period 1973:1-1996:08 were used. Results are presented in the first column of table 1.

table 1 about here

It seems like exchange rate movements indeed have an effect on stock markets. The sign of the estimated slope coefficients are positive for most countries indicating that the stock

[3] The 1977-based weights that we use are reported in International Monetary Fund (IMF), (1985).

market goes up when the exchange rate is depreciating. For instance, over the period a percentage depreciation of the Danish krona has on average been associated with a 0.66 percent increase of the Danish stock market value. Looking at the individual estimates, the impact of exchange rate movements on the stock market is highly significant for some countries, but for others it seems close to zero. These results are quite similar to earlier findings for individual firms and industries. Jorion (1990) found significant exposure for less than 10 percent of his sample of US firms. Bodnar and Gentry (1993) found significant exposure coefficients for 28 percent of the US industries, for 21 percent of the Canadian and for 35 percent of the Japanese industries included in their study. The explanatory value of regressions is low and are not reported here in order to save space. The adjusted R^2 ranges from close to 0 to 0.10 for equation (1). The low explanatory value is also in line with earlier findings for individual firms and industries.

Specifications (2) -(3) show that the point estimates of exchange rate exposure are not very sensitive to the inclusion of a world market portfolio (2) or interest rates[4] (3) as explanatory variables. Inclusion of the world market portfolio lowers the standard deviation on the estimated exchange rate exposures. It also results in much higher explanatory values of regressions, adjusted R^2 for specification (2) are generally much higher than for (1) and range from 0.07 to 0.78. Return on a world market portfolio is thus an important determinant of return on these national stock markets. Inclusion of interest rates as explanatory variable (3) tends to decrease the significance of the coefficient on the exchange rate. The probable reason for this is that both the exchange rate and the interest rate are partly affected by the same domestic shocks which implies multicollinearity. In equation (4) we use the "local" stock market index (e.g. Nikkei, S&P 500) as dependent variable, we then have a sample of 13 countries.

[4] Bond yield on long-term bonds, (heading 61 in IFS, 5-10 years). This was the interest rate that was most consistently available over the period and the countries studied.

We have experimented with different sample periods (also extending the sample period back to 1957) as well as with another measure of the effective exchange rate[5]. The general pattern that we find (positive or zero exposure) seems to be quite robust for this sample of countries.

The estimated exposure coefficient can be interpreted as the average exposure of the firms in the stock market to changes in the exchange rate. We now proceed by relating the estimated exposure for a country to the degree of openness for that country. Figure 1 below plots the estimated exchange rate exposure coefficients from table 1 (specification (1)) against a measure of the openness of the respective economy.

figure 1 about here

A more open economy seems to show a stronger relationship between return on the stock market and exchange rate changes. To formally test this hypothesis we state that the exposure can be written as a linear function of the degree of openness,

$$\beta_{1,i} = \alpha_0 + \alpha_1 Openness_i + u_i \qquad i = 1, \ldots\ldots, N \tag{5}$$

where $\beta_{1,i}$ is the estimated exposure for country i from equation (1) , *Openness* is defined as the average (import+export)/GDP ratio over the study period and u_i is an error term. The coefficients α_0 and α_1 in equation (5) can be estimated using a two step approach where in the first step the exposure coefficients are estimated from equation (1) and in the second step we use these coefficients as dependent variables in an Ordinary Least Squares regression to estimate equation (5). An alternative specification would be to substitute $\beta_{1,i}$ by $\alpha_0 + \alpha_1$ $Openness_i$ into equation (1) and estimate α_0 and α_1 directly by Generalized Least Squares (GLS),

[5] The effective nominal exchange rates in the International Monetary Funds IFS data base (TCW).

(6) $$R_{i,t} = \beta_{0,i} + (\alpha_0 + \alpha_1 Openness_i)\Delta S_{i,t} + \mu_{i,t} \qquad i = 1,.....N \qquad t = 1,.....T$$

The OLS and GLS estimates of the coefficient of openness, α_1, are both significant at the 1% level and indicate a positive relation between the magnitude of exposure and the degree of openness. The point estimate of α_1 using OLS is 0.77 and 0.56 using GLS[6].

III. Discussion

One should be careful not to exaggerate our result that stock markets in more open countries are more exposed to exchange rate changes than stock markets in more closed countries. The number of countries in our sample is low. Nevertheless, a discussion of the result is in place. The more open a country, the more is the business of the typical firm related to foreign trade and thus potentially exposed to exchange rates. Our finding that more openness implies a stronger positive relationship between stock market valuation and the exchange rate does not follow immediately from this however. One would expect that some activities should be affected positively (primarily exports) and some negatively (importing or import-competing). These effects on the stock market index could very well cancel.

One explanation for the pattern that we find is related to recent findings of how prices of traded goods respond to exchange rate changes[7]. A stylized fact is that import prices, for a wide range of goods, respond less than proportionately to exchange rate changes. Menon (1995) and Goldberg and Knetter (1996) summarize the literature. For instance 40 out of the 46 studies surveyed by Menon find less than complete exchange rate pass-through - a less than proportionate response of import prices to exchange rate changes.

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[6] The point estimate of α_1 using GLS and specificication (2), (3) and (4) are 0.61, 0.60 and 0.33 respectively, all significant at the 5% level.

[7] Dumas (1994) and Friberg (1997) are two, of but a few papers, that make the connection between exchange rate pass-through and exchange rate exposure.

Limited price responses (in the importer's currency) imply limited quantity responses relative to what would be the case if import prices were allowed to be affected more by exchange rate changes. A low exchange rate pass-through should imply that the value of importing and import-competing firms should tend to be affected little by exchange rate surprises. If the input prices of an importing firm change little when the exchange rate changes, there should be little direct effect on the value of that firm from exchange rate fluctuations. Similar reasoning applies to an import-competing firm.

Exporting firms will be affected positively by a depreciation even in the case of no exchange rate pass-through (if they are not fully hedged). If prices are kept stable in the importer's currency demand will be affected little by exchange rate changes. This stabilizes total revenues in foreign currency. The value of an exporter will then be affected positively by a depreciation since foreign revenue is being translated into the home currency at a more favorable exchange rate. Limited exchange rate pass-through thus implies that we should expect a positive influence from an exchange rate depreciation on the valuation of the stock market. Exporting firms will tend to be affected positively by a depreciation and effects will tend to be stronger for exporting than for importing or import-competing firms. The more open the economy the larger is the share of internationally trading companies on a national stock market. Limited exchange rate pass-through should thus lead us to predict a pattern of openness and exchange rate exposure of national stock indexes as that we observed in section II.

Given the low variability of consumer price indexes in relation to exchange rates and equity prices we expect the pattern of openness and exposure that we have found earlier to hold also if we regress real stock market returns on real exchange rates. The first column in table 2 below presents point estimates from such regressions. The GLS point estimate of the openness coefficient is 0.35, which is significant at the 5% level.

table 2 about here

Another potentially interesting question is how exposed a national stock market is to different regions and currencies. The second column in table 2 reports exchange rate exposure coefficients against the US dollar and column three reports exposure against an "small EMU effective exchange rate" (Austria, Belgium, Germany, France, Netherlands; calculations are described in appendix 2). The estimated exposure coefficients against the dollar are remarkably similar to the ones for the small EMU (but generally lower than the exposure to the MERM exchange rate which we reported in table 1). One explanation for the similarity of coefficients is that the correlation between a country's effective exchange rates against various regions is high, domestic shocks and news will generally affect a country's exchange rates against various regions similarly. We have also experimented with regressions where we separated the total exchange rate exposure into different regions. Appendix 2 reports the results from some regressions of that kind. Point estimates are generally insignificant (likely due to multicollinearity) and were also quite sensitive to the time period chosen.

IV. Concluding remarks

This paper has established a positive relationship between stock market exposure to exchange rates and the openness of a country for 10 (13) industrialized countries in the post Bretton-Woods period. Could the effect of openness on the correlation between stock market valuation and exchange rate changes, that we have documented above, be spurious? The best way to study these issues would be to empirically test a fully worked out model that incorporates financial issues with issues of monetary non-neutrality and international Industrial Organization (limited pass-through, segmented goods markets). That is indeed a formidable task. A perhaps more promising direction for research is to study the exchange rate exposure of similar industries in many countries. One would be interested in export intensive industries as well as in importing and import-competing industries.

In this paper we have only studied the contemporaneous relationship between stock market valuation and the exchange rate. As explored by Bartov and Bodnar (1994) and Chow, Lee and Stolt (1997) adjustment may be a more drawn out process which would lead to inclusions of lagged explanatory variables in regressions. We leave these questions for future research.

There is clearly a need for more formal theoretical analysis in the studies of exchange rate exposure. Our present work points to that it should be fruitful to further integrate issues of exchange rate pass-through and exchange rate exposure.

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Appendix 1 - Data description

The Morgan-Stanley stock market indexes and world market index are from Morgan-Stanley. For all countries they are adjusted for dividends.

Data on national Consumer Price Indexes, nominal exchange rates and "local" stock market data were collected from the Ecowin database. The stock market index used for different countries are presented below.

Country	Stock Market Index
Austria	ATX
Belgium	BEL20
Switzerland	BK IND.
Germany	DAX
Denmark	COPENHAGEN SE
Finland	HEX
France	CAC 40
Italy	MIB
Japan	NIKKEI
Netherlands	CBS
Norway	All stocks
Sweden	AFGX
USA	S&P 500

Interest rates, yield on long-term government bonds, were collected from the International Monetary Funds IFS data base, (heading 61). The term length is for 5-10 years depending on the country.

The IFS data base was also the source for the data used when calculating *Openness*; Gross Domestic Product (heading 99b), total value of exports (heading 90c) and total value of imports (heading 98c).

Appendix 2 - Exchange rate exposure; different areas

We run two sets of regressions,

$$R_{i,t} = \theta_{a,0,i} + \theta_{SEMU,i}\Delta S_{SEMU,i,t} + \theta_{a,USA,i}\Delta S_{USA,i,t} + \theta_{ROW1,i}\Delta S_{ROW1,i,t} + \varsigma_{a,i,t}$$

$$R_{i,t} = \theta_{b,0,i} + \theta_{EU,i}\Delta S_{EU,i,t} + \theta_{b,USA,i}\Delta S_{USA,i,t} + \theta_{ROW2,i}\Delta S_{ROW2,i,t} + \varsigma_{b,i,t}$$

where $R_{i,t}$ is return on stock market i at time t, θs are coefficients to be estimated and $\Delta S_{j,i,t}$ is the change in the effective exchange rate index for country i against region j. The composition of regions is given below. The respective share of each country k in group j was calculated for each country i (the MERM-weight of that country divided by the total MERM-weights for that group of countries). Each such weight was then multiplied by the exchange rate between country i and k. The sum of these products make up the effective exchange rate of country i versus group j.

$$S_{j,i,t} = \sum_{k=1} \frac{MERMWEIGHT_{k,i}}{\sum_{k} MERMWEIGHT_{k,i}} * EXCHANGERATE_{k,i}$$

If a country belongs to a certain group the calculations were simply done for the rest of that group. Regression results are presented in table 3 below.

SEMU: Austria, Belgium, Germany, France, Netherlands
USA: United States
ROW1:Switzerland, Denmark, Finland, Italy, Japan, Norway, Sweden, Canada, U.K., Australia, Ireland, Spain
EU: Austria, Belgium, Germany, Denmark, Finland, France, Italy, Netherlands, Sweden, Ireland, U.K. Spain.
ROW2: Switzerland, Japan, Norway, Canada, Australia

Table 3 Exchange rate exposure, different areas

Country	θ_{SEMU}	θ_{USA}	θ_{ROW1}	θ_{EU}	θ_{USA}	θ_{ROW2}
Austria	-0.602	0.612	0.281	-0.133	0.191	0.241
Belgium	-0.013	0.299	0.218	0.112	-0.151	0.206
Denmark	0.415	0.113	-0.382	-0.234	0.472**	-0.033
France	0.412	-0.348	-0.039	-0.478	-0.292	-0.163
Germany	0.313	-0.177	0.045	0.028	0.036	0.181
Italy	0.931***	-0.160	-0.915**	0.887***	-0.346	-0.631**
Japan	0.287	-0.096	-0.397	-0.138	-0.478	-0.625
Netherlands	0.281	0.326	-0.372	0.161	0.255	-0.065
Sweden	0.260	0.464	-0.414	0.284	0.210	-0.196

*** significant at 1%, ** at 5%, * at 10%.

Exposure for some stock markets and regions turn out significant, but most estimates have large standard errors (not reported).

Table 1 Exchange Rate Exposures for National Stock Markets, 1973:1 - 1996:08.

Country	*(1)*	*(2)*		*(3)*		*(4)*
	$\beta_{1,i}$	$\chi_{1,i}$	$\chi_{2,i}$	$\gamma_{1,i}$	$\gamma_{2,i}$	$\phi_{1,i}$
Austria	0.383*	0.373**	0.368***	0.296	-0.313*	0.444***
	(0.207)	(0.201)	(0.115)	(0.207)	(0.173)	(0.187)
Belgium	0.505**	0.501***	0.761***	0.487**	-0.584***	0.374
	(0.212)	(0.186)	(0.076)	(0.206)	(0.108)	(0.268)
Denmark	0.659***	0.623***	0.551***	n.a	n.a	0.585***
	(0.202)	(0.168)	(0.064)			(0.205)
France	0.0822	-0.117	0.978***	-0.111	-0.721***	-0.013
	(0.251)	(0.205)	(0.072)	(0.260)	(0.166)	(0.270)
Germany	0.223	0.212	0.715***	0.262	-0.483***	0.306*
	(0.207)	(0.180)	(0.097)	(0.206)	(0.109)	(0.165)
Italy	-0.115	-0.153	0.782***	-0.142	-0.246*	0.096
	(0.221)	(0.211)	(0.086)	(0.227)	(0.132)	(0.230)
Japan	-0.163	-0.146	0.909***	-0.203	-0.065	-0.098
	(0.13)	(0.095)	(0.085)	(0.134)	(0.085)	(0.123)
Netherlands	0.791***	0.801***	0.889***	0.820***	-0.360***	0.635***
	(0.248)	(0.138)	(0.062)	(0.246)	(0.105)	(0.215)
Sweden	0.486	0.572**	0.865***	0.452	-0.499***	0.312
	(0.371)	(0.308)	(0.093)	(0.380)	(0.140)	(0.315)
United States	0.0496	0.010	0.998***	-0.069	-0.341***	0.043
	(0.135)	(0.053)	(0.043)	(0.133)	(0.067)	(0.109)
Finland						0.298*
						(0.176)
Norway						0.314
						(0.264)
Switzerland						0.453***
						(0.121)

Heteroskedasticity-consistent standard errors within parenthesis. Variables starred with *** are significant at 1%, ** at 5% and * at 10%.

(1) $R_{i,t} = \beta_{0,i} + \beta_{1,i}\Delta S_{i,t} + \varepsilon_{i,t}$

where R is the change in Morgan-Stanley index

(2) $R_{i,t} = \chi_{0,i} + \chi_{1,i}\Delta S_{i,t} + \chi_{2,i}\Delta W_{i,t} + \eta_{i,t}$

where R is the change in Morgan-Stanley index and ΔW is the change in the Morgan-Stanley world equity index

(3) $R_{i,t} = \gamma_{0,i} + \gamma_{1,i}\Delta S_{i,t} + \gamma_{2,i}\Delta I_{i,t} + \upsilon_{i,t}$

where R is the change in Morgan-Stanley index and ΔI is the change in long-term interest rates

(4) $LR_{i,t} = \phi_{0,i} + \phi_{1,i}\Delta S_{i,t} + \zeta_{i,t}$

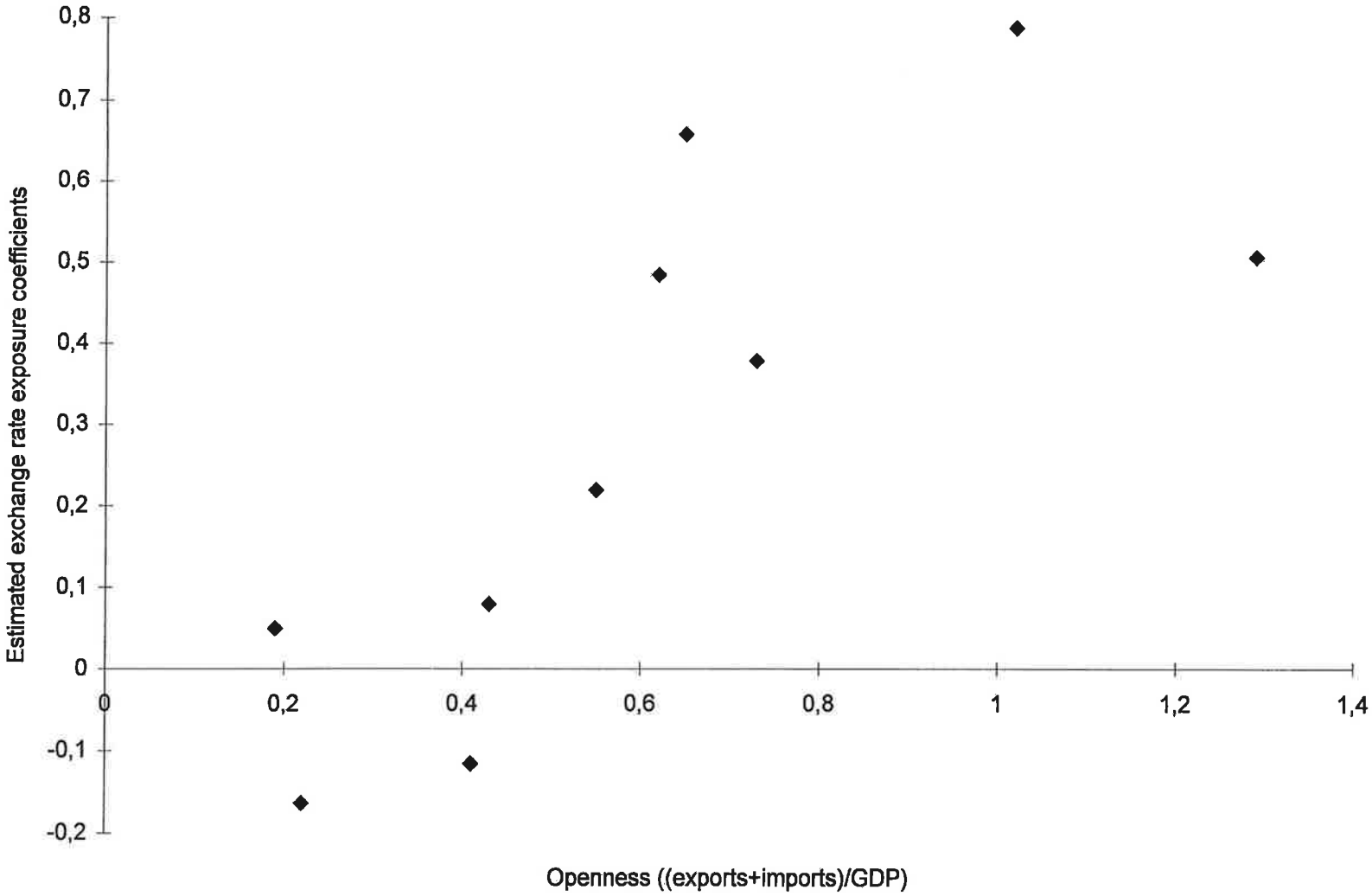
where LR is the change in the local index as defined in appendix 1.

