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Price setting in international markets

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Kiel Working Paper No. 915

Price setting in international markets

by

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Abstract

In this paper, an oligopolistic framework in which goods and market characteristics can be varied parametrically, is used to explain pass-through of prices as a reaction to exchange rate or cost changes. Price setting is compared between different markets for the same product and between different producers in the same market. The aim of this paper is to account for these price differentials by analyzing the contributions of all relevant factors in order to explain differences across sectors.

Keywords: Exchange rate, pass-through, pricing to market

JEL-Classification: D43, D21, F10

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Contents

I. INTRODUCTION AND BASIC CONCEPTS	3
II. THE ANALYTICAL FRAMEWORK	5
A. MONOPOLY.....	8
B. DUOPOLY.....	21
C. OLIGOPOLY.....	36
III. CONCLUSION	42
IV. BIBLIOGRAPHY	45
V. APPENDIX	46

I. Introduction and basic concepts

The interest in examining prices from an international perspective is still at a high level. From the theoretical point of view, several competing concepts are predominant in this area: Firstly, the *law of one price* suggests that prices for identical goods should be equal when measured in the same currency. If the law of one price holds for all products, then the purchasing power parity theory of the exchange rate in its absolute form will be valid. Secondly, the concept of *pass-through* is about how much of an exchange rate change the exporter transmits to export prices in the currency of the importing country. It is therefore of interest to look at the consequences if the exchange rate alters relative production costs between two producers. If a shock to the exchange rate, or alternatively, to the cost of one of the producers occurs, the law of one price poses certain restrictions on pass-through behaviour. Suppose that both producers leave their home market prices unaltered. Either the producer for whom the currency has appreciated keeps his price in the destination market constant, implying that pass-through is zero, or he raises this price by a fraction of the relative appreciation, which results in positive but incomplete pass-through, or he even passes through the full amount of the shock. In the first case of zero pass-through, the law of one price across producers holds, but not across countries, since the producer lowers the export price in his own currency. The relation of export to home market price therefore falls. This market-specific price adjustment when prices are compared in the same currency is termed *pricing-to-market*. At the other extreme with full pass-through we observe no pricing-to-market and the law of one price holds across countries, but not across producers. For the law of one price to be valid in both forms, it is necessary that also domestic prices adjust to exchange rate changes. However, the quite restrictive assumptions necessary for this are that products be homogeneous and that transportation and resale costs are nonexistent. In practice, much of the trade between industrial countries is in differentiated products, giving rise to price differences across producers. Also a substantial amount of value added from the sale of industrial products is from additional services linked to the purchase of that products, which are localized at the

country of sale and therefore inhibit resale to other countries. This makes pricing-to-market possible. The questions that arise are: firstly, what factors contribute to high and what factors to low pass-through; secondly, how the amount of pricing-to-market can be derived from the profit-maximizing behaviour of producers; thirdly, under what conditions does profit maximization in conjunction with a specific assumption on market behaviour result in pricing rules for different suppliers in the same market which are incompatible with the law of one price across producers?

Another interesting question is whether pricing-to-market is indicative of a high or low degree of competition. On the one hand, it may be argued that more competition forces producers to more adjust their market-specific markups over marginal cost because the scope for price differentials across producers is smaller. This will lead to more pricing-to-market, implying a much smoother evolution of prices from the view of the importing country, but at the expense of creating market-specific price gaps for the producer. On the other hand, under the extreme form of perfect competition and with perfect arbitrage it follows that all prices are identical so that the law of one price holds without any scope for pricing-to-market. In this paper all relevant pricing concepts are analyzed in a unified framework and the impact of various demand and product market characteristics will be investigated, so that intersectoral differences in pricing behaviour can be explained.

Discussion of pricing-to-market had been initiated by Krugman (1986) and was complemented by a variety of authors, e.g. Knetter (1993,1995) and Athukorala and Menon (1994). For a general discussion of different methodological approaches in this area, see Goldberg and Knetter (1997). A good overview with regard to the literature on purchasing power parity is also given in Rogoff (1996).

Concerning the theoretical framework, different assumptions for market structure and behaviour have been used by Dornbusch (1987), who derives the implications when the exchange rate is incorporated into some standard theoretical frameworks for price determination based on Cournot and Dixit-Stiglitz. Giovannini (1998) draws on a model of monopolistic competition and also allows for uncertainty. Froot and Klemperer (1989) build a two-period model of an international duopoly and distinguish between

temporary and permanent exchange rate changes. However, these contributions treat price elasticities of demand as exogenous variables rather than giving an account of their determinants. Feenstra, Gagnon and Knetter (1996) highlight the role of market share for pass-through if utility is a CES function, but they do not allow explicitly for other market characteristics. A recent paper by Bodnar, Dumas and Marston (1997) investigates price and quantity competition allowing for different degrees of substitutability in product space. Their paper focuses on pass-through and exposure, but does not cover the aspect of pricing-to market since only one market is analyzed.

This paper generalizes the theoretical approach of Bodnar, Dumas and Marston (1997) to more than two producers in the framework of a general demand system which combines several relevant determinants in a single framework. The degree of substitutability can be varied parametrically, and it thus incorporates the pure case of monopoly when there is no substitution. At the other extreme, one approaches perfect substitution. Competition and price setting in several markets is modelled simultaneously so that the relevance of both pricing-to-market and variation in relative producer prices in the same market can be underpinned theoretically.

II. The analytical framework

The linear demand schedule for modelling product differentiation is quite common in the industrial organization literature and can be derived from a quadratic utility function. This specification is similar to that of Shaked and Sutton (1990). The linearity in prices is justified since only marginal changes are analyzed. In order to cover an arbitrary range of own and cross price elasticities of demand, a second parameter, the reservation price, is used as an additional tool to vary price elasticities with a given degree of substitutability.

Consider a representative agent who consumes N varieties of a heterogenous good and spends the rest of his money on all other goods, the utility of which is measured in monetary units. x_i denotes the quantity purchased of variety i , with each variety being

produced by only one firm. The consumer maximizes his utility function in each period, which is quadratic in consumption of each single variety, and all N varieties are treated symmetrically:

$$[1] \quad U_t(x_{1t}, x_{2t}, \dots, x_{Nt}, x_{1,t-1}, x_{2,t-1}, \dots, x_{N,t-1}) = \sum_i (\alpha x_{it} - \beta x_{it}^2 + \gamma x_{it} x_{i,t-1}) - \beta \sigma \sum_{i \neq j} x_{it} x_{jt} + M_t, \quad \text{where}$$

$$0 \leq \sigma < 2.$$

The marginal utility of M is constant, so the optimal quantities of the heterogenous good only depend on their prices and the number of varieties, provided income is such that an interior solution exists (i.e. $M > 0$). This utility function has been chosen because it incorporates several useful properties: utility is increasing in the number of varieties, analogous to the love of variety approach of Dixit-Stiglitz. Note that as N increases, the fourth term, which reflects the cross effects over all varieties, gets a larger weight, so utility is rising only underproportionally in N . This term also implies that each variety's own price elasticity of demand rises with N , reflecting the plausible assumption that demand is becoming more elastic the larger the number of substitutes.

The third term was added to account for intertemporal interdependencies on the side of consumption. Specifically, it is assumed that marginal utility of consumption of a certain variety is proportional to consumption the period before. This can be due to the fact that consumers get used to that variety or incur switching costs (see, for example, Klemperer, 1995). In this framework, hysteretic effects of exchange rate shocks can be handled consistently without relying on the sunk cost hypothesis if N is treated as an endogenous variable, which responds to large and persistent exchange rate misalignments. Producers who are already in the market enjoy an advantage over newcomers due to the positive impact of past quantities on demand. Small and temporary exchange rate changes do not cause exit or entry into a market as opposed to large misalignments, which bring about changes in market structure and have an additional impact on price setting. In this paper, however, N is exogenous. The following pass-through analysis can thus be interpreted to apply for exchange rate changes which are too small to cause entry or exit.

Utility maximization by consumers yields demand for variety i :¹

$$[2] \quad x_{i,t} = \frac{\alpha(2-\sigma) + \sigma \sum_{j \neq i} p_{j,t} - p_{i,t}(2 + \sigma(N-2)) + \gamma(2 + \sigma(N-2))x_{i,t-1} - \sigma\gamma \sum_{j \neq i} x_{j,t-1}}{\beta(2-\sigma)(2 + \sigma(N-1))}$$

where $0 \leq \sigma < 2$.

Consumers and producers are located in two countries, A and B . It is assumed that consumers can not trade products between national markets, but have to buy them either from domestic producers at the domestic price or from the other country's exporters at their export price. This assumption that reimports are excluded can be justified by national product standards or additional services which are included in the selling price of the product, but consumers can only benefit from them in the country of purchase.

Let there be n^A producers in A and n^B producers in B , and $N = n^A + n^B$. The producer's objective is to maximize his intertemporal value function Π as the sum of all discounted profits of each period, restricted for simplicity to the case of two periods, where λ denotes the discount rate. The subscripts 1 and 2 indicate the point of time. The first superscript denotes the country of the firm and the second that of the consumer:

$$[3] \quad \Pi_i^{rs} = \Pi_{i1}^{rs} + \lambda^r \Pi_{i2}^{rs} = (q_{i1}^{rs} - c_1^r)x_{i1}^{rs} + \lambda^r [(q_{i2}^{rs} - c_2^r)x_{i2}^{rs}] \quad \lambda^r < 1,$$

$$r = A, B, \quad s = A, B, \quad i = 1, \dots, n^r.$$

Note that all prices p are denoted the in currency of the destination country and q in the currency of the country of production. Both prices coincide for sales in the respective home market, but have to be transformed by the exchange rate e , which is defined in terms of units of currency of A needed to buy one unit of currency of country B . For the sake of simplicity, marginal costs are constant and for now are assumed not to depend on prices of imported goods. From the general formula [2] some special cases emerge depending on the values selected for n^A and n^B . As a starting point, I discuss the

¹ Since the subsequent analysis of exchange rate and cost changes starts from the symmetry condition of equal costs and thus equal prices of all producers and since prices are only varied marginally, demand for each variety is strictly positive for sufficiently small γ and for σ in the range given above.

simple case of the monopolist's pricing rule first, and then consider the much more sophisticated case of pricing in an oligopolistic market structure.