Table 2. Exchange rate exposures for national stock markets, 1973:1- 1996:08. Real stock returns and real exchange rates, and exposure against US dollar and small EMU.

Country	$RR_{i,t} = \varphi_{a,0,i} + \varphi_{a,1,i}\Delta RS_{i,t} + \varsigma_{a,i,t}$	$R_{i,t} = \varphi_{0,b,i} + \varphi_{b,1,i}\Delta USD_{i,t} + \varsigma_{b,i,t}$	$R_{i,t} = \varphi_{c,0,i} + \varphi_{c,1,i}\Delta SEMU_{i,t} + \varsigma_{c,i,t}$
	$\varphi_{a,1,i}$	$\varphi_{b,1,i}$	$\varphi_{c,1,i}$
Austria	0.171	0.190*	0.178*
	(0.208)	(0.098)	(0.099)
Belgium	0.465*	0.178**	0.174*
	(0.242)	(0.090)	(0.096)
Denmark	0.497***	0.264***	0.268***
	(0.169)	(0.095)	(0.096)
France	0.127	0.022	0.076
	(0.257)	(0.117)	(0.114)
Germany	0.377*	0.136	0.161
	(0.206)	(0.098)	(0.104)
Italy	0.322	0.109	0.269
	(0.246)	(0.162)	(0.151)
Japan	0.019	-0.134	-0.0233
	(0.140)	(0.100)	(0.088)
Netherlands	0.504**	0.355***	0.361***
	(0.215)	(0.096)	(0.096)
Sweden	0.291*	0.363**	0.339***
	(0.157)	(0.174)	(0.108)

Heteroskedasticity-consistent standard errors within parenthesis. Variables starred with *** are significant at 1%, ** at 5% and * at 10%.

Figure 1, Exchange rate exposure and openness



Price adjustments by a gasoline retail chain*

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Abstract

This paper provides a detailed examination of price responses in the Swedish gasoline market to changes in the world market price. We use daily price data from one of the leading retail chains together with input costs for the period January 1980 to December 1996. Predictions of a simple Ss-model are tested with an ordered probit sample selection model. The results show that price adjustments are more likely to occur when either the input price or the exchange rate has moved significantly since the last price adjustment. However, our results indicate that prices are not adjusted to the long run equilibrium price at once. An error correction model (ECM), shows that in the short run prices are gradually moving towards the long run equilibrium in response to cost shocks. There is some evidence that, in the short run, prices are stickier downwards than upwards.

Key words: Price adjustment; sticky prices, price rigidities; exchange rate pass-through; ordered probit sample selection; error correction model; gasoline market.

JEL classification: C22; C24; C25; E31; F14; L71.

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1.Introduction

In this paper we study the pass-through of cost changes to retail prices in the Swedish gasoline market. We use 17 years of daily retail gasoline prices from one of the major retail chains (Shell). These data provide an unusually clean case to test hypotheses about how firms react to changes in the underlying costs of inputs, since both price and costs are observable on a daily basis. For the same period and frequency we have spot market prices of gasoline (quoted in US dollars) in Rotterdam and the exchange rate between Swedish kronor and US dollars. Even though both the input price and the exchange rate exhibit daily fluctuations the retail price is rigid in the short run. In the longer run, however, prices appear to follow the cost movements quite closely. Much of the paper is concerned with the details of price adjustment and in particular the decision to change the price or not. In the second part of the econometric analysis we study the long-run pass-through of costs.

Figure 1 shows the relationship between price and costs in the Swedish gasoline market for the sub-period September-November, 1995. Output price remains fixed for some period of time and when it is adjusted it is in the direction motivated by the underlying variable. This pattern can be regarded as typical for prices of individual products. The stickiness of prices is a well known phenomenon and has been the focus of considerable theoretical and empirical attention (see Andersen (1994), Blanchard and Fisher (1989, p. 372-426) and Mankiw and Romer (1991) for overviews). Figure 1 is used to illustrate how some of the methodological and data problems that previous studies have encountered can be categorized. Of course, this does not mean that these studies are uninformative, but rather points to factors to be kept in mind when discussing the results and what can be learned about price setting behavior.

Figure 1 about here

Our work is related to a number of recent empirical papers that have been concerned with price adjustments in response to cost changes. Awh and Primeaux (1992) use annual price data from electric utilities and measure cost by total operating

expenditure. Dahlby (1992) uses quarterly data on insurance premiums and Kraft (1995) annual price indexes for two digit German industries, and both control for cost with wage indexes. A common feature of these studies is that the data have low frequency which in Figure 1 corresponds to a situation where prices and cost are only observed with long intervals. Moreover, often the prices are average market prices whose development will be smoother than prices set by individual firms.

Another line of research uses quoted prices of specific products and are primarily interested in how often prices are adjusted in response to inflation. Cecchetti (1986) studies the prices of magazines and Kashyap (1995) studies prices in retail catalogs (issued approximately every sixth month). Lach and Tsiddon (1997) provide evidence of the timing of price adjustment of food products and beverages in Israel. In comparison with the data depicted in Figure 1 the price is measured accurately but the development of costs are unobserved in so far as they differ from the general level of inflation.

The relatively clean data on input and output prices have made gasoline prices the subject of many studies of price adjustments. Some recent examples include Bacon (1991), Borenstein et al (1997) and Slade (1992). Additional references are given in Duffy-Deno (1996). However, all studies that examine a long time period use price data aggregated to regional or national levels. Again referring to Figure 1, information about when an individual firm decides to change its price is lost.

The variability of exchange rates has spurred a growing literature that studies the pass-through of exchange rate changes into import prices. Menon (1995) provides a survey. The papers generally use unit value data (total customs declared value of imports divided by the quantity of imports in the industry) and do not consider other cost shifters than the exchange rate. This makes them vulnerable to the same types of criticism that can be directed against the papers mentioned above. There is a lack of detailed case studies of individual markets (Goldberg's (1995) study of the U.S. automobile market is one exception).

A recurring theme in the literature is whether price adjustments are symmetric with respect to some underlying variable(s). For example Borenstein et al (1997) are interested in whether gasoline prices are more flexible upwards than downwards. Feenstra (1989) tests if the long-run pass-through of tariffs and exchange rates onto

prices of Japanese cars, trucks and motorcycles in the US market are equal. In this paper we study various types of symmetry, e.g. upwards and downwards flexibility of prices, symmetry in response to input costs and taxes.

The paper is organized as follows. Section 2 sketches a theoretical model of price setting when there are fixed adjustment costs. Section 3 describes the market and defines the variables used. It also provides a first look at the behavior of prices, costs and time between price adjustments. Section 4 contains the econometric analysis. We employ both a (an ordered probit sample selection) model that corresponds closely to the theoretical model, as well as an error correction model. Section 5 concludes and discusses the results.

2. A theoretical framework

There are a large number of theories that try to explain why prices would be fixed in response to small shocks in some underlying variable. Several of them do not offer predictions for *how* the price should be adjusted, for example models building on a kinked demand curve. One of the most important theories that actually does present hypothesis for how prices are adjusted is the Ss-model, where Barro (1972) is one of the earliest references. The central argument rests on fixed costs of price adjustments, which implies that prices remain fixed for minor disturbances. When the underlying stochastic variable follows a random walk with no drift, the price will be adjusted back to the static optimum whenever the stochastic variable passes an upper bound (S) or a lower bound (s). At a first glance the Swedish gasoline industry seems to correspond closely to the assumptions of the simple Ss-model. We can not reject that input prices follow random walks during the sample period (see Section 3) and the good can be analyzed as being non-storable.[1]

[1] Further, adjustment seems to take place by changing the retail price rather than changing other decision variables such as the quality or terms of delivery of the good (which Carlton (1986) found to play a significant role on the markets that he studied).

To formalize the ideas we sketch a simple Ss-model of price setting when there are shocks to two cost variables and demand is linear with slope b.[2] Assume that if the price was set to maximize contemporaneous operating profits in each period, the maximization problem would be given by

$$\max_{P_t}\left(RP_t - SP_t E_t - TAX_t\right)\left(1 - bRP_t\right) \tag{1}$$

where SP, E and TAX represent cost variables and RP represents the retail price. The optimal per period price, denoted by an asterisk, is the standard monopoly price

$$RP_t^* = \frac{1}{2b}\left(1 + b\left(SP_t E_t + TAX_t\right)\right). \tag{2}$$

In a frictionless world this is the price that we would observe at every moment. Assume now that there is a fixed cost, f, associated with price changes. Suppose that price at time t is set optimally for some values of SP_t, E_t and TAX_t and further that at time $t+n$ they have changed with ΔSP, ΔE and ΔTAX. Let SP and E follow random walks whereas TAX is non-stochastic. Denote by L the opportunity cost of keeping prices fixed in the face of cost changes. A little algebra gives that the loss function is

$$L_{t+n} = \frac{b}{2}\left(E_t \Delta SP + SP_t \Delta E + \Delta SP \Delta E + \Delta TAX\right)^2. \tag{3}$$

Price will adjust when the opportunity cost of not adjusting the price, L, reaches some threshold level. The opportunity cost depends on the change in costs since the last time that price was set.

How much will the price change when it actually does change? When costs follow random walks their current values summarize all relevant information for predicting tomorrow's values. Therefore in a period when the price changes the resulting price will only be dependent on the current costs. Let ΔRP^* denote the

[2] The model is based on the Blanchard and Fischer (1989, p. 402) rendition of Barro's (1972) state

difference between the optimal price that was set at time t and the optimal price that is set at time $t+n$, when costs have drifted far enough to motivate a price adjustment. It is easily shown that

$$\Delta RP^{*} = \frac{1}{2}\left(SP_t \Delta E + E_t \Delta SP + \Delta TAX + \Delta SP \Delta E\right). \qquad (4)$$

Figure 2 below gives a simple representation of the adjustment pattern of the price that we would expect based on fixed costs of adjustment. When the opportunity cost of not adjusting price has drifted far enough, a threshold is reached and the firm adjusts its price. Since the adjustment cost is independent of the size of the change, the firm will adjust to the static optimum once it finds that the benefit of changing its price outweighs the cost of doing so.

Figure 2 about here

The simple form that equation (4) takes hinges on that we assume that the firm acts as a monopolist facing a linear demand function. Thus we disregard that there are competitors in the market who will be affected by the same cost shocks. More generally, the pass-through of cost changes to prices depends on the properties of the demand and on the correlation of cost shocks across competitors.[3] Adding more realism to the model is certainly desirable but unfortunately the tractability decreases sharply. Nevertheless we will offer some qualitative predictions about adjustment patterns under some different assumptions. The above pattern clearly relies on fixed adjustment costs. If we instead only had quadratic adjustment costs (no fixed cost) price should be adjusted every period (see for instance Rotemberg (1982)). We would then observe a partial adjustment pattern, since it is less costly to change the price in several small steps instead of in one large leap. With a combination of fixed and

dependent price setting model.

[3] See e.g. Feenstra, Gagnon and Knetter (1996). Slade (1996) studies effects of strategic interaction in a Ss framework, without fully solving the model however.

quadratic adjustment costs one would find no small price adjustments and a gradual adjustment pattern when there has been a large shock.[4]

One typically thinks of fixed adjustment costs in pricing as stemming from some physical cost of changing prices (printing price lists, informing dealers or the like). On the other hand, it is hard to imagine any tangible costs that are increasing in the size of the price change. Rather, as Rotemberg (1982) argues, quadratic costs arise if consumers prefer a number of small price adjustments over one large.

Keeping the limitations of the stylized model in mind, equations (3) and (4) form the basis for the econometric specification in section 4.1. We predict that price adjustment is more likely to occur the further costs and taxes have drifted since the last price adjustment. More specifically the opportunity cost should be dependent on the squared drift(s). Price adjustment, when it does take place, will be dependent only on the drift. If we find that current price adjustment is explained by cost changes prior to the previous adjustment, this is inconsistent with only fixed adjustment costs.

3. Market and data description

As noted in the Introduction we study the price of leaded premium gasoline to consumers in Sweden for the period January 1, 1980 to December 31, 1996. Gasoline is almost exclusively sold by branded stations and prices in the retail market are determined by the list prices of retail chains (from now on refereed to as "firms"). In this respect the Swedish gasoline market is thus quite different from the one in e.g. the United States (see Borenstein et al (1997)), where vertical integration is much less prevalent. The quantity of gasoline sold annually has increased slightly over the period (from 4913' m^3 in 1980 to 5682' m^3 in 1996). Firm concentration shows a weak tendency to rise, the Herfindahl-index has increased from 0.127 in 1980 to 0.152 in 1996. Some previous studies (e.g. Neumark and Sharpe (1992), Weiss (1993)) have tested if market structure has an effect on the nature of price adjustment. We have tested if firm concentration significantly influenced the long-run equilibrium prices

[4] We are aware of no model that analyzes the effects of a combination of fixed and variable adjustment costs on pricing decisions. One way of proceeding would be along the lines of Dixit and Pindyck (1994, p. 381-391).

(reported in (5) below) but found no evidence that the small increase in concentration had any measurable effect.

From January 1990 and onwards the data set includes prices for virtually all the retail chains (the seven firms in the sample represent 94.5% of sales in 1996). For the period from January 1980 to December 1989 price data are available for two of the firms (Shell and Norsk Hydro).We restrict our attention to the retail list price of one of the firms, Shell, which throughout the period is either the largest or the second largest firm (with a market share of 16.5-21.0%).[5] The behavior of Shell's retail price is representative for the prices of other firms, since more often than not, firms' list prices are identical and they all adjust their prices the same day or within a day.[6] Even though the prices are more or less identical for a retail chain across the country (save for some minor differences due to transport costs) there is some local variation in retail prices. The local variation refers to constant differences in price levels and not to differences in the pattern of price adjustments.[7]

The chain from input price to consumer price is very simple in Sweden. For the firms the relevant input price is the Rotterdam spot price for gasoline. Some firms buy their gasoline at this price in the spot market, but even those who operate their own refineries claim to use it as the transfer price between the producing and the selling divisions.

3.1 Variable definitions and sample period

We study the retail price divided by (1+VAT) which is denoted *RP*. This price is observed every day and can, in principle, be adjusted any day. The Rotterdam spot market price of gasoline in USD, *SP*, and the SEK/USD exchange rate, *E*, are not

[5] Swedish Petroleum Institute Annual Report, various issues.

[6] According to discussions with Shell the procedure to adjust the price is as follows. Executives meet before noon and decide whether to adjust, and if so, the magnitude. This suggested retail price is then submitted by fax to all the gasoline stations. The price is adjusted by the stations the following morning. It is not possible to keep a price adjustment secret to rival firms until the next morning. Also news agencies are notified and transmit the information to rivals. According to Shell the cost of conveying the message has decreased over time as a consequence of improvements in information technology.

quoted on weekends and public holidays. We assume these variables to be unchanged during these days. The marginal cost of gasoline in SEK is denoted *MC* and defined as *SP*E*. Table 1 below defines all the variables and gives the data sources. The price changes are denoted *ΔRP* and changes in marginal cost *ΔMC*. For some of our regressions we separate *ΔMC* into movements in the exchange rate, *ΔE*SP(-1)* and spot price *ΔSP*E(-1)* according to the definition in Table 1. Another variable of prime importance is the quantity tax, denoted *TAX*, which in 1996 accounted for about 50 % of the retail price. Figure 3 shows the development of *RP, MC* and *TAX* over the sample period.

Table 1 about here

Figure 3 about here

We have identified three price wars (partly from information in the documents given to us by the companies), January 2, 1984 - February 21, 1984, April 2, 1988 - May 6, 1988 and September 30, 1993 - October 28, 1993. For the purpose of this paper it is natural to exclude the price war periods since our interest is in the relation between costs and prices, and during periods of price wars price changes do not reflect costs changes (one episode is illustrated in Figure 4).[8] We drop from our sample the period beginning the day after the last price adjustment prior to the price war and ending the day after the price increase that ends the price war. The period August 29, 1986 -August 23, 1987 is excluded because of a legally imposed price freeze.

Figure 4 about here

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[7] Clearly this is not a perfectly competitive market in the sense that the demand for a firm's product instantaneously disappears if it charges a higher price than competitors (e.g. due to localization of the retailers).

[8] Several recent empirical papers (e.g. Borenstein and Shepard (1996), Ellison (1994), Slade (1992)) have dealt with the causes and timing of price wars. Casual inspection of the three episodes in our sample revealed no apparent explanation to why they occurred. It could certainly be interesting to study the price wars in more detail but any econometric attempts to predict three price wars during seventeen years are likely to be unsuccessful.

3.2 Descriptive statistics

Much of the recent literature on pricing has been concerned with the distribution and frequency of price adjustments. The possible asymmetry between price increases and decreases has been an intensely debated question. To add to the evidence on the behavior of prices we begin by a fairly detailed description of the distribution of price adjustments, before relating them to cost changes. Even though our sample contains 250 price adjustments they are quite infrequent (roughly once every third week). For the sample there are about the same number of price increases as price decreases and their sizes are of the same magnitude as seen in Table 2. Thirteen of the price adjustment are associated with tax changes and correspond to the largest price increases. These price adjustments are different from the other price adjustments in some aspects, primarily because tax changes are known by the firms in advance. Excluding these results in 117 upward and 120 downward price adjustments, with a mean adjustment of 7.59 for increases and -6.62 for decreases. Considering that the data contains seventeen years of which several had high general inflation this may seem surprising. However, the retail price of gasoline is largely determined by the highly volatile spot market price (in USD) and the likewise volatile SEK/USD exchange rate, which together resulted in the input cost in SEK being almost the same in 1980 as in 1996.