A. Monopoly

Assume that there is a single firm located in country A that produces for A and B, implying that $n^A = 1$ and $n^B = 0$. Since there is only one producer the subscript i vanishes. Demand in period t for the representative consumer in country A and B reduces to

$$[4] \quad x_t^{As} = \frac{\alpha - p_t^{As} + \gamma x_{t-1}^{As}}{2\beta}, \quad s = A, B.$$

Now consider the two period intertemporal profit function defined above. Period 2 prices are obtained by static optimization, whereas in the first period the monopolist has to care about demand and profit in the following period when setting his price. It is also assumed for simplicity that demand in the first period does not depend on previous sales, which are thus set to zero in the general utility function.² The profit-maximizing prices and corresponding quantities and profits for the two markets in period 2 are:

$$[5] \quad \bar{p}_2^{AA} = \frac{\alpha + c_2^A + \gamma x_1^{AA}}{2}, \quad \bar{p}_2^{AB} = \frac{\alpha + c_2^A/e_2 + \gamma x_1^{AB}}{2},$$

$$[6] \quad \bar{x}_2^{AA} = \frac{\alpha - c_2^A + \gamma x_1^{AA}}{4\beta}, \quad \bar{x}_2^{AB} = \frac{\alpha - c_2^A/e_2 + \gamma x_1^{AB}}{4\beta},$$

$$[7] \quad \bar{\pi}_2^{AA} = \frac{(\alpha - c_2^A + \gamma x_1^{AA})^2}{8\beta}, \quad \bar{\pi}_2^{AB} = \frac{e_2(\alpha - c_2^A/e_2 + \gamma x_1^{AB})^2}{8\beta}.$$

Concerning future values for exchange rates and costs, rational expectations and the absence of uncertainty are assumed when determining first period prices. Thus, the first order conditions are:

² This assumption is justified since an extension of analysis to more than two periods would not change the qualitative results.

$$[8] \quad \frac{\partial \Pi^{AA}}{\partial p_1^{AA}} = x_1^{AA} + (p_1^{AA} - c_1^A) \frac{\partial x_1^{AA}}{\partial p_1^{AA}} + \lambda^A \frac{\partial \bar{\Pi}_2^{AA}}{\partial x_1^{AA}} \frac{\partial x_1^{AA}}{\partial p_1^{AA}} = 0 \text{ and}$$

$$[9] \quad \frac{\partial \Pi^{AB}}{\partial p_1^{AB}} = e_1 x_1^{AB} + (e_1 p_1^{AB} - c_1^A) \frac{\partial x_1^{AB}}{\partial p_1^{AB}} + \lambda^A \frac{\partial \bar{\Pi}_2^{AB}}{\partial x_1^{AB}} \frac{\partial x_1^{AB}}{\partial p_1^{AB}} = 0 ,$$

where $\frac{\partial \bar{\Pi}_2^{AA}}{\partial x_1^{AA}}, \frac{\partial \bar{\Pi}_2^{AB}}{\partial x_1^{AB}} > 0$ according to [7].

The last two terms in [8] and [9] are negative, so quantity is higher and price is lower the larger the direct price elasticity of demand and the more next period's profit is increasing in first period quantity. Equilibrium prices, quantities and profits in period 1 are:

$$[10] \quad \bar{p}_1^{AA} = \frac{8(\alpha + c_1^A)\beta^2 - \lambda\alpha\gamma^2 - 2(\alpha - c_2^A)\lambda\beta\gamma}{16\beta^2 - \lambda\gamma^2} ,$$

$$[11] \quad \bar{p}_1^{AB} = \frac{8(\alpha e_1 + c_1^A)\beta^2 - \lambda\alpha\gamma^2 e_2 - 2(\alpha e_2 - c_2^A)\lambda\beta\gamma}{16\beta^2 e_1 - \lambda\gamma^2 e_2} ,$$

$$[12] \quad \bar{x}_1^{AA} = \frac{4(\alpha - c_1^A)\beta - (\alpha - c_2^A)\lambda\gamma}{16\beta^2 - \lambda\gamma^2} ,$$

$$[13] \quad \bar{x}_1^{AB} = \frac{4(\alpha e_1 - c_1^A)\beta - (\alpha e_2 - c_2^A)\lambda\gamma}{16\beta^2 e_1 - \lambda\gamma^2 e_2} .$$

For equilibrium values to be positive, it must hold for the reservation price α that $\alpha \geq c_1^A$ for the home and $\alpha e_1 \geq c_1^A$ for the foreign market and that γ is sufficiently small, a necessary condition being that $\gamma^2 < 16\beta^2/\lambda$.

1. Exchange rate changes

Since the focus of this analysis is on how prices react to exchange rate or cost changes, the exact nature of the exchange rate process has to be specified. It is assumed that the exchange rate starts from its equilibrium cost based purchasing power parity value which is equal to 1 when local currency production costs are normalized to one in either country. The first exchange rate shock occurs in period 1, and e either remains constant in period 2 or returns to its original value.

Temporary change of the exchange rate

Assume that the exchange rate shock lasts for only one period, i.e. $e_0 \neq e_1$ and $e_2 = e_0$. Since the discount rate λ^A is constant in currency of A ($\lambda^A = \lambda$), the relative value of future profit to current profit for a producer in A does not change with the exchange rate. Consequently, the selling price for the home country does not change with e :³

$$[14] \quad \frac{\partial p_1^{AA}}{\partial e_1} = 0 \quad \text{and} \quad [15] \quad E(p_1^{AA}, e_1) = 0$$

All elasticities are evaluated at e and c normalized to unity. For the export market B, the absolute and relative movement of the consumption price are:

$$[16] \quad \frac{\partial p_1^{AB}}{\partial e_1} = \frac{-8\beta^2 [16\beta^2 - \lambda\alpha\gamma^2 - 4(\alpha-1)\lambda\beta\gamma]}{(16\beta^2 - \lambda\gamma^2)^2},$$

$$[17] \quad E(p_1^{AB}, e_1) = \frac{-8\beta^2 [16\beta^2 - \lambda\alpha\gamma^2 - 4(\alpha-1)\lambda\beta\gamma]}{(16\beta^2 - \lambda\gamma^2) [8(\alpha+1)\beta^2 - \lambda\alpha\gamma^2 - 2(\alpha-1)\lambda\beta\gamma]}.$$

Since the reservation price can not be lower than unit costs in internal equilibrium, the range for α is $\alpha \geq 1$. For $\lambda < 1$ and for positive equilibrium prices and quantities the denominator must always be positive, whereas the numerator is negative for small γ .

³ In the following the bar denoting equilibrium values will be suppressed.

$$\frac{\partial p_1^{AB}}{\partial e_1} < 0 \quad \text{and} \quad E(p_1^{AB}, e_1) < 0 .$$

If the exporter's currency depreciates (e rises), then prices in the destination market B fall, measured in local currency. For a small enough γ , the absolute value of the pass-through elasticity is smaller than one, resulting in incomplete pass-through.

$$[18] \quad -1 < E(p_1^{AB}, e_1)$$

A sufficient condition for pass-through to be incomplete is that $\gamma^2 < 8\beta^2/\lambda$.⁴ Throughout this paper, it will always be assumed that the value of γ is small compared to all other parameters when the sign of an expression is computed. In particular, for the special case of no intertemporal spillover term in consumer demand ($\gamma=0$), one obtains

$$\left. \frac{\partial p_1^{AB}}{\partial e_1} \right|_{\gamma=0} = -0.5 \quad \text{and} \quad E(p_1^{AB}, e_1) \Big|_{\gamma=0} = \frac{-1}{\alpha + 1} .$$

For $\gamma=0$, one can easily verify that there is always a certain amount of pass-through for any finite value of α . Since α must be at least one the limit for pass-through is minus one half, and the amount of pass-through is decreasing in α :

$$[19] \quad -0.5 \leq E(p_1^{AB}, e_1) \Big|_{\gamma=0} < 0 ,$$

So far, with γ equal to zero, prices are determined only by the movement of costs, valued in the currency of the importing country. However, for γ greater than zero the interest rate effect as a second determinant is also working on pass-through. The reason is that the discount rate relating profits from foreign currency between period one and two in terms of the importer's currency depends on e_t as follows:

$$[20] \quad \lambda^B = \frac{e_2}{e_1} \lambda^A .$$

⁴ The square bracket in the numerator of [17] is always smaller than that of the denominator. If the sufficient condition holds, $8\beta^2$ is also smaller than the parenthesis of the denominator.

Suppose that currency A depreciates temporarily (e_t rises), which would reduce the value of expected second period revenue relative to the first if, as assumed, λ^A is constant, and this induces the monopolist to more exploit first period revenue by raising p_1 above the price he would set for zero γ . When covered interest parity holds, λ^B can also be interpreted as the discount rate in country B (see Froot and Klemperer(1989)).

Permanent change of the exchange rate

Next I consider the case $e_0 \neq e_1 = e_2 \equiv e$.

As above, there is no change in the home market price when the exchange rate change is permanent. For the price reaction in the foreign market, one obtains:

$$[21] \quad \frac{\partial p_1^{AB}}{\partial e} = \frac{-2\beta(4\beta + \lambda\gamma)}{16\beta^2 - \lambda\gamma^2} \quad \text{and}$$

$$[22] \quad E(p_1^{AB}, e) = \frac{-2\beta(4\beta + \lambda\gamma)}{8(\alpha + 1)\beta^2 - \lambda\alpha\gamma^2 - 2(\alpha - 1)\lambda\beta\gamma}$$

The pass-through elasticity is always negative for the range of parameters as defined above. For $\gamma = 0$, pass-through is again

$$[23] \quad E(p_1^{AB}, e) \Big|_{\gamma=0} = \frac{-1}{\alpha + 1}$$

The differential behaviour between temporal and permanent exchange rate effects can be seen as the producer's reaction to an expected change in the future exchange rate e_2 , as it must be the case that

$$[24] \quad E(p_1^{TS}, e) = E(p_1^{TS}, e_1) + E(p_1^{TS}, e_2)$$

The producer's reaction to a change only of the spot exchange rate e_1 plus the single effect of an expected future exchange rate change e_2 is the same as the impact of an exchange rate change perceived to be permanent (see Froot and Klemperer, 1989). The role of expectations with regard to the future exchange rate can also be shown separately:

$$[25] \quad \frac{\partial p_1^{AB}}{\partial e_2} = \frac{2\lambda\beta\gamma[-16\alpha\beta^2 - 4(\alpha-1)\beta\gamma + \lambda\gamma^2]}{(16\beta^2 - \lambda\gamma^2)^2} \quad \text{and}$$

$$[26] \quad E(p_1^{AB}, e_2) = \frac{-2\lambda\beta\gamma[16\alpha\beta^2 + 4(\alpha-1)\beta\gamma - \lambda\gamma^2]}{(16\beta^2 - \lambda\gamma^2)[8(\alpha+1)\beta^2 - \lambda\alpha\gamma^2 - 2(\alpha-1)\lambda\beta\gamma]}.$$

For both expressions, the numerator is negative for $\lambda > 0$ and $\gamma > 0$, whereas the denominator is positive, so that current prices always fall to an expected depreciation of the exporter's currency and vice versa. The intuition behind this result is that future sales become more valuable relative to current sales in case of an expected depreciation. Here, there are two effects working into the same direction: the future cost effect and the interest rate effect. The first one lets future profits rise relative to current profits, both evaluated in currency *B*, whereas the second one makes future profits even higher in currency of *A*.