Table 2 about here

Figure 5 about here

Additional evidence on the symmetry of the distribution of price changes is given by Figure 5. The size distribution of price increases is similar to that of price decreases. Thus there is no apparent asymmetry such as price decreases being smaller or larger. The figure also points at one important feature of the adjustments, namely that there is a minimum absolute size of $|\Delta RP|=2$. This strongly indicates that there is some fixed cost associated with price changes that keeps firms from making very

small adjustments.[9] Moreover, conditional on $|\Delta RP|>>2$, small adjustments are more frequent than large ones. All adjustments larger than |18| are associated with tax changes or large discrete changes in E due to devaluations of the Swedish krona.[10] The next important fact is the existence of absolute changes of quite different magnitude in this interval (between |2| and |18|). The size of the price adjustments and the time between them is not stable over time. Table 3 shows that there are more adjustments which on average are smaller in size in the 90's than in the 80's. Although this is the case there is considerable variability of the size of adjustment, also within subperiods. The frequency of price adjustments increases around 1990. The average time between two price adjustments is less than half in the 90's compared to the previous decade.

Table 3 here

Further evidence of the timing arise from breaking down price adjustments into the day of the week and month of the year as we do in Table 4. Firstly, for the gasoline market there is some seasonal variation in sales over the year with a peak in the summer months. If there are fixed costs of adjusting price, but the loss of having a misadjusted price is proportional to the sales volume, one would expect to find relatively more adjustments during the high demand months (holding marginal costs constant). This is not borne out by the table but could be an interesting method to determine the nature of adjustment costs in markets with a more pronounced seasonal pattern. Secondly, we find substantial differences in the number of price adjustments over the week, with few adjustments on Saturdays, Sundays, and Mondays. Of course the pattern may have several explanations. The most convincing one is that financial markets and the Rotterdam spot market are closed on Saturdays and Sundays and thus no new information arrives on these days.

[9] Carlton (1986) reports similar findings for petroleum products. In 1 percent of the price adjustments the price changed less than ¼ percent, in 9 percent of the price adjustments the price changed less than 1 percent and 47 percent of the price adjustments changed the price less than 2 percent.

[10] Sweden had a fixed exchange rate against a basket of currencies in which the USD was included until May 17, 1991. Even though the USD was included in the basket, E exhibited large fluctuations.

Table 4 here

We now turn to an investigation of the relationship between price and cost. As a first step we use monthly data to estimate the long run relationship in levels between *RP* and the explanatory variables *MC*, *TAX* and *WAGE*. *WAGE* is an index of the nominal wage but is not measured in the same units as the others and the coefficient is therefore not readily interpreted. This regression fills a dual purpose. First, the high explanatory value of the regression indicates that these three variables are able to explain almost the entire variation in price. Second, the estimated error term will be used as input in later regressions. The estimated relationship is

$$\underset{(6.26)}{RP = 22.9} + \underset{(0.03)}{0.902 * MC} + \underset{(0.03)}{0.658 * TAX} + \underset{(0.12)}{2.01 * WAGE} + u \qquad (5)$$

D-W: 0.63 adj.R^2: 0.988

In the long run there is a near one-to-one relationship between *RP* and *MC*. Over the period *TAX* and *WAGE* both increase more or less monotonically and the resulting high correlation explains the low coefficient on *TAX*. Not surprisingly the Durbin-Watson statistic shows evidence of positively autocorrelated error terms. This suggests that periods with relatively high prices tend to be followed by another period of relatively high prices, and vice versa.

Standard theories of price adjustments agree that there should be a non negative relation between recent cost changes and price adjustments.[11] Our data suggest that this is true on average, but that there are considerable deviations from this in many cases. The means and medians of ΔMC have the expected signs for $\Delta RP>0$ and $\Delta RP<0$ respectively. Note that average ΔMC is of roughly the same absolute size

[11] In general one could argue that some price adjustments are done in anticipation of changes in underlying cost variables. For a product such as gasoline this is probably not correct. The reason being that it is well known that asset prices in liquid markets (such as the foreign exchange market and spot market for gasoline) are intrinsically unpredictable, i.e. follow random walks. Augmented Dickey Fuller tests for random walks in our data on *E* and *SP* confirm this presumption. Still we asked the firm whether they tried to predict future costs. They clearly indicated that this was not the case. Neither did hedging possibilities and inventory situation influence the pricing decision.

for both price increases and decreases.[12] Although the expected relation between ΔMC and ΔRP holds for the means and medians, the minimum and maximum values of ΔMC show that sometimes the price is reduced when the marginal cost has increased significantly. We illustrate this in Figure 6 where one expects no observations in the second and fourth quadrant. In fact, about one fifth of the price adjustments are in these two quadrants. Although this could be explained by omitted variables in the marginal cost measure this is probably not the case here. The reason is that if any important cost variables are omitted we would arguably get far lower explanatory power in regression (5). This was also illustrated in Figure 3.

Figure 6 about here

As a first pass at an econometric description of the relationship between price adjustment and marginal cost changes, we fit ΔRP on ΔMC and ΔTAX.[13] In addition we estimate separate OLS-regressions for price increases and price decreases. Doing this we ignore complications such as sample selection bias and the possible influences of past cost changes, which are discussed in detail in Sections 4.1 and 4.2. The results are

$$\Delta RP = \underset{(0.40)}{0.420} + \underset{(0.043)}{0.553} * \Delta MC + \underset{(0.0466)}{0.889} * \Delta TAX \qquad \text{adj.}R^2\text{: } 0.679 \quad (6)$$

$$\Delta_+ RP = \underset{(0.43)}{5.96} + \underset{(0.0428)}{0.267} * \Delta MC + \underset{(0.0318)}{0.795} * \Delta TAX \qquad \text{adj.}R^2\text{: } 0.832 \quad (6')$$

$$\Delta_- RP = \underset{(0.38)}{-5.80} + \underset{(0.0444)}{0.165} * \Delta MC \qquad \text{adj.}R^2\text{:}0.098 \quad (6'')$$

The regressions (6)-(6'') are displayed in Figure 6. Using all price changes, as in equation (6), we find that the constant is not significantly different from zero. Further, we note that about half of the change in MC since the last price change is

[12] We postpone the discussion of the relative effects of $\Delta SP*E(-1)$ and $\Delta E*SP(-1)$ until sections 4.1 and 4.2.

[13] $\Delta WAGE$ is not used as an explanatory variable since it is only observed monthly and price adjustments do not have a fixed frequency. Moreover, this series shows very little variation and is difficult to separate from a trend variable.

reflected in today's price change. The coefficient on ΔMC is 0.267 for price increases and 0.165 for price decreases. The absolute size of the constant in (6') and (6'') is the same and significantly different from zero. This is a reflection of the fact that there is a minimum absolute size of price changes. Thus, pooling all price changes will result in a bias towards a steeper slope of the regression line compared to the slopes conditional on the direction of the adjustment. The explanatory power of (6'') is much lower than for (6'). One explanation for this is that we are very successful in estimating the effects of tax changes. As mentioned above, the sample selection bias is ignored in (6)-(6''). We address this problem in the next section.

4. Econometric results

4.1 Daily frequency

We now attempt to estimate when, and how much, firms adjust prices using daily data and a sample selection model. The 250 out of 5732 days when the firm decided to adjust its price is presumably not a random sample of days. Neither are the days when the price is increased (decreased) a random draw from the days when the price was adjusted. Based on an input cost variable there is a natural ranking between three mutually exclusive alternatives. When there has been a large downward movement in costs we are more likely to observe a price decrease; for small movements the price is likely to be held constant; and finally for large positive movements we expect to see the price increase. Ignoring the sample selection problem may lead to biased estimates in a regression with the size of adjustments as dependent variable. Therefore we employ an econometric technique similar to the well known Heckman (1979) two-stage procedure.[14] The first step is to estimate the probabilities for the price being decreased, held constant, or increased. In the second step we estimate the size of price increases and price decreases in separate regressions, using the probabilities estimated in the first step to control for the sample selection problem. More formally, the first stage selection mechanism is an ordered (rather than a standard binary)[15] probit model and the second stage, the price change regression, is an ordinary least squares estimator with a correction for sample selection.

The magnitude of the price adjustment can only be observed when the price is increased or decreased and is then determined by the regression model

$$\Delta RP = \beta_j^{'}\mathbf{X}_j + \varepsilon \qquad \text{for j=decrease or increase} \qquad (7)$$

where β is a vector of parameters and $\mathbf{X}$ are explanatory variables, which are allowed to be different for increases and decreases. As discussed and defined in Appendix 1,

[14] This methodology captures the idea that the firm's decision to adjust price is done in two steps. First it decides whether to decrease, hold constant or increase the price. Second, conditional on this, it decides on the size of the adjustment.

[15] The problem with a binary choice model (used e.g. in Slade (1995)) for the decision to adjust price is easy to explain with an example. When e.g. the cost has decreased we expect price to be adjusted downward, and vice versa. With the dependent variable being one when the price is adjusted (upwards

the expectation of the error term in (7) is $E[\varepsilon|Z = j] = \rho\sigma\lambda$, where λ is a parameter related to the sample selection bias.

To give a broad picture of the data and of the limitations of the theoretical models we estimate several specifications. If the price is adjusted back to the static optimum then the movements in the explanatory variables since the last adjustment should be included in the ordered probit and OLS regressions. First, we follow the approach in the previous section and estimate a model with *ΔMC* and *ΔTAX*. Second, following more closely the theoretical model in Section 2, a specification with the two components of *ΔMC*; *ΔSP*E(-1)* and *ΔE*SP(-1)* together with *ΔTAX*. One deviation from the theoretical model is that *ΔMC* is included in the ordered probit regressions together with the signed square term of the movements, $(\Delta MC)^2$=sign$(\Delta MC)*\Delta MC*\Delta MC$.

The results are reported in the first three columns in Table 5 and Table 6 respectively.[16] The coefficient of *ΔMC* is positive while $(\Delta MC)^2$ is negative in the ordered probit regression. Thus it is more (less) likely that the price is increased (decreased) when the marginal cost has increased since the last price adjustment. However, it is proportionally less likely that firms adjust prices at large marginal cost changes. The marginal effects of *ΔMC* and $(\Delta MC)^2$ are small but in all the reported regressions they are essentially symmetric, e.g. evaluated at the means the marginal effect of *ΔMC* are -0.0028 and 0.0028 on the probability of a price increases and decreases respectively. This suggests that there is no evident asymmetry in the decision to adjust the price upward and downward in response to changes in marginal cost. Because the observations to about 95% consists of days when the price is held constant it will be quite difficult to predict exactly which day it will be adjusted and the predictive ability is naturally poor.[17] In what follows this implies that the sample selection parameter we suspect is important in the OLS regression will have little

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or downwards) a positive (negative) coefficient of the change in cost implies that positive movements in the costs increase both the probability that the price will increase *and* decrease.

[16] For the econometric estimation we have used the software LIMDEP and the procedure stated in the 7.0 Manual (1995 p.656-659). There are some typos in the manual. The definitions of U2, U3, XG should be Part(B,KP1,KP1), [10000], [XG1,XG2] respectively. Finally, the first definition of VC should be renamed and used in place of VC in the following.

[17] Reducing the frequency to weekly data gives higher predictive power, but the measure of the timing of the adjustment becomes less precise.

variation across days. Turning to the OLS regression we find that for both price increases and decreases only about 0.28 of ΔMC is reflected in ΔRP. This is in line with (6') and (6'') but in sharp contrast to the regression where all price adjustments were pooled (6) which yielded a coefficient of 0.55. As illustrated in Figure 5, the difference in point estimates is explained by the existence of a minimum absolute size of adjustments. Compared to (6'') the significance levels of the coefficients are considerably lower in the OLS regressions for price decreases in Table 5 due to the low variation in the sample selection variable λ. Finally, the effects of tax changes in the regressions show that prices are more likely to be adjusted upwards when there has been an increase in taxes ($DTAX=1$) and the coefficient of the size of the tax adjustment (ΔTAX) is about 0.8 for price increases.

When ΔMC in Table 6 is decomposed into $\Delta SP*E(-1)$ and $\Delta E*SP(-1)$ each of them has the expected sign for price increases and decreases in both the ordered probit and OLS regressions. The most noteworthy in the ordered probit regression is that a Wald test can not reject that the two are equal at the 10% level. On the other hand, in the OLS regression for price increases the coefficient on $\Delta E*SP(-1)$ is higher at the 10% level. Thus a given change in the marginal cost leads to a greater price increase if it stems from the exchange rate than from the spot market price. Again, however, the significance levels in the OLS regressions are low.

The low point estimates of ΔMC in relation to the almost complete pass through of MC in the long run raise doubts about the econometric specification. We therefore introduce additional variables in our attempt to estimate the size of price adjustments. First, lagged variables are included to account for the possibility that price adjustments partly reflect previous changes in the cost variables. Second, to account for any potential asymmetry in responses to upward and downward movements in cost variables we separate ΔMC into $\Delta_{+}MC$ and $\Delta_{-}MC$. Likewise, the last change, ΔMC_{-1}, is split into $\Delta_{+}MC_{-1}$ and $\Delta_{-}MC_{-1}$. Finally, we include the estimated error from the long run relation between RP and MC, TAX and $WAGE$, which in Section 3 was denoted $\hat{u}$. This is done to account for the possibility that both

the decision to adjust price as well as the size of the price adjustment may reflect the deviation from the long run equilibrium relation.[18]

In the ordered probit regression $\Delta_{+}MC$, ΔMC, $\Delta_{+}MC_{-1}$, and ΔMC_{-1} are all individually significant and point estimates for the lagged variables are considerably lower. Even though inclusion of ΔMC_{-1} leads to lower point estimates of ΔMC, the total effect of changes in marginal cost is larger than those in the second and third columns. It can not be rejected (at the 10% level) that $\Delta_{+}MC$ equals ΔMC and $\Delta_{+}MC_{-1}$ equals ΔMC_{-1}. This is another indication that there are no apparent asymmetric effects from upward and downward movements in the marginal cost. The negative and significant $\hat{u}$ shows that when the current price is above the long run equilibrium price it is less (more) likely that the price is raised (cut). In the OLS regressions the coefficient of $\hat{u}$ is about -0.1 and significant for both price increases and decreases which suggests that when the price is at a relatively high level the price increases (decreases) are relatively smaller (larger). The level of significance of the OLS coefficients in the regression with price decreases is low due to the low variation in λ.

The decomposition of ΔMC and ΔMC_{-1} is of minor importance to the results. It is possible to reject that $\Delta E*SP(-1)$ and $\Delta SP*E(-1)$ have the same effect in the ordered probit regression (at the 10% level). It can also be rejected, in both the ordered probit and OLS regression for price increases, that $\Delta E*SP(-1) + (\Delta E*SP(-1))_{-1}$ and $\Delta SP*E(-1) + (\Delta SP*E(-1))_{-1}$ are equal. This is an indication that not only do changes in the exchange rate have a more rapid effect than changes in the spot market price on the decision to adjust price, but also that price increases are more sensitive to changes in the former.[19]

To sum up the results of this section we find that, as expected, the price is more likely to be adjusted when there has been large movement(s) in the underlying cost variable(s). However, it appears as if the cost changes can be quite large without causing any price adjustment. Lagged independent variables are significant such that price adjustments reflect past changes in cost variables. The only asymmetry in

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[18] $\hat{u}$ is an estimated variable and thus our parameter estimates will be inefficient.

[19] See Table A1 in Appendix 2 which summarizes the tests of symmetries in the behavior of prices in response to different cost changes.

response to cost changes is that it is more likely that price is adjusted when there has been a change in the exchange rate than in the spot market price. When we estimated the size of the change we found quite low point estimates (about 0.2-0.3) of ΔMC. One striking feature is that the explanatory power of the regression for the size of price decreases is quite low, suggesting that in the short run it is difficult to predict exactly how large a decrease will be.

4.2 Monthly frequency

Even though we introduced lagged independent variables and a measure of the deviation from the long run equilibrium relation in section 4.1, it was done in quite an arbitrary fashion. The standard procedure for studying dynamic adjustment is to employ an error correction framework, which is pursued in this section. Instead of using changes in the cost variables since the last price adjustment we now look at cost and price changes at a monthly basis. Since the price is almost never unchanged for more than a month this reduces the problem of the dependent variable being zero for the majority of observations as is the case with data of daily and weekly frequency. In the theoretical discussion it was pointed out that quadratic adjustment costs cause a gradual movement towards the equilibrium level. That is, the price is not adjusted all the way to its equilibrium level once it does adjust. Partial adjustment implies that an error correction model may be a better description of our data - there remains an "error" from the last adjustment.[20]

The first step in an error correction approach is to estimate the relationship in levels between price and the explanatory variables. This long-run equilibrium relation was reported in equation (5). In the short run the price may deviate from the long-run equilibrium level because of stochastic shocks and adjustment costs. The estimated error term $\hat{u}$ may be interpreted as the deviation from long run equilibrium. For all specifications reported in tables 7 and 8 Engle-Granger tests reject that $\hat{u}$ has a unit root so that (5) represents a cointegrating relationship. The second step is estimation of the error correction form

[20] Kasa (1992) is one example of earlier work that applies an error correction model to (quantity) adjustment when there are exchange rate shocks.

$$\Delta RP_t = \alpha_0 + \alpha_1 \hat{u}_{t-1} + \alpha_2 \Delta \mathbf{X}_t + \alpha_3 \Delta \mathbf{X}_{t-1} + \alpha_4 \Delta \mathbf{X}_{t-2} + v_t, \qquad (8)$$

where it is assumed that two lags of the independent variables are sufficient to capture the dynamics.[21] α_1 is the estimate of how much of the misadjustment (relative to long-run equilibrium) in the previous period that is corrected in this period.

Table 7 about here

Table 7 shows that the parameter estimates are stable across specifications. Overall, contemporaneous explanatory variables are significant at the 1 percent level whereas lagged variables have varying significance levels. First we focus on the estimation reported in column (1). A change in marginal costs of one unit on average leads to a price adjustment of 0.54 in that same month (which is similar to the point estimate in the naïve (6)). The important fact to note is that not all adjustment takes place in the same month. The price change on average reflects 0.18 of the previous month's change in marginal cost. Further, the estimated coefficient for $\hat{u}$ indicates that about -0.27 of the misadjusted price from the previous month is corrected in this month. The estimates reported in Table 7 confirm the findings in the preceding section that tax-changes are immediately passed through to prices (coefficient of 0.74) since lagged values have low point estimates and are not statistically significant. *ΔWAGE* shows much less variation than the other variables and is highly correlated with the consumer price index. A change of one unit in the nominal wage index implies a nominal price change of about unity. We postpone further discussion of the pass-through pattern of *TAX, E* and *SP* until further below.