Effect of γ on exchange rate pass-through

It has been argued that exchange rate pass-through decreases when γ rises above zero. This can also be shown algebraically, first for the case of a temporary exchange rate shock:

$$[27] \quad \left. \frac{\partial E(p_1^{AB}, e_1)}{\partial \gamma} \right|_{\gamma=0} = \frac{\lambda\alpha(\alpha-1)}{4(\alpha+1)^2\beta} > 0$$

and more generally,

$$[28] \quad \frac{\partial E(p_1^{AB}, e_1)}{\partial \gamma} = \frac{16\beta^3(\lambda\gamma + 4\beta)}{[8(\alpha+1)\beta^2 - \lambda\alpha\gamma^2 - 2(\alpha-1)\lambda\beta\gamma]^2} > 0$$

This suggests that a rise in γ , i.e. in the intertemporal dependency in consumption due to switching costs, makes pass-through less negative (see Figure 1). The producer more smoothes out the effect on prices of any intermittent movement in the exchange rate. If γ , λ and α are large relative to β , the perverse result of an adverse price reaction to an

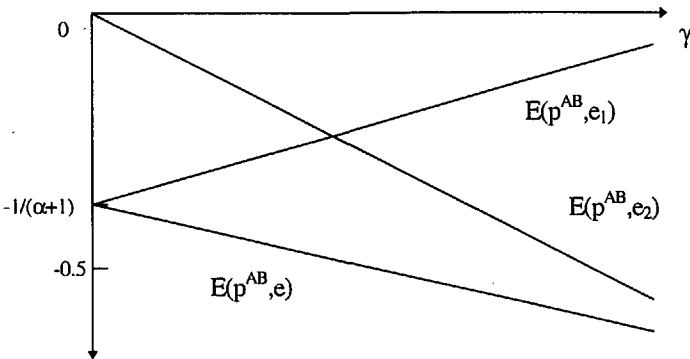
exchange rate shock might be possible (see [16] and [17] above). If this occurs, the discount rate effect overcompensates the first period cost effect.

For permanent exchange rate changes, a rise in switching costs increases the negative value of pass-through:

$$[29] \quad \frac{\partial E(p_1^{AB}, e)}{\partial \gamma} = \frac{-2\lambda\alpha\beta(16\beta^2 + 8\beta\gamma + \lambda\gamma^2)}{[8(\alpha+1)\beta^2 - \lambda\alpha\gamma^2 - 2(\alpha-1)\lambda\beta\gamma]^2} < 0,$$

The expression is negative since the numerator is always negative for the restricted domain of parameters. Contrary to the case of a temporary exchange rate shock, pass-through is not decreasing, but increasing in γ . This is because the effect of a permanent exchange rate change on λ^B cancels, and the interest rate effect disappears. What is more, the intertemporal link in consumption magnifies the effect of a permanent exchange rate shock. Take again the case of an appreciation, which is now expected to be permanent. Since second period profit is reduced due to the second period cost effect the monopolist raises its price even above the level of static profit maximization, where only the first period cost effect is effective.

Figure 1 — Pass-through elasticities with increasing switching costs¹



¹ In order to simplify the graphical presentation all curves have been linearized.

Effect of α on exchange rate pass-through

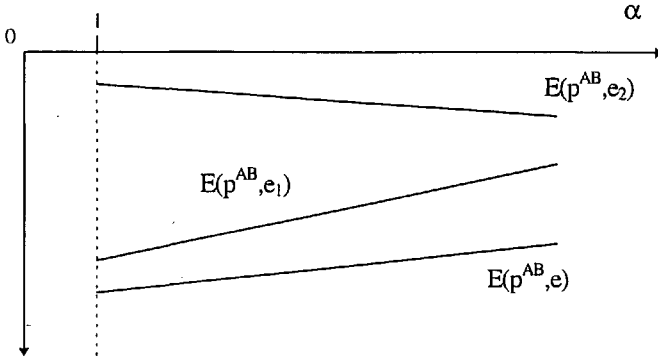
As the reservation price rises relative to unit costs ($\alpha \uparrow$), making demand more inelastic, the monopolist has greater power to set a price above marginal costs.

$$[30] \quad \left. \frac{\partial E(p_1^{AB}, e_1)}{\partial \alpha} \right|_{\gamma=0} = \frac{1}{(\alpha+1)^2} > 0$$

and for nonzero γ

$$[31] \quad \frac{\partial E(p_1^{AB}, e_1)}{\partial \alpha} = \frac{16\beta^3(4\beta + \lambda\gamma)}{[8(\alpha+1)\beta^2 - \lambda\alpha\gamma^2 - 2(\alpha-1)\lambda\beta\gamma]^2} > 0 .$$

An exchange rate depreciation can now be seen as a positive cost shock in terms of the importing country's currency. Due to the declining cost component in price when α rises (see [11]), a positive cost shock measured in country B's currency as a result of his own currency depreciation therefore has a relatively smaller impact on price the higher is α (see Figure 1). The magnitude of the cost effect is therefore cushioned by a higher mark-up at the relevant price, or alternatively, a lower price elasticity of demand. Note that the absolute reaction $\partial p_1^{AB} / \partial e_1$ is always minus one half, so a higher mark-up (high α) causes a rise in the absolute value of the price elasticity of demand via a higher level of price at the starting point.