The regression reported in column (2) of Table 7 allows us to study if the responsiveness of price is symmetric in decreases and increases of the marginal cost. An increase in *MC* of one unit results in a contemporaneous price increase of about 0.7. There is no statistically significant effect of previous month's increases in *MC* on the price change. A decrease in *MC* of one unit, on the other hand, results in a

[21] In preliminary regressions we experimented with longer lags of the independent variables as well as lagged *ΔRP*. However their coefficients were always small and statistically insignificant.

contemporaneous price decrease of only 0.35. However, there is a statistically significant effect of the previous months decrease in *MC* on the price change of about 0.31. Taken together this means that the price responded more rapidly to cost increases than to decreases, but that the long-run pass-through is symmetric for increases and decreases. The accumulated pass-through after two months is slightly lower than 0.7 for both price increases and price decreases. It is not possible to reject at any reasonable level that the long run pass-through of ΔMC and ΔTAX is equal.

Despite the marked differences in market structure we thus find a similar pattern in our Swedish data as previously have been found on British and U.S. data. Using semi-weekly survey data for the period 1986-1992 Borenstein et al. (1997) find that retail gasoline prices in the United States responded more rapidly to cost increases than to cost decreases.[22] Bacon (1991) uses British retail prices (fortnightly data) for the period 1982-1989 and the Rotterdam spot market price as cost. Bacon also found that retail gasoline prices responded more rapidly to increases in costs than to decreases. Kirchgässner and Kübler (1992) on the other hand, using monthly data, find that for the German gasoline market retail price adjustment has been rapid, symmetric and full to Rotterdam spot price changes during 1980-1989 (but asymmetric for 1972-1979).

Another question related to symmetry is if price is equally responsive to changes in *E* and *SP*. Table 8 below presents the results of an error correction specification when *MC* has been separated into *E* and *SP*.

Table 8 about here

Comparing Table 8 with Table 7 we see that the point estimates of $\hat{u}$, ΔTAX and $\Delta WAGE$ are essentially unchanged. There are now some more restrictions to be tested. From the results of column (1) we can reject, at the 10% level, that the long-run pass-through of ΔTAX and ΔSP and ΔE are equal. Long run pass-through of these

[22] There is much more vertical differentiation in the U.S. gasoline market(s) than in the Swedish (see section 3). Borenstein et al. (1997) study price responses at various levels in the distribution chain; crude oil, spot market gasoline price, local wholesale price ("terminal") and retail price. As discussed in section 3 the relevant input price for the retail pricing decision in the Swedish gasoline market is the spot price of gasoline in Rotterdam (converted into Swedish kronor).

variables is about 0.6-0.7. The timing of pass-through is somewhat different for the different explanatory variables. For *TAX* and *E* more of the adjustment takes place in the same month compared to *SP*.

Further insights may be gained by separating changes into increases and decreases in *E* and *SP* respectively. This is done in column (2). For *SP* increases we see that they are passed through in the same month as they occur (point estimate of about 0.62), whereas price adjustment to *SP* decreases is about the same but is distributed over two months (pass-through of about 0.3 in the same month and of about 0.28 from the previous month). Similarly the adjustment to *E* changes takes place fully the same month as changes occur. Also in the case of *E* the price response to increases (0.94) is significantly larger than the response to decreases (0.74). One study to compare with is Feenstra (1989) who tests if the long-run pass-through of tariffs and exchange rates (onto prices of Japanese cars, trucks and motorcycles in the U.S. market) are equal. He does not reject the hypotheses that pass-through is symmetric, i. e. that a tariff change is passed through to the same extent as a exchange rate change.[23]

We experimented with specifications where all variables were deflated by consumer price index. Column (3) in Table 7 below reports one of those regressions. The estimated parameters (except for the constant) are roughly the same as for the nominal regressions where *WAGE* was included as explanatory variable.[24]

Summing up Section 4.2 we have found the following results about price adjustment; the timing of pass-through is asymmetric in the sense that increases in *MC* and *SP* are passed through more rapidly onto retail prices than decreases. Pass-through is also asymmetric in the sense that the coefficients of contemporaneous *TAX* and *E* changes are larger than for *SP* changes. This implies that the stochastic structure and other characteristics of a variable affect its short run effect on price. *TAX* is non-stochastic as opposed to *E* and *SP*, the later two both follow random walks. The long run pass-through is largely symmetric and reached in as short a period as two months.

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[23] Again we refer to Table A1 in appendix 2 which summarizes the tests of symmetries in the behavior of prices in response to different cost changes.

[24] *WAGE* was not included in the CPI deflated regressions since it is highly correlated with CPI.

5. Concluding remarks

Economists' interest in price rigidities is primarily motivated by their implications for macro-economic adjustment and transmission of cost and demand shocks. The prices on the Swedish gasoline market are flexible enough to expect that the price rigidity on this market is of limited macro-economic consequence. This said, using a long series of daily input and output prices for a major retail chain (Shell) gives an unusual opportunity to test implications of different price setting theories. One can distinguish between three main theories for how prices are set when there are costs of adjustment; state-dependent pricing with fixed adjustment costs (Ss), time-dependent pricing, and partial adjustment. Below we summarize the contribution that each one of these theories make to the understanding of price adjustment on the Swedish gasoline market.

At a first glance the Swedish gasoline industry seems to offer a text-book example of state-dependent pricing in its simplest form. Even though input prices move virtually every day we observe infrequent price adjustment (on average every third week) and no small price changes. In Section 4.1 we found that price adjustment is more likely to take place the further input costs have drifted since the last adjustment. The price adjustment to tax changes is also consistent with fixed (or zero) adjustment costs, adjustment appears to take place immediately and almost fully. These are three observations consistent with fixed adjustment costs. Evidently there is a fixed cost component of price adjustments for the retail chain (referred to as the firm). At a minimum there is the cost of disseminating the information to all individual gasoline stations associated with the firm (according to the Swedish Petroleum Institute they were 612 in January 1996).

However, there are some features of our data that are not explained by only fixed adjustment costs. The most obvious inconsistency (not only with the fixed adjustment cost hypothesis!) is that there are a number of cases when the price is increased (decreased) despite the fact that cost has decreased (increased). Another feature left unexplained is that there are extended periods when price is well above the long run equilibrium level and that prices are not adjusted to this level when they are set. Even more striking is the fact that lagged independent variables have explanatory

power in the ordered probit model in Section 4.1, which would not be the case if prices were always adjusted back to the static optimum.

We study the timing of the price changes and find only very limited evidence of time-dependent pricing, that is of price adjustment taking place at a specific point in time (e.g. "prices are set on the first day each month"). As discussed by Blanchard and Fischer (1989, p 413) time dependent price setting rules are likely to be most relevant when it is costly to learn about the state and when one wants to economize on information collection. However, since the most important factors for price setting in the gasoline market are all readily observable and change rapidly, the firm states that it continuously monitors the market for significant changes in underlying conditions. The lack of evidence supporting time-dependent pricing is therefore not surprising.

The lagged independent variables were significant and important when we estimated the size of price adjustments. In addition we found that there is a very strong relationship between prices and cost in the long run. These two features of the data were incorporated in the error correction model in Section 4.2. Our results are in line with previous studies of gasoline prices, adjustments depend on both current and lagged independent variables and prices are adjusted gradually towards the long run equilibrium. The general motivation for the inclusion of lagged variables and deviation from the long run equilibrium is that there are quadratic costs of adjusting the price. However, the full and rapid pass-through of tax changes is inconsistent with adjustment costs that are quadratic in the price change *per se*. As Rotemberg (1982) argued, if consumers dislike large price changes it results in a gradual price adjustment. For a moment interpret this as a dislike for large price changes due to reasons that consumers do not fully understand, whereas 'well motivated' price changes are not be perceived as equally bad. Tax increases are given extensive media coverage and could not be blamed on the firm. This behavioral assumption is consistent with both the gradual pass-through of marginal cost changes and the instantaneous pass-through of taxes. Still, it is difficult to explain the large number of price changes of the 'wrong' sign.

Thus, none of the above theories is consistent with all the features of price adjustments. This may in itself not be surprising since there are specificities of each single price adjustment that are unobservable to the researcher. A good example of

such unobservables is the beliefs of the firm regarding the competitors' responses to price adjustments. In the paper we have not studied any strategic considerations by the firm, but they are clearly important for price setting in the short run. We have discussed the issue with the firm. It pointed to that although all price adjustments can be observed almost instantaneously, rivals have the option of sticking to their old prices or changing by a different amount. This was given as motivation for avoiding 'very large' price changes, even though they may be called for due to large changes in the observable underlying variables. These behavioral assumptions would also be consistent with gradual adjustment. Again, for the tax changes there is a natural focal point since they are known in advance. As the firm said, "everybody knows that tax changes are passed through fully and at once".

Finally, referring back to Figure 1 in the Introduction, inferences on price setting behavior will be highly dependent on the data analyzed. For example, if one only had access to the price series (or only the distribution of price adjustments) it would be easy to conclude that the Ss-model is an accurate description of price setting. On the other hand, if data were sampled only at (longer) discrete intervals the conclusion could instead be in favor of the partial adjustment model. This may seem like a negative conclusion to be drawn after going through all the statistics of the paper. However, considering the complexity of real world behavior it is comforting to note that within a relatively short time prices revert back to some long run equilibrium level.

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Table 1. Variable definitions and data sources.

VARIABLE	*DEFINITION AND DATA SOURCE*
RP	Retail list price for premium leaded gasoline for one of the firms, namely Shell. The retail price is at 0-zone, i.e. where the transport cost is the lowest. VAT is excluded from the price according to the formula: *RP*=consumer price/(1+*VAT*) measured in SEK*100/litre. Source: Shell.
SP	The spot market price of premium leaded gasoline. From November 1985 to December 1996 it is the average of high (from refinery) and low (stored or blended material) daily quotations, FOB Rotterdam for Premium 0.15 g/l. Size is barges (1,000-5,000 mt) and delivery is North West Europe. Prices are assessed daily up until 1830 GMT. For the period January 1980 to October 1985 it is for Mediterranean/Italian delivery of regular gasoline plus USD 24, which was the average difference between the two prices for the period where we have access to both. The FOB price is transformed from USD/mt to USD/liter by the factor 8.35*159. *SP* is measured in USD*100/litre. Source: Platt's, London.
E	The exchange rate between Swedish kronor and US dollars. Source: Findata (January 1983 to December 1996), Stefan Nydahl, Uppsala University (January 1980 to December 1982).
MC	Spot market price of premium leaded gasoline measured in SEK*100/litre. MC is obtained by the formula: *MC=SP*E*
CPI	Consumer price index. Source: International Financial Statistics.
WAGE	Index of nominal hourly wages in the manufacturing sector (SNI 3). Source: International Financial Statistics, heading 14465.zf
DAYSFIXED	The number of days the price has been fixed since latest price adjustment.
TAX	Total tax per liter premium leaded gasoline. Source: The Swedish Petroleum Institute, Annual report 1995.
$\Delta_{sgn}X_{lag}$	Changes in the variable *X* is denoted ΔX. In Section 2 and Section 4.1 Δ refers to the change since the last price adjustment and in Section 4.2 it refers to the change since last month. The sign of the change is displayed in the subscript on Δ. The subscript on *X* denotes the number of lags.
	One example: In Section 4.2 $\Delta_{+}MC_{-2} = MC_{-2} - MC_{-3}$ conditional on it being positive
$\Delta SP*E(-1)$	Change in *SP* holding the value of *E* fixed.
$\Delta E*SP(-1)$	Change in *E* holding the value of *SP* fixed.
$(\Delta SP*E(-1))_{-1}$	One period lag of the change in *SP* holding the value of *E* fixed.
$(\Delta E*SP(-1))_{-1}$	One period lag of the change in *E* holding the value of *SP* fixed.
VAT	Value added tax. Calculated on producer price including *TAX*. A *VAT* of 23.46% was levied on gasoline on March 1, 1990, it was subsequently (July 1, 1991) increased to 25.00%. Source: The Swedish Petroleum Institute, Annual report 1995.

Table 2: Descriptive statistics for all price adjustments.

	Mean	*Std.Dev*	*Skew*	*Kurt*	*Min*	*Max*	*Median*	*Cases*
ΔRP≠0								
ΔRP	1.55	11.05	3.0	23.7	-16.20	95.20	3.20	250
ΔMC	0.04	9.26	0.3	6.0	-37.26	35.54	-0.27	250
*ΔSP*E(-1)*	-0.31	8.84	0.4	6.2	-35.09	35.42	0.00	250
*ΔE*SP(-1)*	0.37	3.94	1.4	15.2	-14.27	26.24	0.12	250
DAYSFIXED	21.59	23.90	2.6	12.4	0	177	13	250
ΔRP>0								
ΔRP	9.09	10.22	5.4	41.8	2.00	95.20	6.00	130
ΔMC	4.62	8.69	0.9	5.3	-17.00	35.54	3.98	130
*ΔSP*E(-1)*	3.11	8.37	0.9	5.5	-17.64	35.42	1.79	130
*ΔE*SP(-1)*	1.54	4.46	1.4	14.0	-14.27	29.24	0.70	130
DAYSFIXED	24.81	26.64	2.6	12.3	1	177	14	130
ΔRP<0								
ΔRP	-6.62	3.59	-1.4	3.9	-16.20	-2.00	-5.60	120
ΔMC	-4.92	7.05	-1.2	8.5	-37.26	21.14	-3.55	120
*ΔSP*E(-1)*	-4.02	7.38	-0.8	7.1	-35.09	24.02	-2.78	120
*ΔE*SP(-1)*	-0.89	2.65	-0.5	4.4	-9.77	5.33	-0.68	120
DAYSFIXED	18.10	20.06	2.2	7.8	0	104	11	120

Table 3: Descriptive statistics for the sub periods 1980-84, 1985-89, and 1990-96. (Standard deviations in parenthesis.)

	|ΔRP| *Mean*	*|ΔMC|* *Mean*	*ΔSP*E(-1)* *Mean*	*ΔSP*E(-1)* *Mean*	*DAYSFIXED* *Mean*	*Nobs.* *ΔRP>0*	*Nobs.* *ΔRP<0*
1980 - 1984	8.89	7.61	7.10	4.08	38.18	28	16
	(8.54)	(7.33)	(6.61)	(4.79)	(27.49)		
1985 - 1989	9.45	9.06	8.63	3.30	31.84	20	24
	(5.13)	(7.57)	(7.99)	(3.30)	(36.30)		
1990 - 1996	7.22	5.53	4.93	1.88	14.30	82	80
	(8.23)	(5.81)	(5.81)	(2.05)	(13.13)		
1980 - 1996	7.90	6.52	5.96	2.52	21.59	130	120
	(7.86)	(6.56)	(6.52)	(3.06)	(23.90)		

Table 4: Number of price adjustments over the year and week.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Quantity	370	386	438	446	465	497	526	501	450	448	422	433
1000m^3												
ΔRP>0	12	13	10	17	5	13	9	12	11	10	7	11
ΔRP<0	9	6	9	6	7	11	10	10	13	14	11	14
	Mon	*Tue*	*Wed*	*Thu*	*Fri*	*Sat*	*Sun*					
ΔRP>0	9	31	33	29	18	5	5					
ΔRP<0	13	34	25	20	20	8	0					

Table 5. Ordered probit and OLS estimates. MC. Daily frequency.

	(1) Ordered Probit	*(2) OLS*	*(3) OLS*	*(4) Ordered Probit*	*(5) OLS*	*(6) OLS*
VARIABLE	Z	ΔRP|ΔRP>0	ΔRP|ΔRP<0	Z	ΔRP|ΔRP>0	ΔRP|ΔRP<0
CONSTANT	2.13***	2.42	3.93	2.14***	3.86***	5.93
	(0.0426)	(1.61)	(10.9)	(0.0549)	(1.38)	(13.0)
ΔMC	0.0686***	0.283***	0.275*		0.217***	0.186
	(0.00737)	(0.0469)	(0.148)		(0.0496)	(0.169)
$\Delta_{+}MC$				0.0639***		
				(0.00905)		
$\Delta_{-}MC$				0.0575***		
				(0.00906)		
ΔMC_{-1}					0.141***	0.133
					(0.0405)	(0.105))
$\Delta_{+}MC_{-1}$				0.0111*		
				(0.00567)		
$\Delta_{-}MC_{-1}$				0.0115*		
				(0.00670)		
$(\Delta MC)^2$	-0.00167***			-0.00152*		
	(3.03E-4)			(3.10E-4)		
$\hat{u}$				-0.00876***	-0.0942***	-0.147**
				(0.00293)	(0.0366)	(0.0664)
DTAX	3.63***			3.73***		
	(0.413)			(0.425)		
ΔTAX		0.851***			0.820***	
		(0.0410)			(0.0359)	
μ_1	4.27***			4.31***		
	(0.0632)			(0.0675)		
Lambda		1.59**	4.02		0.744	4.53
		(0.701)	(4.48)		(0.604)	(5.33)
AdjR2		0.838	0.112		0.860	0.317
D-W		1.59	1.14		1.57	1.41
LogL	-1090.4			-1067.1		
NOBS	5693	130	120	5595	129	120

Variables starred with *** are significant at the 1% level, with ** at the 5% level and with * at the 10%level

Table 6. Ordered probit and OLS estimates. SP and E. Daily frequency.

	(1) Ordered Probit	*(2) OLS*	*(3) OLS*	*(4) Ordered Probit*	*(5) OLS*	*(6) OLS*
VARIABLE	Z	ΔRP|ΔRP>0	ΔRP|ΔRP<0	Z	ΔRP|ΔRP>0	ΔRP|ΔRP<0
CONSTANT	2.13***	1.59	2.72	2.16***	3.13**	9.39
	(0.0433)	(1.66))	(15.2)	(0.0455)	(1.40)	(28.3)
*ΔSP*E(-1)*	0.0564***	0.272***	0.226	0.0467***	0.203***	0.210
	(0.00810)	(0.0496)	(0.177)	(0.00848)	(0.0517)	(0.287)
$(\Delta SP*E(-1))_{-1}$				0.0132***	0.127***	0.149
				(0.00390)	(0.0443)	(0.187)
*ΔE*SP(-1)*	0.0747***	0.415***	0.260	0.0773***	0.329***	0.323
	(0.0130)	(0.0955)	(0.356)	(0.0134)	(0.0848)	(0.669)
$(\Delta E*SP(-1))_{-1}$				0.00971	0.190**	0.144
				(0.00695)	(0.0843)	(0.239)
$(\Delta SP*E(-1))^2$	-0.00128***			-0.00105***		
	(3.48E-4)			(3.61E-4)		
$(\Delta E*SP(-1))^2$	-0.00165**			-0.00183**		
	(7.93E-4)			(8.44E-4)		
$\hat{u}$				-0.0100***	-0.101***	-0.168
				(0.00295)	(0.0378)	(0.115)
DTAX	3.61***			3.72***		
	(0.414)			(0.425)		
ΔTAX		0.861***			0.827***	
		(0.0414)			(0.0360)	
μ_1	4.26***			4.31***		
	(0.0660)			(0.0700)		
Lambda		1.89***	3.53		1.01*	5.87
		(0.724)	(6.21)		(0.614)	(11.4)
AdjR2		0.844	0.100		0.864	0.300
D-W		1.51	1.10		1.49	1.37
LogL	-1090.9			-1063.7		
NOBS	5693	130	120	5595	129	120

Variables starred with *** are significant at the 1% level, with ** at the 5% level and with * at the 10%level

Table 7. Error correction model. Monthly frequency. Heteroskedacity consistent standard errors.

	(1) OLS	*(2) OLS*	*(3) OLS*[a]
VARIABLE	ΔRP	ΔRP	ΔRP/CPI
CONSTANT	0.717	0.736	0.003
	(0.599)	(1.0050)	(0.0071)
û	-0.275***	-0.274***	-0.221***
	(0.0523)	(0.0532)	(0.0470)
ΔTAX	0.745***	0.750***	0.741***
	(0.0515)	(0.0512)	(0.0684)
ΔTAX_1	-0.0591	-0.0586	-0.0984
	(0.0525)	(0.0522)	(0.0699)
ΔWAGE	1.0186***	0.939**	
	(0.452)	(0.450)	
ΔMC	0.541***		0.430***
	(0.0549)		(0.0554)
ΔMC_1	0.183***		0.211***
	(0.0586)		(0.0589)
ΔMC_2	-0.0643		0.0148
	(0.0551)		(0.0544)
Δ+MC		0.695***	
		(0.0970)	
Δ+MC_1		0.0289	
		(0.103)	
Δ+MC_2		-0.1003	
		(0.104)	
Δ-MC		0.349***	
		(0.103)	
Δ-MC_1		0.311***	
		(0.107)	
Δ-MC_2		-0.0361	
		(0.0978)	
D-W	1.96	1.97	2.05
Sum of squares	9273.9	8962.4	1.5
Adj. R2	0.693	0.698	0.586
NOBS	178	178	178

Variables starred with *** are significant at the 1% level, with ** at the 5% level and with * at the 10%level

a) The explanatory variables are deflated with CPI.

Table 8. Error correction model. Monthly frequency. Heteroskedacity consistent standard errors.

	(1) OLS	*(2) OLS*
VARIABLE	*ΔRP*	*ΔRP*
CONSTANT	0.408	0.102
	(0.589)	(1.346)
û	-0.292***	-0.288***
	(0.0520)	(0.0538)
ΔTAX	0.726***	0.723***
	(0.0520)	(0.0523)
ΔTAX$_{-1}$	-0.0951*	-0.0907*
	(0.0525)	(0.0529)
ΔWAGE	1.0116**	0.898**
	(0.440)	(0.447)
*ΔSP*E(-1)*	0.476***	
	(0.0564)	
*(ΔSP*E(-1))*$_{-1}$	0.194***	
	(0.0608)	
*(ΔSP*E(-1))*$_{-2}$	-0.112**	
	(0.0566)	
*ΔE*SP(-1)*	0.850***	
	(0.123)	
*(ΔE*SP(-1))*$_{-1}$	0.208*	
	(0.124)	
*(ΔE*SP(-1))*$_{-2}$	0.166	
	(0.126)	
*Δ+SP*E(-1)*		0.624***
		(0.101)
*(Δ+SP*E(-1))*$_{-1}$		0.0660
		(0.110)
*(Δ+SP*E(-1))*$_{-2}$		-0.175
		(0.110)
*Δ-SP*E(-1)*		0.298***
		(0.108)
*(Δ-SP*E(-1))*$_{-1}$		0.282***
		(0.108)
*(Δ-SP*E(-1))*$_{-2}$		-0.0438
		(0.0983)
*Δ+E*SP(-1)*		0.940***
		(0.172)
*(Δ+E*SP(-1))*$_{-1}$		0.235
		(0.178)
*(Δ+E*SP(-1))*$_{-2}$		0.118
		(0.182)
Δ-E$_{-1}$**SP(-1)*		0.745**
		(0.305)
*(Δ-E*SP(-1))*$_{-1}$		-0.0368
		(0.288)
*(Δ-E*SP(-1))*$_{-2}$		0.297
		(0.286)
D-W	1.91	1.93
Sum of squares	8593.9	8269.5
Adj. R2	0.711	0.711
NOBS	178	178

Variables starred with *** are significant at the 1% level, with ** at the 5% level and with * at the 10%level

Appendix 1

Let the selection mechanism be

$$Z^* = \delta' \mathbf{W} + e \qquad \text{(A1)}$$

where Z^* is unobservable and the error term e has a standard normal distribution. δ is a vector of parameters to be estimated and **W** a vector of explanatory variables (including a constant). Z can be observed according to

$$Z = \begin{cases} 0 & \text{if} \quad Z^* \leq 0 & \text{"decrease price"} \\ 1 & \text{if} \quad 0 < Z^* \leq \mu_1 & \text{"keep price constant"} \\ 2 & \text{if} \quad \mu_1 \leq Z^* & \text{"increase price"} \end{cases}, \qquad \text{(A2)}$$

where μ_1 is an additional parameter to be estimated. This specification states that the price is more likely to be decreased when δ′**W** is small and increased when large. Let Φ(.) denote the cumulative normal distribution to give the probabilities of the outcomes

$$\text{Prob}(Z = j) = \begin{cases} \Phi(-\delta' \mathbf{W}) & \text{for} \quad j = 0 \\ \Phi(\mu_1 - \delta' \mathbf{W}) - \Phi(-\delta' \mathbf{W}) & \text{for} \quad j = 1 \\ 1 - \Phi(\mu_1 - \delta' \mathbf{W}) & \text{for} \quad j = 2 \end{cases}. \qquad \text{(A3)}$$

The magnitude of the price change can be observed only when $j=0$ or $j=2$ and is then determined by the regression model

$$\Delta RP = \beta_j' \mathbf{X}_j + \varepsilon \qquad \text{for j=0 or 2} \qquad \text{(A4)}$$

where β is a vector of parameters and **X** explanatory variables which may be different for j=0 and j=2. The error terms e and ε is assumed to have a bivariate normal distribution (0,0,ρ,1,σ). The expectation of the error term ε in (A4) is

$$E[\varepsilon | Z = j] = \rho\sigma\lambda \qquad \text{for j=0 or j=2} \tag{A5}$$

where λ can be shown to be

$$\lambda = \begin{cases} -\phi(-\delta'\mathbf{W}) / \Phi(-\delta'\mathbf{W}) & \text{for j} = 0 \\ \phi(\mu_1 - \delta'\mathbf{W}) / (1 - \Phi(\mu_1 - \delta'\mathbf{W})) & \text{for j} = 2 \end{cases} \tag{A6}$$

where ϕ(.) is the normal distribution function. Thus the estimation of (A4) includes as an independent variable λ estimated by (A1).

Appendix 2

Table A. Tests for symmetric price responses to various cost changes.

Model	*Tab:Col*	*Frequency*	*SR/LR*	*Restriction*	*P-value*
OP	5:4	Daily	SR	$\Delta_+MC = \Delta_-MC$	0.4992
OP	6:1	Daily	SR	$\Delta SP*E(-1) = \Delta E*SP(-1)$	0.1663
OP	6:4	Daily	SR	$\Delta SP*E(-1) = \Delta E*SP(-1)$	0.0241
OP	6:4	Daily	LR	$\Delta SP*E(-1) = \Delta E*SP(-1)$	0.0658
ECM	7:1	Monthly	LR	$\Delta TAX = \Delta MC$	0.8293
ECM	7:2	Monthly	SR	$\Delta_+MC = \Delta_-MC$	0.0368
ECM	7:2	Monthly	LR	$\Delta_+MC = \Delta_-MC$	0.9984
ECM	8:1	Monthly	LR	$\Delta SP*E(-1) = \Delta TAX$	0.0950
ECM	8:1	Monthly	LR	$\Delta E*SP(-1) = \Delta TAX$	0.0270
ECM	8:1	Monthly	SR	$\Delta SP*E(-1) = \Delta E*SP(-1)$	0.0039
ECM	8:1	Monthly	LR	$\Delta SP*E(-1) = \Delta E*SP(-1)$	0.0026

SR stands for short run (current coefficients), LR for long run (accumulated coefficients), OP for ordered probit and ECM for error correction model.

Figure 1
Development of VAT-adjusted retail price (*RP*) and costs (*MC+TAX*), fall 1995

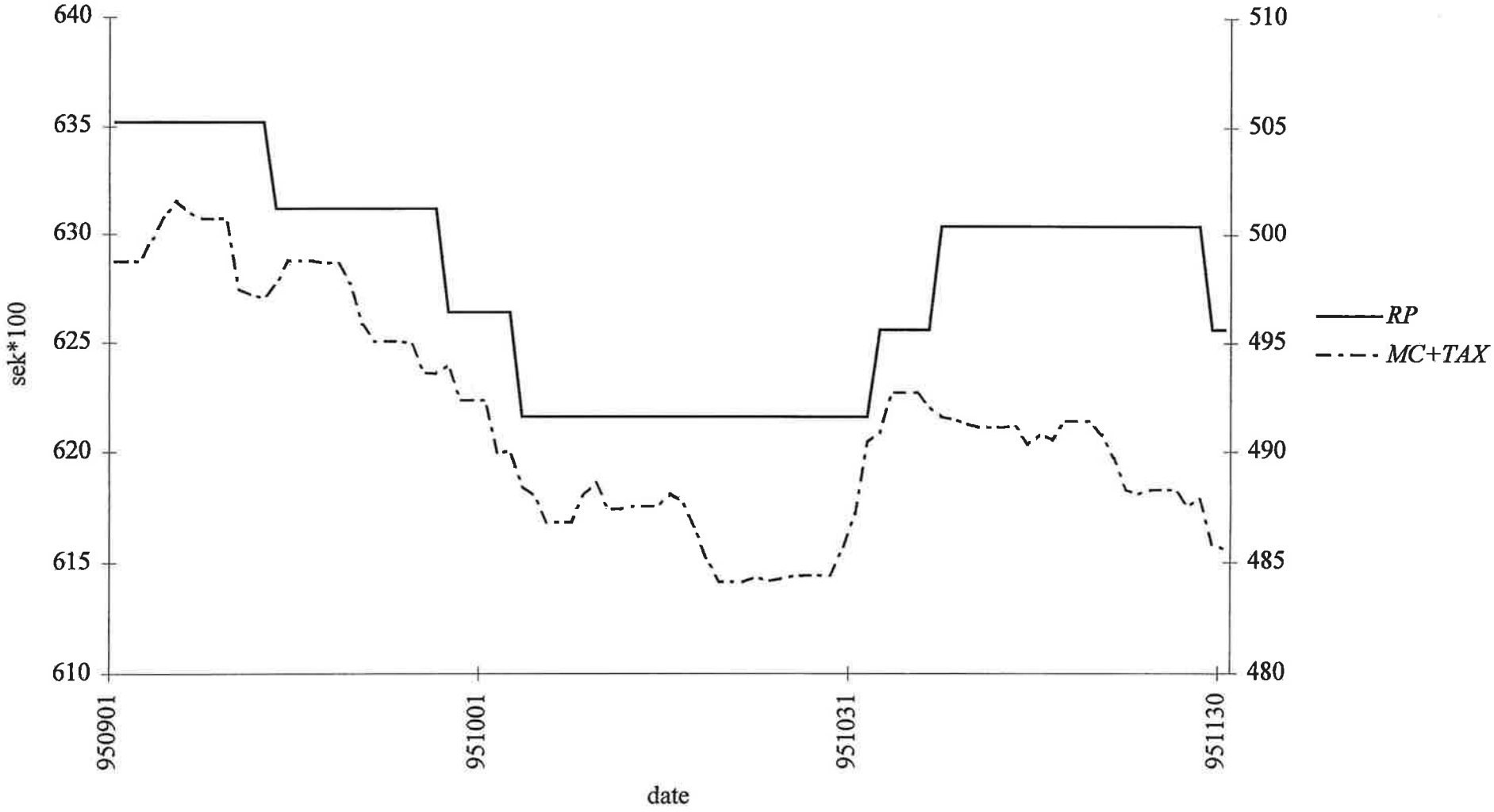


Figure 2
Difference between actual price and optimal price.