Figure 2 — Pass-through elasticities with increasing α ¹

¹ In order to simplify the graphical presentation all curves have been linearized.

Note that the amount of pass-through of future exchange rate changes is increasing in α , i.e. pass-through is more negative (or at least constant):

$$[32] \quad \frac{\partial E(p_1^{AB}, e_2)}{\partial \alpha} = \frac{-2\lambda\beta\gamma(2\beta + \gamma)(4\beta + \lambda\gamma)}{[8(\alpha + 1)\beta^2 - \lambda\alpha\gamma^2 - 2(\alpha - 1)\lambda\beta\gamma]^2} \leq 0$$

This finding is contrary to what was concluded for the pure current exchange rate change. The intuition behind this result is that a larger α makes the cost component of the price smaller in favour of the mark-up component. Since the latter is variable profit per unit it is straightforward to conclude that future profits react more to future exchange rate changes and therefore play a greater role in the current pricing decision the larger is α , and thus the smaller the price elasticity of demand (see Figure 2).

For permanent exchange rate changes, the first period effect is diluted by that of future exchange rate changes, so the impact of α is smaller in the sum.

2. Domestic Cost Changes

The above analysis rests on exchange rate changes which in turn cause relative cost movements between countries when costs are measured in the same currency. It was argued that exchange rate changes also alter the discount rate for weighting future against current profits from exporting. To better understand the role of either component it is straightforward to consider the case that changes in relative production costs are not driven by the nominal exchange rate, but by domestic costs. This way, the interest rate effect is not working, and for both the domestic and the export market the discount rate is invariable. Analogously to exchange rate changes, cost changes can be classified into current, permanent or expected future cost changes. However, it now becomes necessary to also look at prices for domestic sales and to interpret the different behaviour of export and domestic prices.

A temporary current cost change has the same effect in markets A and B and causes prices to move into the same direction as costs, provided the usual assumption of a small γ holds:

$$[33] \quad \frac{\partial p_1^{As}}{\partial c_1^A} = \frac{8\beta^2}{16\beta^2 - \lambda\gamma^2} > 0 \quad \text{and}$$

$$[34] \quad E(p_1^{As}, c_1^A) = \frac{8\beta^2}{8(\alpha+1)\beta^2 - \lambda\alpha\gamma^2 - 2(\alpha-1)\lambda\beta\gamma} > 0 .$$

Compared to the exchange rate elasticity one finds the following relationship, which suggests that the absolute value of the exchange rate elasticity is smaller or than or equal to that of the cost elasticity:

$$[35] \quad \left| E(p_1^{AB}, e_1) \right| = \underbrace{\frac{16\beta^2 - \lambda\alpha\gamma^2 - 4(\alpha-1)\lambda\beta\gamma}{16\beta^2 - \lambda\gamma^2}}_{\leq 1} E(p_1^{As}, c_1^A) .$$

$$[36] \quad \left| E(p_1^{AB}, e_1) \right| \leq E(p_1^{As}, c_1^A) .$$

This result is not surprising since the short-run cost elasticity does not comprise any discount rate effect, which works against the cost effect.

When cost changes are perceived to be permanent, however, there is no difference in pricing behaviour compared to exchange rate changes so that.

$$[37] \quad E(p_1^{AB}, e) = -E(p_1^{As}, c^A)$$

As to the role of future variables, one finds that expected cost changes do not have as much influence on prices as exchange rate changes, again because of the missing discount rate effect in the cost elasticity. Algebraically, it can be shown that:

$$[38] \quad E(p_1^{AB}, c_2^A) = \frac{2\lambda\beta\gamma}{[8(\alpha+1)\beta^2 - \lambda\alpha\gamma^2 - 2(\alpha-1)\lambda\beta\gamma]},$$

$$[39] \quad \left| E(p_1^{AB}, e_2) \right| = \underbrace{\frac{16\alpha\beta^2 + 4(\alpha-1)\beta\gamma - \lambda\gamma^2}{16\beta^2 - \lambda\gamma^2}}_{>1} \times E(p_1^{As}, c_2^A) \quad \text{and}$$

$$[40] \quad \left| E(p_1^{AB}, e_2) \right| > E(p_1^{As}, c_2^A).$$

Effect of rising γ on cost pass-through

It has already been argued that a rise in switching costs leads the monopolist to charge a lower price, implying a lower mark-up in the first period. A first period cost increase, irrespective of its duration, therefore increases the elasticity of first period prices to cost changes since the cushioning mark-up component is reduced:

$$[41] \quad \frac{\partial E(p_1^{AB}, c_1^A)}{\partial \gamma} = \frac{16\lambda\beta^2[(\alpha-1)\beta + \alpha\gamma]}{[8(\alpha+1)\beta^2 - \lambda\alpha\gamma^2 - 2(\alpha-1)\lambda\beta\gamma]^2} > 0$$

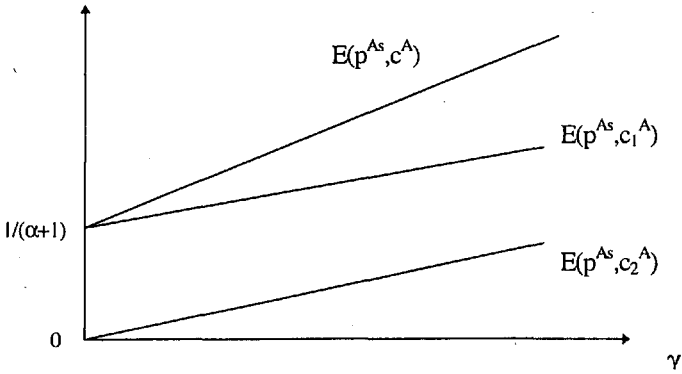
$$[42] \quad \frac{\partial E(p_1^{AB}, c^A)}{\partial \gamma} = \frac{2\lambda\alpha\beta[8(2\beta + \gamma)\beta + \lambda\gamma^2]}{[8(\alpha+1)\beta^2 - \lambda\alpha\gamma^2 - 2(\alpha-1)\lambda\beta\gamma]^2} > 0$$