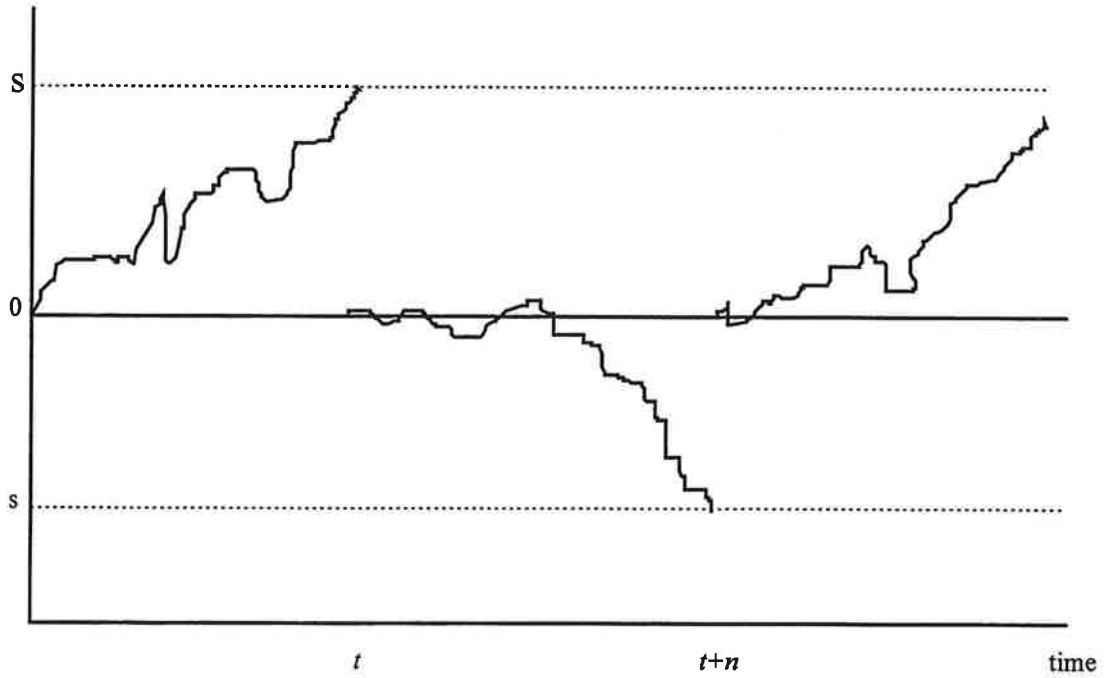


Figure 3
RP, MC, TAX

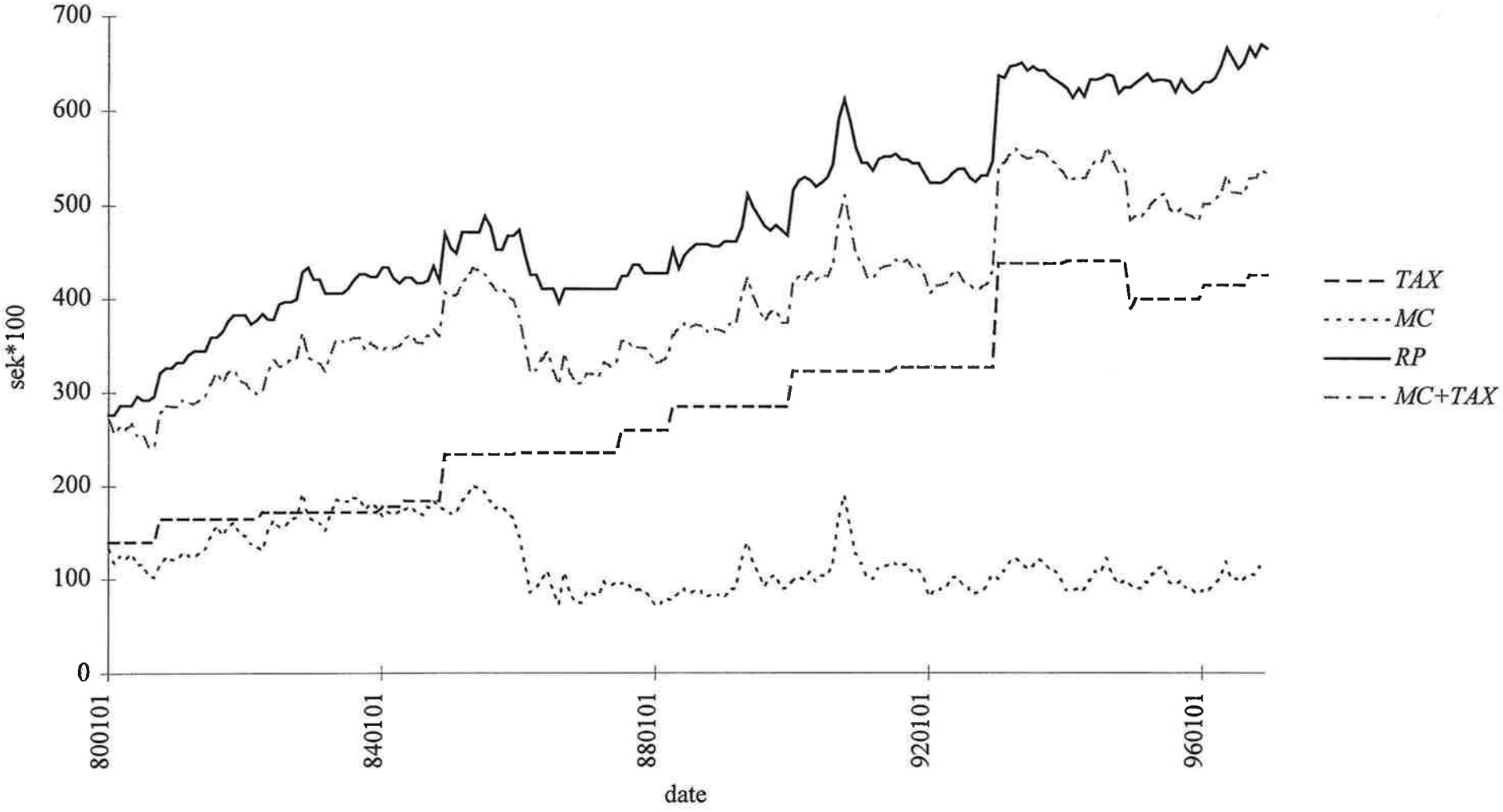


Figure 4
RP and *MC+TAX* during the October 1993 price war

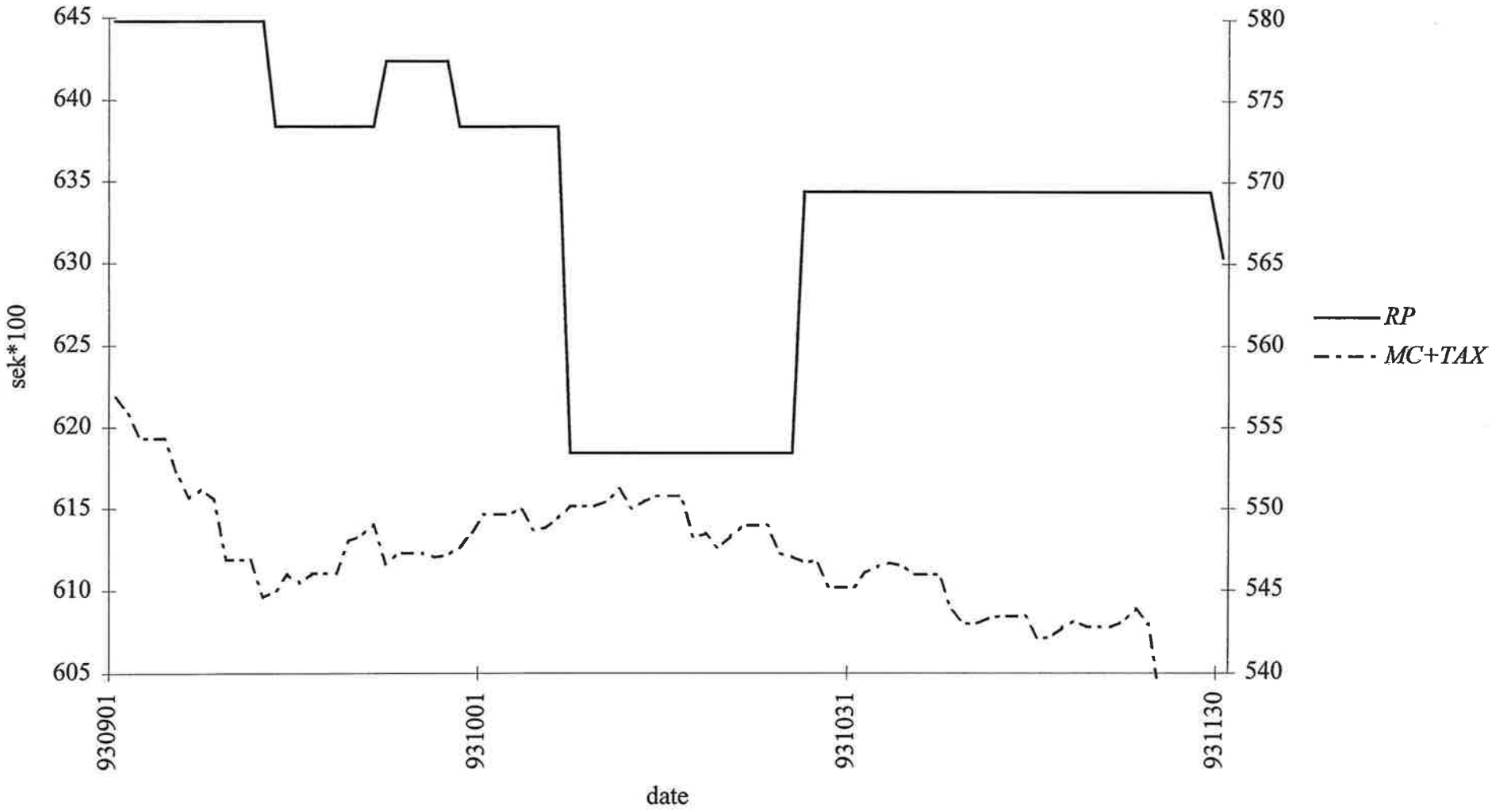


Figure 5

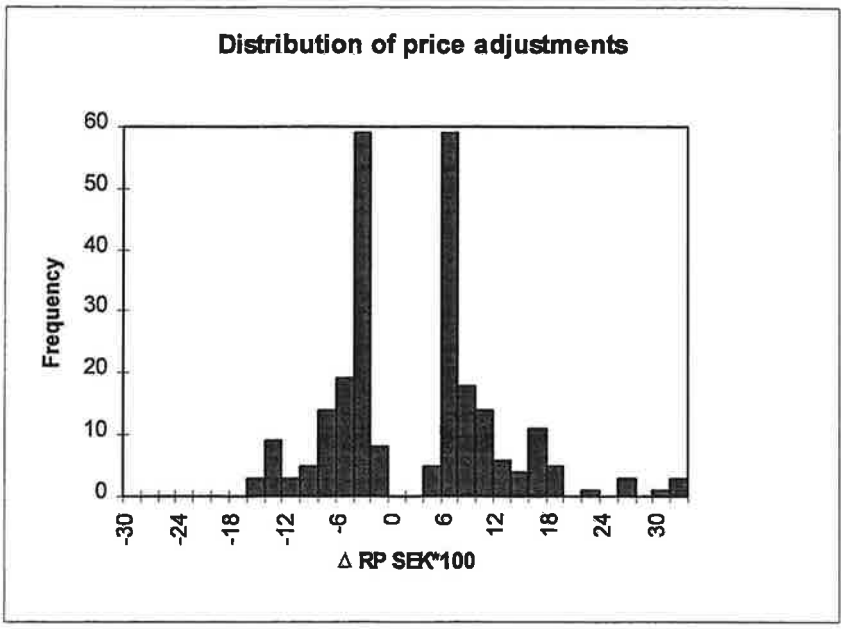
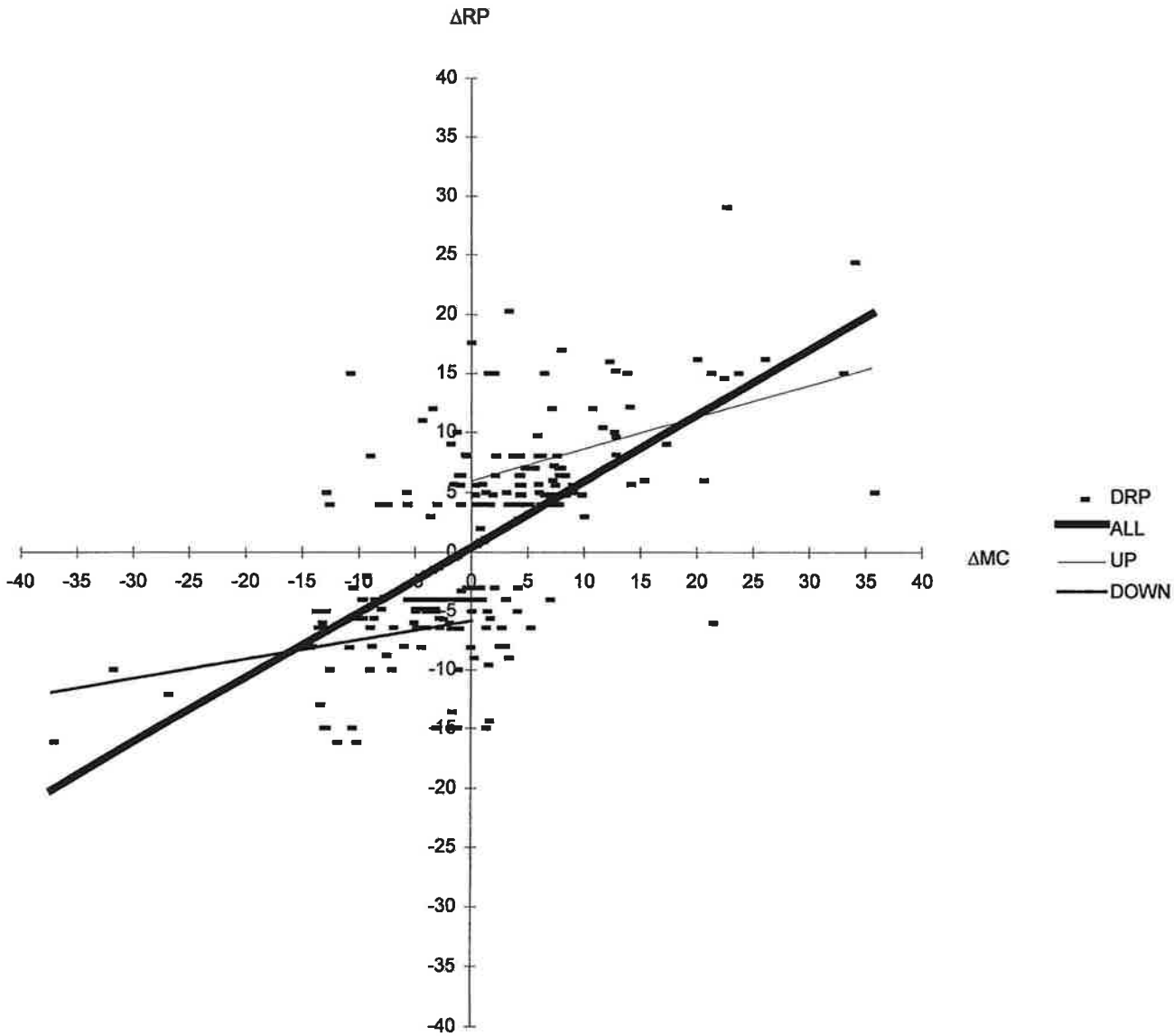

Distribution of price adjustments
Frequency
60
50
40
30
20
10
0
-30
-24
-18
-12
-6
0
6
12
18
24
30
Δ RP SEK*100

Figure 6
ΔRP in relation to ΔMC



Should the core fear the outs?

Price setting practices and international monetary transmission

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Abstract

This paper examines the response of national consumption, production and welfare to asymmetric monetary shocks. We do so in a two-country model (country "core" and country "out") characterized by monopolistic competition and price rigidities. A large degree of goods market segmentation and local currency pricing leads to monetary policy having beggar-thy-neighbor effects. Increased price setting in the "core" currency by "outs" lessens the negative spill-over on "core" from "out" monetary policy. It also makes the welfare spill-overs on "outs" from "core" monetary policy negative.

JEL classification: F36, F41, F42.

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1 Introduction

Welfare effects of monetary policy are important for a great number of issues in international economics. The choice of nominal exchange rate regime is just one such issue. However, the Mundell-Fleming framework that has been the workhorse in international macroeconomics lacks microfoundations and is therefore not well suited for welfare analysis. Recently Obstfeld and Rogoff (1995a, 1996, Ch. 10) have proposed an intertemporal two-country framework that they claim maintains the empirical realism of a Mundell-Fleming world while allowing for explicit welfare results since it builds from optimizing agents. One of the starkest results in their model is that a monetary expansion in one country raises welfare in both countries proportionately. This suggests that fears of "beggar-thy-neighbor" effects of a depreciating exchange rate are misguided or at least exaggerated. Their analysis thus has potentially important ramifications for e.g. the relationship between the ins and outs of a European Monetary Union. In their main analysis Obstfeld and Rogoff assume that the law of one price holds and that prices are set in the exporter's currency.[1] This is a potentially important assumption. Real effects of monetary policy depend on price rigidities and it follows that it is not unimportant in which currency that prices are rigid.

This paper investigates welfare effects of international monetary transmission under different assumptions of price setting practices. We do so in a simple one-period version of the Obstfeld and Rogoff model that has been developed by Betts and Devereux (1995, 1996).[2] Betts and Devereux assume that the price of a share of goods are set in the importer's currency and that the law of one price does not hold for these goods. Betts and Devereux (1996) use the model to study how

[1] Obstfeld and Rogoff (1996) also perform a welfare analysis of international monetary transmission under two variations of the main model. In one (1996, p.689-694) each country has a non-traded goods sector and a traded goods sector that is perfectly competitive with a flexible price. In that set-up monetary policy has real effects only in the originating country. They also sketch a formulation (1996, p.709-712) where wages are pre-set but output prices are flexible. In that set-up the effects of monetary policy on consumption differentials and the exchange rate are the same as in the main analysis. We return to a discussion of this last formulation in our concluding comments.

[2] Obstfeld and Rogoff (1995b) develop a one-period version of their model.

price stability in the importers' currency affects exchange rate volatility. Their framework produces the result that separation of national markets and pre-set prices increases the volatility of exchange rates relative to what would be the case if the law of one price held.[3] A working paper version (1995) of the article contains a brief welfare analysis of monetary transmission. We expand that discussion. We also extend their model to allow for the possibility that a share of goods produced in one country, for which the law of one price holds, are priced in foreign currency. A short motivation for the assumptions are given below.

The assumption of Obstfeld and Rogoff that the law of one price holds is at odds with the large body of evidence on the breakdown of the law of one price for many traded goods, see e.g. Alexius and Vredin (1996) or Goldberg and Knetter (1996). Further, many studies suggest that prices for a large share of traded goods are stabilized in the importer's currency, a phenomenon known as Pricing-to-market (PTM) or limited exchange rate pass-through. The assumption below that a share of goods has prices that are pre-set in the local currency and that markets are segmented is a simple way to model this.

Why would an exporter of goods for which the law of one price holds set price in foreign currency? We illustrate with the case of a Volvo car. Today prices on different national markets tend to be stable in local currency and prices differ when expressed in common currency.[4] As the common market grows in age it is likely that the law of one price will hold to a greater extent. It is reasonable to assume that a share of Swedish (British, Norwegian,...) exporters will then choose to keep prices stable to the large Euro market rather than to the smaller domestic market. Support for this is the belief that many large firms based in countries outside an EMU will switch to using Euro as their functional currency.[5] Further support may be given by studying currency use in Canadian-US

[3] The result holds for empirically reasonable values of the consumption elasticity of money demand and the price elasticity of demand.

[4] See Flam and Nordström (1995) for a study of car prices on different European markets.

[5] For Sweden this is argued in e.g. the contributions by the Swedish Employers' Confederation and the Stockholm Chamber of Commerce in Finansdepartementet (1997). For Denmark see Olsen (1997).

trade. There is a case to made for there being similarities in the situation of Canada vis-a-vis the US and that of potential "ins" and "outs" of EMU. Feenstra and Kendall (1997) argue that Canadian exports to the US are almost exclusively denominated in US dollars.

The Obstfeld-Rogoff framework is quite new and in that sense there is little precedent to the present article apart from the one's mentioned above.[6] Of course welfare issues are implicit in the huge literature on e.g. optimal exchange rate arrangements that use a Mundell-Fleming type framework; see for instance the survey by Genberg (1989). The implications of PTM for how exchange rates affect consumption and production have been noted informally by previous observers. For instance Krugman (1989, p. 39) states that "the exchange-rate changes since the dollars peak in 1985 dwarf those that were central to great historical disputes. Yet, looking at the domestic performance of the major economies, one sees only marginal impacts from these changes....that exchange rates do not affect trade flows or aggregate prices as much as one might expect is due in large part to [Pricing-to-Market]".

In the next section we set out our simple extension of the Betts and Devereux model. Section 3 presents our analysis and the last section concludes.

2 The model

Assume that the world is inhabited by a continuum of agents. Let $[0, n]$ agents be located in the country denoted Out and $(n, 1]$ agents be located in the country denoted Core. There are the same number of goods produced in a country as there are agents in that country. Each good i is only produced by firm i. Each firm produces only one good and all goods are sold on both markets. A share s of firms from both countries produce a good for which markets are segmented and price is set

[6] Kollmann (1997) provides extensive references to related literature, e.g. international real business cycle research. Beaudry and Devereux (1995), Chari, Kehoe and McGrattan (1997) and Kollmann (1997) use related models to make quantitative studies of how price stability in importers' currencies affect variability and persistence of deviations from Purchasing Power Parity. Svensson and van Wijnbergen (1989) study production and consumption responses to monetary shocks in a world similar to that of Obstfeld and Rogoff.

in the local currency on both markets. We call these PTM goods. $x(i)$ denotes the quantity of PTM good i produced for the home market and $z(i)$ the quantity produced for the foreign market. Denote goods produced by Core with a star. A share $1-s$ of firms in each country produce a good for which markets are not separated so that the law-of-one price always holds. We call these non-PTM goods. The $y^*(i)$ non-PTM goods produced in the Core country are all priced in the Core currency. A share $1-a$ of the non-PTM firms from Out set price on their goods $y(i)$ in the Out currency. A share a of non-PTM firms from Out set price in the Core currency. Denote each of these goods by $w(i)$. This is the extension that we make compared to Betts and Devereux (1995, 1996). Let $p(i)$ be a price denominated in the Out currency and $q(i)$ a price denominated in the Core currency. Figure 1 illustrates our assumptions about the home country and price setting behavior of firms.

Figure 1 about here

An Out country agent maximizes the utility function given by

$$U = logC + \frac{\gamma}{1-\varepsilon}\left(\frac{M}{P}\right)^{1-\varepsilon} + \eta log(1-h) \tag{1}$$

where C is a consumption index, M are nominal balances, P is the price level in Out and h denotes the time worked.[7] Expressions for C and P are given in appendix 1. Maximization is subject to the individual's budget constraint given by $PC+M = Wh+\pi+M_0+TR$. The cost of consumption and money holdings at the end of the period equal wage earnings (Wh) plus profits from ownership (π), government transfers (TR) and initial nominal money holdings (M_0).[8] The output of firms depends

[7] One may ask why an Out agent would not receive utility by holding Core money. For the issues we focus on it is realistic to assume that agents hold wealth in their domestic currency and only exchange it for foreign currency the moment they buy something denominated in foreign currency. See Obstfeld and Rogoff (1996, p. 551-554) for a discussion of inclusion of foreign currency holdings in the utility function. The issue of interest there is "Dollarization", when there is widespread substitution away from the use of domestic currency, such as under a hyper-inflation.