For expected future cost changes, future profits are reduced relative to current profits, so the producer cares less about intertemporal spillover of demand and rises his first

period price. Expected cost changes therefore lead to price changes before the actual price increase is incurred by the producer.

$$[43] \quad \frac{\partial E(p_1^{AB}, c_2^A)}{\partial \gamma} = \frac{2\lambda\alpha\beta[8(\alpha+1)\beta^2 + \lambda\alpha\gamma^2]}{[8(\alpha+1)\beta^2 - \lambda\alpha\gamma^2 - 2(\alpha-1)\lambda\beta\gamma]^2} > 0$$

Figure 3 — Cost pass-through elasticities with increasing γ ¹



¹ In order to simplify the graphical presentation all curves have been linearized.

Effect of rising α on cost pass-through

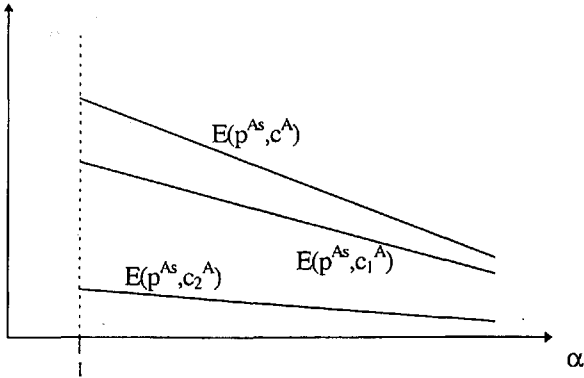
An increasing reservation price and decreasing price elasticity of demand leads to a higher mark-up, which in turn reduces the producer's price reaction to cost changes. This result holds for temporary, permanent or expected cost developments:

$$[44] \quad \frac{\partial E(p_1^{AB}, c_1^A)}{\partial \alpha} = \frac{-8\beta^2[8\beta^2 - \lambda\gamma(2\beta + \gamma)]}{[8(\alpha+1)\beta^2 - \lambda\alpha\gamma^2 - 2(\alpha-1)\lambda\beta\gamma]^2} < 0,$$

$$[45] \quad \frac{\partial E(p_1^{AB}, c^A)}{\partial \alpha} = \frac{-2\beta(4\beta + \lambda\gamma)[8\beta^2 - \lambda\gamma(2\beta + \gamma)]}{[8(\alpha+1)\beta^2 - \lambda\alpha\gamma^2 - 2(\alpha-1)\lambda\beta\gamma]^2} < 0,$$

$$[46] \quad \frac{\partial E(p_1^{AB}, c_2^A)}{\partial \alpha} = \frac{-2\lambda\beta\gamma[8\beta^2 - \lambda\gamma(2\beta + \gamma)]}{[8(\alpha + 1)\beta^2 - \lambda\alpha\gamma^2 - 2(\alpha - 1)\lambda\beta\gamma]^2} < 0 .$$

Figure 4 — Cost pass-through elasticities with increasing α^1



¹ In order to simplify the graphical presentation all curves have been linearized.

3. Implications for relative prices

For the purpose of comparing prices between the export and home market, the price in the export market p^{AB} has to be expressed in currency units of the exporter's country q^{AB} . The relation between both pass-through elasticities is then

$$[47] \quad E(q^{AB}, e) = E(p^{AB}, e) + 1 .$$

This formula holds for both temporary and permanent exchange rate changes. The producer's export price is responsive to the exchange rate as long as pass-through is incomplete. To show only the example of static price setting with $\gamma=0$, where pass-through was shown to be incomplete, the producer's export price rises when his currency depreciates according to

$$[48] \quad E\left(q_1^{AB}, e\right)_{\gamma=0} = \frac{\alpha}{\alpha+1}.$$

Factors which increase pass-through reduce this elasticity and vice versa. Pricing-to-market occurs if this elasticity is different for the home market. If that is the case, the ratio of the producer's export price relative to that in the home market is affected by the exchange rate. Since the general relationship is

$$[49] \quad E\left(q^{AB}/p^{AA}, e\right) = E\left(q^{AB}, e\right) - E\left(p^{AA}, e\right)$$

it is straightforward that pricing-to-market as a response to exchange rate changes necessarily exists for the monopolist since the sales price for the domestic market is unresponsive to that kind of shocks. Remember that for domestic cost changes as the driving force, it was argued in [34] that price setting is uniform across both markets.

B. Duopoly

Now I turn to the case of two firms, one firm being located in either country. It is assumed that both firms engage in Bertrand competition in price setting, taking each other prices as given. For the second period we have the standard duopoly result with prices, quantities and profits of either competitor being dependent on costs in both countries, but which is augmented by lagged quantity variables due to the specification of consumer utility as defined above. The demand function for the supplier from country r in country s , which can be derived from the general expression above, is:

$$[50] \quad x^{rs} = \frac{\alpha(2-\sigma) + \sigma p^{ss} - 2p^{rs} + 2\gamma x_{-1}^{rs} - \sigma \gamma x_{-1}^{ss}}{\beta(2-\sigma)(2+\sigma)}, \quad r=A, B; \quad s=A, B;$$

$$0 \leq \sigma < 2.^5$$

⁵ If $\sigma=2$, all varieties are perfect substitutes. Under price competition, only the producer with the lowest marginal costs would survive in the market. In order to have continuous pricing functions, σ is restricted to be lower than 2. The case of perfect substitutability is then approached if σ reaches the neighbourhood of 2.