[8] Assume that all individuals work in, and own shares of, one firm of each type from his own country in equal proportions. In this sence the situation for all agents from a country is the same. Assume that wage is pre-set so that changes in firm revenue are distributed through profits rather than through wages.

linearly on employment in the firm by a factor A.

Below we set out profits of an Out PTM firm (2), an Out non-PTM firm which prices in the Out currency (3) and an Out non-PTM firm which prices in the Core currency (4). e is the nominal exchange rate expressed as units of Out currency needed to buy one unit of Core currency.

$$\pi(i) = p(i)x(i) + eq(i)z(i) - (W/A)(x(i) + z(i)) \tag{2}$$

$$\pi(i) = p(i)y(i) - (W/A)y(i) \tag{3}$$

$$\pi(i) = eq(i)w(i) - (W/A)w(i) \tag{4}$$

Price of each good is set to maximize profits. The set-up is analogous for the Core country. Denote Core variables with a star. The government of each country finances lump sum money transfers to its residents by printing money. Note that demand elasticities are the same for all goods. In equilibrium price will thus be equal for all goods and we suppress i from here on. Output in the Out country is given by $nY = n(1-s)((1-a)y + aw) + ns(x+z)$.

Following a number of steps (given in appendix 1) we can characterize a sticky price equilibrium by the equations (5) through (15) below.

A sticky price equilibrium is characterized by; the money market clearing equations in each country,

$$\frac{M}{P} = (\gamma C)^{1/\varepsilon} \tag{5}$$

$$\frac{M^*}{P^*} = (\gamma C^*)^{1/\varepsilon} \tag{6}$$

the national balance of payments equations for each country, stating that national consumption (on the left hand side) should equal national revenue (right hand side).

$$nPC = n(1-s)\left(aweq + (1-a)yp\right)) + ns(px + eqz) \tag{7}$$

$$(1-n)P^*C^* = (1-n)(1-s)q^*y^* + (1-n)s(\frac{p^*}{e}x^* + q^*z^*) \tag{8}$$

Equations (9)-(15) below give the market clearing condition for each good (all goods of the same type are symmetrical). The demand for an Out non-PTM good priced in the Out currency is thus given by equation (9) and equation (10) gives the demand for the good produced by an Out non-PTM firm that prices in the Core currency. Equation (11) gives demand for Core non-PTM goods. Demand for Out PTM goods on the Out market is given by (12) and for PTM goods from Out sold on the Core market by (13). (14) gives demand on the Out market for PTM goods from the Core and finally (15) gives demand for Core PTM goods on the Core market.

$$y = \left(\frac{p}{P}\right)^{-\rho} nC + \left(\frac{p}{eP^*}\right)^{-\rho} (1-n)C^* \tag{9}$$

$$w = \left(\frac{eq}{P}\right)^{-\rho} nC + \left(\frac{q}{P^*}\right)^{-\rho} (1-n)C^* \tag{10}$$

$$y^* = \left(\frac{eq^*}{P}\right)^{-\rho} nC + \left(\frac{q^*}{P^*}\right)^{-\rho} (1-n)C^* \tag{11}$$

$$x = \left(\frac{p}{P}\right)^{-\rho} nC \tag{12}$$

$$z = \left(\frac{q}{P^*}\right)^{-\rho} (1-n)C^* \tag{13}$$

$$x^* = \left(\frac{p^*}{P}\right)^{-\rho} nC \tag{14}$$

$$z^* = \left(\frac{q^*}{P}\right)^{-\rho} (1-n)C^* \tag{15}$$

3 Transmission of monetary shocks

We are interested in how the system (5) through (15) responds to monetary shocks. We will study effects on consumption, production and welfare from monetary surprises. Use price indexes from appendix 1, totally differentiate and let a^denote percentage change (dX/X) where X is the initial

zero-shock value of a given variable. The symmetry of equilibrium prices, consumption and production is used to solve the model and greatly simplifies expressions. All individual prices are fixed in the currency in which they are denominated.

3.1 The exchange rate, production and consumption

The exchange rate change depends on the change in nominal money in the two countries as given in equation (16) below. The derivation is outlined in appendix 2. We note that setting $a = 0$ implies that (16) collapses to the same expression as in Betts and Devereux (1996), setting $a = s = 0$ makes the expression identical to the expression for exchange rate in a one-period version of the Obstfeld and Rogoff (1995b) model.

$$\widehat{e} = \frac{\varepsilon(\widehat{M} - \widehat{M^*})}{(1-s)(\varepsilon + (1-na)(\rho - 1)) + s} \tag{16}$$

Pricing-to-market, $s > 0$, implies that the response of the exchange rate to monetary shocks will be greater than would be the case if the law of one price held. This is true if $\varepsilon > 2 - \rho$, that is if the consumption elasticity of money demand $(1/\varepsilon)$ is low enough relative to the price elasticity of demand. This can be expected to hold quite generally. ε is positive and estimates of ρ are typically larger than 2. This result is due to Betts and Devereux (1996). When $a = 0$ a differential monetary shock affects the exchange rate through the reallocation of demand $(\rho - 1)$ that takes place on the goods whose price is allowed to change to consumers $(1 - s)$. A higher degree of price setting in the Core currency, a, also implies a higher response of the exchange rate to differential money growth. When $a > 0$ a monetary shock tends to switch consumption from Core to Out goods to a lesser extent (equation (39) in appendix 2) and the response of the exchange rate is unambiguously higher. Now turn to production and consumption as a function of monetary surprises in the two countries.

A monetary expansion raises demand and hence production since production is demand driven in the short run when prices are pre-set at a level above marginal cost. After some algebra we can express the percentage response of Out country production (both total and average production) to Out and Core monetary shocks. We show in appendix 3 that the change in Out production can be

written as a function of the change in world money and the relative production difference, (17). Use (40) and (41) from appendix 3 and that in equilibrium $C = C^*$ to reach (18). Using (16) in (18) establishes (19).

$$\begin{aligned}
\widehat{Y} &= \varepsilon\left[\widehat{M}n + (1-n)\widehat{M}^*\right] + (1-n)\left[\widehat{Y} - \widehat{Y}^*\right] && (17)\\
&= \varepsilon\left[\widehat{M}n + (1-n)\widehat{M}^*\right] + (1-n)\left[\widehat{e}(1-s)(1-a)\rho\right] && (18)\\
&= \varepsilon\left[\widehat{M}n + (1-n)\widehat{M}^*\right] + (1-n)\left[\frac{(1-s)(1-a)\varepsilon\rho\left(\widehat{M} - \widehat{M}^*\right)}{(1-s)(\varepsilon + (\rho-1)(1-na)) + s}\right] && (19)
\end{aligned}$$

We note from (19) that Out production is a positive function of Out monetary policy. The intuition behind how a and s affect the production response to monetary shocks is perhaps easiest brought out by (18). The first term is the higher production that is induced by the increase in world demand. The second term gives the production switching effect due to the exchange rate change that is associated with asymmetric monetary policy in Out and Core. Think of the case where $\widehat{M}^* = 0$. The exchange rate depreciation will only shift production on the $(1-s)(1-a)$ goods whose prices are set in the Out currency. The shift in production will be dependent on how elastic demand is, ρ. The more elastic demand, the larger shifts in production.

We note that the effect of Core monetary surprises on Out production are ambiguous. The appreciation of the exchange rate leads to less demand for Out goods which counteracts the positive effect from increased global demand. The higher s and a are, the less likely is it that the appreciation will lead to lower Out production.

Now focus on consumption. Use (36) and (37) from appendix 2 and that in equilibrium $C = C^*$ to take us from (20) to (21). Finally, collecting terms and using (16) we establish Out consumption as a function of Out and Core monetary policy, (22).

$$\begin{aligned}
\widehat{C} &= \varepsilon\left[\widehat{M}n + (1-n)\widehat{M}^*\right] + (1-n)\left[\widehat{C} - \widehat{C}^*\right] && (20)\\
&= \varepsilon\left[\widehat{M}n + (1-n)\widehat{M}^*\right] + (1-n)\left[\widehat{e}((1-s)\rho + s + (1-s)(na - \rho na))\right]\left(-\widehat{P} + \widehat{P}^*\right) && (21)\\
&= \varepsilon\left[\widehat{M}n + (1-n)\widehat{M}^*\right] + (1-n)\left[\frac{\varepsilon\left(\widehat{M} - \widehat{M}^*\right)((1-s)(\rho-1)(1-na) + s)}{(1-s)(\varepsilon + (\rho-1)(1-na)) + s}\right] && (22)
\end{aligned}$$

We focus on (21). The first term is as before the increase in consumption due to the increase in world money. The second term gives the consumption switching effect due to changing relative prices as the exchange rate changes. The term within brackets gives the consumption switching due to the change in the exchange rate. Take the case of a monetary expansion in Out which leads to a depreciation of the exchange rate. When $a = 0$ consumption switching (dependent on ρ) will take place on the share of goods where the price to consumers is allowed to change, $(1 - s)$. These goods will become cheaper relative to goods priced in their own currency for Core consumers (and $(1 - s)$ of the imports from Core will become more expensive to Out consumers). The second term, s, is the higher consumption that is due to the wealth effect, the revenue that Out producers collect on sales of PTM goods on the Core market are worth more when translated into the Out currency. When $a > 0$ there is a wealth effect as well given by $(1 - s)na$. This moderates the consumption switching effect $(1 - s)na\rho$ that tends to lower the effect of a depreciation on Out consumption. Finally, the consumption switching is moderated by the movements in the aggregate price indexes, $-\widehat{P} + \widehat{P}^* = -\widehat{e}(1 - s)$.

In (22) we have collected terms and also taken into account how the exchange rate responds to differential money shocks. We see that a higher share of PTM goods increases the effect of Out monetary shocks on Out consumption and that a higher degree of Out goods priced in the Core currency, a, lowers the effect. Intuitively, the more goods that are priced in the Out currency, the more will Out monetary policy be able to affect Out consumption.

We discuss Core consumption and production when focusing on Core utility in section (3.2.3).

3.2 Welfare effects of monetary surprises

We go on to study the welfare effects of monetary policy. As in Obstfeld and Rogoff (1995a,b, 1996) there is a potential welfare-enhancing role for monetary policy. Prices are pre-set and there is an initial distortion due to monopoly pricing which implies that output is suboptimally low in equilibrium. This is seen by noting that in the decentralized equilibrium $h = \frac{(\rho-1)/\rho}{(\rho-1)/\rho+\eta}$ whereas the

socially efficient level of work is given by $h^{opt} = \frac{1}{1+\eta}$[9]. In the decentralized equilibrium the marginal value of additional consumption exceeds the value of foregone leisure. As all stake holders in firms are also consumers they would be better off if markups were lower but since each firm has monopoly power, the individual incentive is to charge a price that maximizes the private profit, not taking into account the externality bestowed on the economy. A monetary expansion raises consumption (equations (5) and (6)) , thus alleviating this distortion. Since price is above marginal cost in equilibrium it is profitable to accommodate the increased demand. The ability to study welfare effects is one advantage of this model compared to a Mundell-Fleming framework. As demonstrated by Obstfeld and Rogoff it can be quite misleading to equate effects on production and consumption individually with effects on welfare. Some terms may cancel, as is indeed the case in the simplest form of the model when $s = a = 0$.

We now proceed to find how the representative agent's utility is affected by monetary surprises. We will discuss how these welfare effects depend on price setting practices. Use (1) and log-linearize (steps given in appendix 4). We can then write the change in Out utility as

$$dU = \widehat{C} + \gamma \left(\frac{M}{P}\right)^{1-\varepsilon} \left(\widehat{M} - \widehat{P}\right) - \left(\frac{\rho - 1}{\rho}\right) \widehat{Y} \tag{23}$$

Following Obstfeld and Rogoff we define the real component of utility as

$$dU^R = \widehat{C} - \left(\frac{\rho - 1}{\rho}\right) \widehat{Y} \tag{24}$$

3.2.1 Out welfare and its own monetary policy

Substituting from (22) and (19) into (24) allows us to write the change in Out utility as a function of the percentage change in Out monetary policy (letting $\widehat{M}^* = 0$).

$$dU^R(\widehat{M}) = \widehat{M}\varepsilon \left[\frac{n}{\rho} + \frac{(1-n)s + (1-n)^2(1-s)(\rho-1)a}{(1-s)(\varepsilon + (\rho-1)(1-na)) + s}\right] \tag{25}$$

Equation (25) shows that the effectiveness of Out monetary policy increases when markets are segmented ($s > 0$). The first term is not dependent on s or a, this is the effect that would be present

[9] This is seen by maximizing $logY - \eta log(1 - AY)$.

if the law of one price held and all prices were set in the producers' currencies. The change in utility would be dependent only on the size of the monetary shock - not on which country it originates in (compare with (26)).[10] When markets are integrated the monetary expansion is coupled with Core goods becoming more expensive since the Out exchange rate depreciates and Core good prices are set in the Core currency.

Now, an additional share of $(1-n)s$ prices are set in the Out currency (Core PTM goods). This leads to a further increase in utility. We also see that a higher degree of Out non-PTM goods being priced in the Core currency (a) *increases* the welfare effect of Out's monetary policy. This result is perhaps counterintuitive. We noted above that increasing the share of non-PTM goods priced in the Core currency lead to Out production and consumption responding *less* to Out monetary policy than if a were lower. The intuition comes from referring back to (24) and noting that an increase in a affects the impact of an exchange rate change on consumption $(1-na)$ less than it does monetary transmission on production $(1-a)$. A monetary expansion implies that agents work harder and consume more. Agents like consumption but dislike work. As in Obstfeld and Rogoff it thus shows that effects on production and consumption can not be equated with welfare effects.

Figure 2 a, b and c below plot Out production, consumption and utility as functions of an Out monetary shock when $n = 0.2$, $\varepsilon = 1$ and $\rho = 6$. That is 20% of world population lives in Out, the consumption elasticity of money demand is unity and the price elasticity of demand is 6.[11]

Figure 2a, 2b, 2c about here

[10] This is the only effect present in Obstfeld and Rogoff (1995a,b, 1996). In equilibrium the marginal value of consumption is set to equal the marginal disutility of work. When $s = a = 0$ the welfare effects of consumption and production switching cancel when taken together. The only first-order effect on welfare is the one due to the relaxing of the distortion caused by monopoly pricing.

[11] We use the same (empirically sensible) parameter values as Betts and Devereux (1996) do when they calibrate the variance of the exchange rate. The implied markup is $1.2 = \rho/(\rho-1)$.

3.2.2 Should Out fear the Core?

Equation (26) below measures the Out welfare effects of a Core monetary policy shock (letting $\widehat{M} = 0$).

$$dU^R(\widehat{M}^*) = \widehat{M}^*\varepsilon\left[\frac{(1-n)}{\rho} - \frac{((1-n)s + (1-n)^2(1-s)(\rho-1)a)}{(1-s)(\varepsilon + (\rho-1)(1-na)) + s}\right] \tag{26}$$

The symmetry with respect to (25) is apparent. The first term is the change in utility that would result if there was no PTM. The presence of PTM means that the positive spill-over from a Core monetary expansion is lowered. Is the change in utility due to a Core monetary expansion positive when we allow for PTM? For simplicity set $a = 0$. From (26) we see that the effect will be positive if and only if

$$\varepsilon > (\rho - 1)\left(\frac{2s-1}{1-s}\right) \tag{27}$$

ε is positive and $\rho > 1$ so that (27) will necessarily hold for $s < 0.5$. For $s > 0.5$ we can have the result that a foreign monetary expansion lowers home welfare - this is the case if PTM is prevalent ($s > 0.5$), the price elasticity of demand is high (high ρ) and the consumption elasticity of money demand is high (low ε). The lower ε, the less must consumption respond to an increase in the real money supply for money markets to clear. The monetary expansion raises world demand so that Out works harder, but Out only gets to reap a limited amount of the benefits of lower prices as a large share of prices are fixed in their own currency. The higher the price elasticity of demand, the more will Out work in response to the monetary shock.

What about a? How should Out view expansionary monetary policy by the Core when a share a of prices for Out goods for which the law of one price holds are set in the Core currency? It is easily shown that the change in utility is always negative in a. This means that if the degree of PTM is large enough that Core monetary policy affects Out utility negatively, a higher degree of non-PTM goods priced in the Core currency (higher a) makes the response even more negative. Figure 3 a, b and c below illustrate the effects on Out production, consumption and welfare for the same parameter values as in Figure 2, $n = 0.2, \varepsilon = 1, \rho = 6$.

Figure 3a, 3b, 3c about here

3.2.3 Should the Core fear Out?

What about the other way around? Should the Core be fearful of competitive depreciations by Out? Equation (28) gives Core utility as a function of Out monetary policy (letting $\widehat{M}^* = 0$).

$$dU^{*R}(\widehat{M}) = \widehat{M}\varepsilon\left[\frac{n}{\rho} + \frac{na(1-s)(\rho-1) - sn}{(1-s)(\varepsilon + (\rho-1)(1-na)) + s}\right] \tag{28}$$

Setting a to zero gives us a mirror image of (26). Below we give the change in Core production and consumption as a function of the increase in Out money and the exchange rate which together form (28). This will help us with the intuition.

$$\widehat{Y}^* = \varepsilon n\widehat{M} - n\widehat{e}(1-s)(1-a)\rho \tag{29}$$

$$\widehat{C}^* = \varepsilon n\widehat{M} - n\widehat{e}((1-s)(\rho-1)(1-na) + s) \tag{30}$$

Start with (29). The first term is the increase in production that comes from higher global demand. When there is no PTM the associated shift in production $(\widehat{Y}^* - \widehat{Y})$, which is the second term, reduces to $n\widehat{e}\rho$. The appreciation of the Core currency associated with an Out monetary expansion implies that Core goods become more expensive for Out consumers and Out goods become cheaper for Core consumers. This effect leads to Core producing less. Both PTM (s) and pricing by Out in the Core currency (a) serve to reduce this production switching effect.

Now turn to (30). The second term now is $(\widehat{C}^* - \widehat{C})$, the consumption switching effect. A share s of Out goods will not become cheaper to Core consumers, this lowers the positive spill-over relative to the no PTM case. Also on the non-PTM goods will there be less consumption switching due to the share na of goods that are priced in the Core currency and will not become cheaper. The total utility change, (28), is increasing in a reflecting that monetary transmission on consumption is affected less than production by an increase in a. A higher a lessens the beggar-thy-neighbor effect of an Out monetary expansion. Figure 4a, b and c plot Core production, consumption and utility as a function of Out monetary policy using the same parameter values as in Figures 2 and 3.

Figure 4a, 4b, 4c about here

We see that for a high degree of PTM Out monetary surprises may affect Core negatively. To the extent that our model is applicable to a future EMU we see that both increasing market integration (lower s) and increasing pricing in the Core currency (higher a) tend to make the welfare spill-over from Out monetary policy to Core positive.

4 Concluding Comments

The framework that we have used in this paper is very stylized and we view the results as preliminary. Nevertheless we would like to sum up the findings of the present paper. The paper was motivated by issues regarding the relationship between "ins" (Core) and "outs" of an EMU. Should the Core fear monetary expansion by Out? The answer that this paper gives is, maybe today, but there will be less grounds for fear tomorrow. Both increased market integration (lower s in our model) and more use of the Core currency by Out (for goods for which the law of one price holds, higher a in our model) work towards creating positive welfare spill-overs on Core utility from Out monetary policy. Increased price setting in the Core currency by Out firms (higher a in our model) works towards creating negative welfare spill-overs from Core monetary policy onto Out utility. There would be grounds for Out to fear expansionary monetary policy by the Core, also tomorrow.

We also noted that (holding a constant) a lower s, increased market integration, decreases the extent to which Out monetary policy can affect Out utility. This should have implications for how the attractiveness of joining a monetary union evolves over time. The classical case for a monetary union builds on a trade-off between microeconomic benefits on the one hand and the loss of not having access to an independent monetary policy in the face of asymmetric shocks on the other hand. Increased market integration, other things equal, would thus decrease the value of having access to an independent monetary policy. Note that such an argument for "wait-and-integrate" does not depend on changing patterns of trade as in Frankel and Rose (1997). Frankel and Rose show that stronger trade ties between two countries have historically been associated with a higher correlation between business cycles in those countries. The argument of Frankel and Rose is that if the creation

of an EMU leads to stronger trade ties between members this should lead to more correlated business cycles and therefore less need for an independent monetary policy. The mechanism that we point to here is that increasing goods market integration will affect the extent to which monetary policy can affect utility. The argument does not rest on changing trade flows. Of course, we do not fully understand the mechanisms that allow prices on different national markets to differ to the extent that they typically do. However it seems reasonable to expect that a project such as the EU common market will make it harder for firms to segment national markets. The abolishing of formal trade restrictions as well as harmonization of technical standards and legal rules should all work in this direction.

The model is extendable in a number of directions and can be used to study other issues than we have done now. Study of intertemporal concerns, productivity shocks (to A) as well fiscal policy shocks should be straightforward although perhaps messy. Another important issue that we have disregarded concerns the time-inconsistency of monetary policy. Rational price setters will recognize the incentive to expand the monetary base and incorporate this when setting prices. In the absence of some mechanism that lets the policy maker commit to not changing the monetary stock this should lead to an inflationary bias in equilibrium. The result of this paper that a monetary expansion raises domestic utility should not be seen as an argument for a systematic expansion of the monetary base. Our motivation is rather the possibility to use monetary policy to counter some shock. Just as the kind of model that we use in this paper should be extendable to study credibility issues it should be extendable to the study of international policy coordination. See e.g. Canzoneri and Henderson (1991) or Persson and Tabellini (1995).[12] Since the international spill-overs change with changing

[12]The work that we are aware of on credibility and international monetary policy coordination relies on postulated social welfare or "loss" functions that do not build from microfoundations. The basic story is that the policymaker would like to raise output above its equilirium level by surprise inflation (which he does not like). He will do so to the point where the marginal utility of output equals the marginal disutility of inflation. In the kind of world that we study in this paper the policymaker would wish for a big enough monetary surprise to reach first-best, there is no trade-off against a dislike for inflation. Another issue that complicates the application of the kind of model used in this paper to the study of credibility or coordination then is that the linearizations that one relies on are only valid

price setting behavior, the policy coordination game would also change.

Empirical studies of international monetary transmissions should also be valuable. For the issues we have discussed here, monetary transmission between Canada and US regions that have extensive trade with Canada should be especially interesting.

We should also comment on the PTM assumption. Obstfeld and Rogoff (1996, p. 711) study a similar framework as the one above but with flexible output prices (but pre-set wages). They note that the model features the same demand elasticities in both countries so that equilibrium prices should be equal even if markets are separated. There will be full pass-through of exchange rate changes onto import prices since it is assumed that the demand elasticity is constant.[13] If prices were flexible we would have full pass-through of exchange rates onto prices. So we would see no PTM. However when prices are pre-set and markets are separated, the law of one price does not hold. So PTM in the above model depends on nominal rigidities and not on properties of the demand schedule. In principle one could also study a "pure" PTM case with different demand elasticities in the different national markets. However, the symmetry of demand elasticities contributes greatly to the (relative) simplicity of the model.

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for small shocks.

[13] Pass-through depends on how the demand elasticity changes as the price changes. See e.g. Feenstra, Gagnon and Knetter (1996).

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Appendix 1

The consumption index that enters Out utility is given by $C = \left[\int_0^1 c(i)^{\frac{\rho-1}{\rho}} di\right]^{\frac{\rho}{\rho-1}}$ where $c(i)$ denotes the representative individuals consumption of good i. The definition of the Core consumption index is exactly analogous (specifically ρ is the same.) Each consumer's demand for a good i is given in standard Dixit-Stiglitz fashion $c(i) = \left(\frac{\vartheta(i)}{P}\right)^{-\rho} C$ where $\vartheta(i)$ is the price of the good i.

Rewrite the budget constraint as $M = Wh + \pi + M_0 + TR - PC$ and substitute into the utility function, (1). Maximize utility over h and C. We can then easily solve for the optimal demand for

real balances (M/P) and time worked.

$$\frac{M}{P} = (\gamma C)^{1/\varepsilon} \tag{31}$$

$$\frac{\eta}{1-h} = \frac{W}{PC} \tag{32}$$

Setting price as to maximize profit, equations (2)-(4), we establish that

$$p(i) = eq(i) = \frac{\rho}{\rho - 1}\frac{W}{A}\ \forall i \tag{33}$$

The price index in the Out country is given by (where we have used that in equilibrium prices are equal since ρ, the demand elasticity is the same for all goods).

$$P = \left[\begin{array}{c} n(1-s)a(eq)^{1-\rho} + n(1-s)(1-a)p^{1-\rho} + nsp^{1-\rho} + (1-n)(1-s)(eq^*)^{1-\rho} \\ +(1-n)s(p^*)^{1-\rho} \end{array} \right]^{\frac{1}{1-\rho}} \tag{34}$$

The terms are in order; the Out non-PTM goods that are priced in the Core currency, the Out non-PTM goods priced in the Out currency, Out PTM goods, Core non-PTM goods, Core PTM goods. Now solve for equilibrium when prices are flexible. Use (31) in (32) and that equilibrium consumption is equal to production $C = Y = Ah$ to find the equilibrium time worked $h = \frac{(\rho-1)/\rho}{(\rho-1)/\rho+\eta}$. We also note that in a flexible price equilibrium Purchasing Power Parity will hold so that $P = eP^*$. Using (31) and its Core counterpart we can thus write $e = \frac{M}{M^*}\left(\frac{C^*}{C}\right)^{1/\varepsilon}$.

The situation for the Core country is exactly analogous except for the price index which is given by

$$P^* = \left[ns(q)^{1-\rho} + n(1-s)a(q)^{1-\rho} + n(1-s)(1-a)\left(\frac{p}{e}\right)^{1-\rho} + (1-n)(q^*)^{1-\rho}\right]^{\frac{1}{1-\rho}} \tag{35}$$

That is in order of appearance; Out PTM goods, Out non-PTM goods priced in the Core currency, Out non-PTM goods priced in the Out currency, goods produced in Core (and priced in Core).

Appendix 2

In this appendix we derive the response of the sticky-price equilibrium to monetary shocks. Totally differentiate the Out price index while holding prices fixed in the currency in which they are set. We then establish that the percentage change in the home price index as a function of exchange

rate changes is given by $\widehat{P} = (1-s)(an + (1-n))\widehat{e}$. Following the same procedure we can express the percentage change in the Core price index as $\widehat{P}^* = -n(1-s)(1-a)\widehat{e}$. Differentiate the balance of payments equations (7) and (8) and use the demand equations, (9) through (15). We can then write

$$\begin{aligned}\widehat{C} &= \frac{\left(\rho\widehat{P} + \widehat{C}\right) nC + \left(\rho\widehat{P}^* + \widehat{C}^*\right)(1-n)C^* + \widehat{e}(C^*(1-n)(\rho - s\rho + s) + Can(1-s)(1-\rho))}{nC + (1-n)C^*} \\ &\quad -\widehat{P} \qquad (36)\end{aligned}$$

$$\widehat{C}^* = \frac{\left(\rho\widehat{P} + \widehat{C}\right) nC + \left(\rho\widehat{P}^* + \widehat{C}^*\right)(1-n)C^* - \widehat{e}(snC + Cn\rho(1-s))}{nC + (1-n)C^*} - \widehat{P}^* \qquad (37)$$

We can then establish that

$$\widehat{C} - \widehat{C}^* = \widehat{e}((1-s)(\rho-1)(1-na) + s) \qquad (38)$$

where we have used that in equilibrium $C = C^*$. Linearize around the equilibrium exchange rate we can establish that $\widehat{P} - \widehat{P}^* = \widehat{M} - \widehat{M}^* - \frac{1}{\varepsilon}\left(\widehat{C} - \widehat{C}^*\right)$. Using the results for price indexes we establish that

$$\widehat{e}(1-s) = \widehat{M} - \widehat{M}^* - \frac{1}{\varepsilon}\left(\widehat{C} - \widehat{C}^*\right) \qquad (39)$$

Using (38) in (39) we establish equation (16).

Appendix 3

Note that the change in world consumption (and analogously production) is given by $\widehat{C}^W = n\widehat{C} + (1-n)\widehat{C}^*$. We can thus express Out consumption as $\widehat{C} = \widehat{C}^W + (1-n)(\widehat{C} - \widehat{C}^*)$. Using results from appendix 1 we can establish that $\widehat{C}^W = \varepsilon\widehat{M}^W$. Using this and the result for consumption difference from appendix 2 we establish (20).

We now turn to production. (17) is established following the same logic as for consumption. Total production is given by $nY = n(1-s)((1-a)y + aw) + ns(x+z)$. Log-linearize Y and Y^* to reach

$$\widehat{Y} = \frac{nC\left(\widehat{C} + \rho\widehat{P}\right) + (1-n)C^*\left(\widehat{C}^* + \rho\widehat{P}^*\right) + (1-s)\rho\widehat{e}((1-n)C^*(1-a) - nCa)}{nC + (1-n)C^*} \qquad (40)$$

$$\widehat{Y}^* = \frac{nC\left(\widehat{C} + \rho\widehat{P}\right) + (1-n)C^*\left(\widehat{C}^* + \rho\widehat{P}^*\right) - (1-s)nC\rho\widehat{e}}{nC + (1-n)C^*} \qquad (41)$$

In the same fashion we find $\widehat{C}^*$ and $\widehat{Y}^*$.

Appendix 4

Totally differentiating the utility function (1) yields $dU = \widehat{C} + \gamma \left(\frac{M}{P}\right)^{1-\rho} (\widehat{M} - \widehat{P}) - \eta \frac{1}{1-h} dh$. Use that $Y = Ah$ and that in equilibrium $h = \frac{(\rho-1)/\rho}{(\rho-1)/\rho+\eta}$ and finally disregard the term that depends on real balances to establish that $dU^R = \widehat{C} - \left(\frac{\rho-1}{\rho}\right) \widehat{Y}$.

Figure 1
Origin and price setting of firms

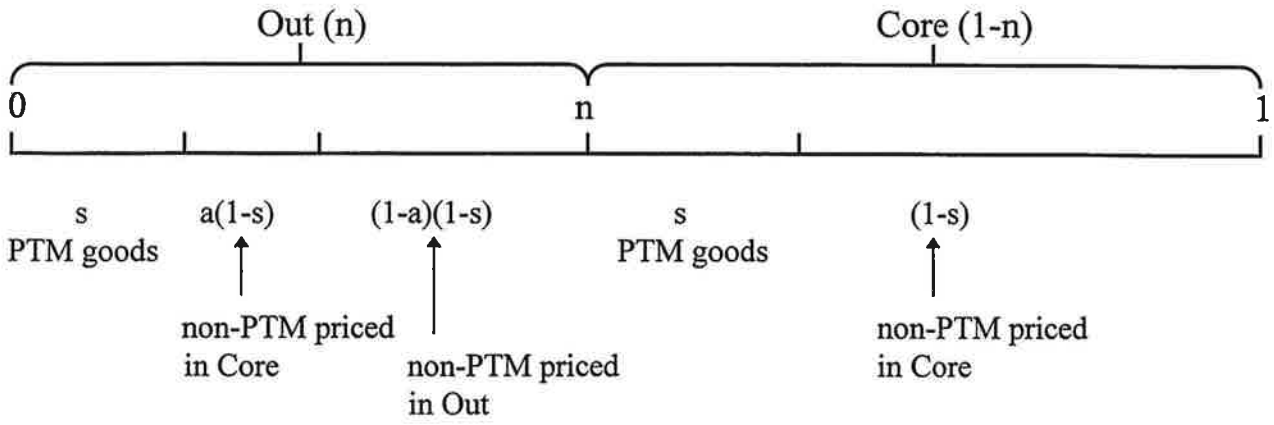


Figure 2a. Out production as a function of Out monetary shocks

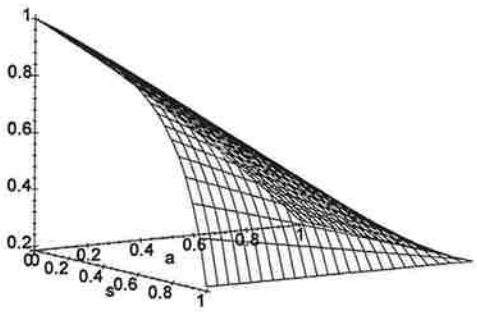


Figure 2b. Out consumption as a function of Out monetary shocks

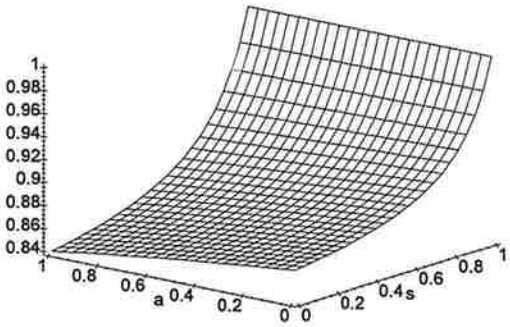


Figure 2c. Out utility as a function of Out monetary shocks.

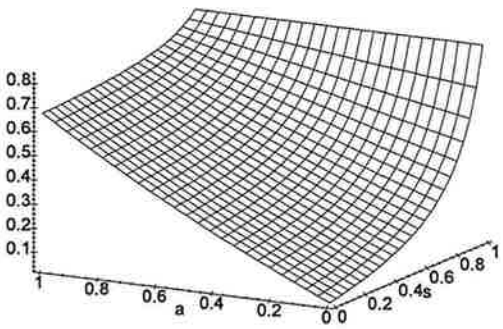


Figure 3a. Out production as a function of Core monetary shocks

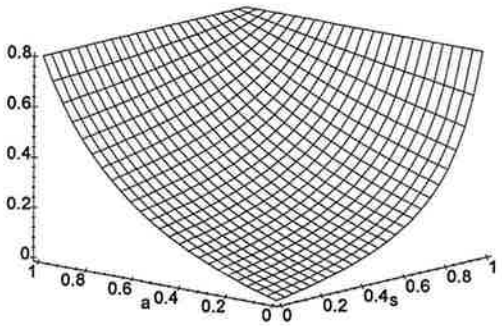


Figure 3b. Out consumption as a function of Core monetary shocks

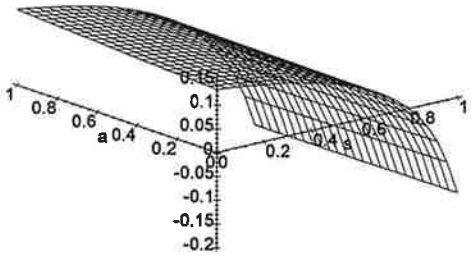


Figure 3c. Out utility as a function of Core monetary shocks.

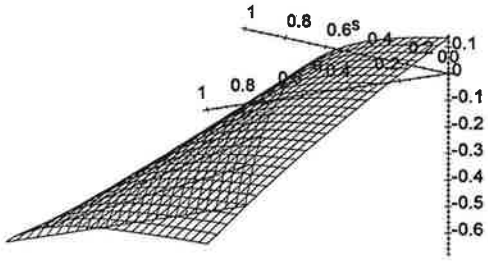


Figure 4a. Core production as a function of Out monetary shocks

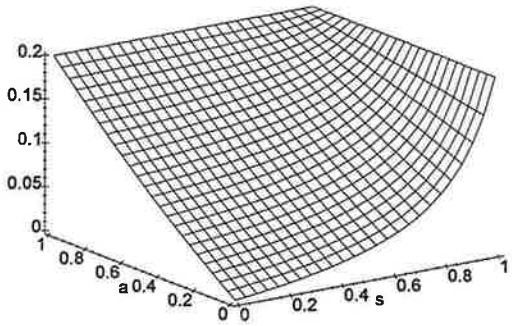


Figure 4b. Core consumption as a function of Out monetary shocks

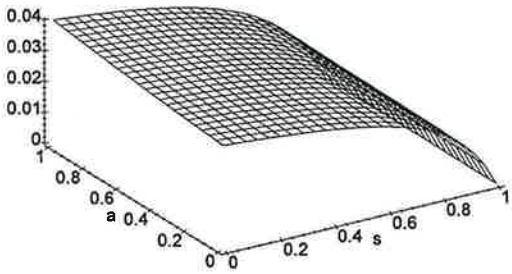
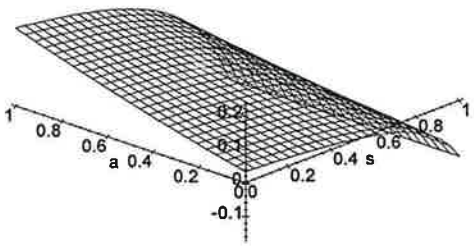


Figure 4c. Core utility as a function of Out monetary shocks



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