For setting the first period price the rationale is analogous to that of the monopolist, and both firms take into account the effect of first period sales on second period profits when maximizing their intertemporal profit function with respect to first period prices. The resulting equilibrium outcomes are as follows:

$$[51] \quad p_1^{AA} = \frac{k_a + k_{aa1}c_1^A + k_{ab1}e_1c_1^B + k_{aa2}c_2^A + k_{ab2}e_2c_2^B}{\left[\beta^2(4-\sigma)^3(4+\sigma)(2+\sigma)^2 - \lambda(8\gamma)^2 \right] \left[\beta^2(4-\sigma)(4+\sigma)^3(2-\sigma)^2 - \lambda(8\gamma)^2 \right]}$$

with $k_a, k_{aa1}, k_{ab1}, k_{aa2} > 0$ and $k_{ab2} < 0$ for sufficiently small γ (see Appendix)

[52]

$$p_1^{AB} = \frac{k_b + k_{ba1}c_1^A + k_{bb1}e_1c_1^B + k_{ba2}c_2^A + k_{bb2}e_2c_2^B}{\left[\beta^2e_1(4-\sigma)^3(4+\sigma)(2+\sigma)^2 - \lambda e_2(8\gamma)^2 \right] \left[\beta^2e_1(4-\sigma)(4+\sigma)^3(2-\sigma)^2 - \lambda e_2(8\gamma)^2 \right]}$$

with $k_b, k_{ba1}, k_{bb1}, k_{ba2} > 0$ and $k_{bb2} < 0$ for sufficiently small γ (see Appendix)

Concerning pass-through elasticities of domestic cost and exchange rate changes for the local price in the export market (p^{AB}), similar relationships hold as for the monopolist. The expressions for prices [51] and [52] have been rearranged so that the impact of cost changes can be seen directly. Domestic cost increases ($c^A \uparrow$) raise p^{AB} , since k_{ba1} is positive, and even more so for permanent changes, since the second period effect reinforces the tendency of the first period impact (k_{ba2} is also positive). For permanent effects, it again makes no difference whether domestic competitiveness is affected by domestic costs or exchange rates. However, like in the monopoly, it can also be shown that the elasticity with regard to temporary movements is greater in absolute value for cost changes and the elasticity with regard to expectations for exchange rate changes, since exchange rate movements between period 1 and 2 also affect the effective intertemporal discount rate for foreign exchange and therefore also comprise a valuation effect. The positive price effects of temporary appreciations, for example, is counteracted by the expectation that the value of foreign exchange relative to the

domestic currency will be higher in the future, and that dampens the increase in current prices due to market share considerations. This would not be the case if cost changes were the underlying cause of diminishing competitiveness.

What is new for the duopoly and what was missing in monopolistic price setting is firstly, that the domestic price p^{AA} is also hit by exchange rate movements, namely through the channel of import competition in the exporter's home market. Secondly, costs in country B enter the stage as a new variable, which are now a determinant for prices in the export and home market. This can be seen by realizing that k_{ab1} and k_{bb1} are positive and identical when e_2 is set to one due to the symmetry condition of demand in both countries. Cost changes in general continue to have the same effect for a particular producer in the domestic and foreign market as long as there is no country bias in demand, no transport costs and equal market shares with respect to the number of firms in both markets. That is because there is nothing which makes the market in country A distinct from that in country B. In addition, contrary to exchange rate movements, cost changes do not imply an intertemporal valuation effect for export earnings and are therefore no source for price discrimination between the home and the export market.

The fact, though, where the cost change takes place does have an impact on elasticities. Both for permanent and temporary cost changes, the impact on prices is larger if costs move in that country where the producer is located ($k_{aa1} > k_{ab1}$ and $k_{aa2} > k_{ab2}$, and equivalently for the export market). Competitor costs have the same qualitative effect, but their impact is smaller. For expected cost changes, on the other hand, even the direction of influence differs. Expected own cost shocks increase both prices of the producer (k_{aa2} and $k_{ba2} > 0$), whereas a positive cost shock in the other country makes the producer cut prices in both markets because his second period variable profit per unit sold will rise and makes market share more valuable (k_{ab2} and $k_{bb2} < 0$). Another interpretation of these findings is that temporary own cost shocks are smaller in their impact than permanent ones, whereas competitor's cost changes are more important for price setting if they are temporary.

Concerning domestic prices, the effect of foreign cost changes is equivalent to that of exchange rate changes for all time horizons since the valuation effect is absent for

domestic sales. Note that for export prices it does matter whether foreign costs or the nominal exchange rate changes. From the values of the elasticities it can be shown that for all time horizons exchange rates exert a larger influence on prices than competitor costs. A formal derivation is left out in favour of the following intuitive explanation suggesting that exchange rate changes also bring about a shift of foreign demand from the sight of the domestic producer, and this increases the impact relative to competitor cost movements.

1. Pass-through elasticities

In the preceding analysis both the kind of shock and the time horizon were highlighted as determinants for pass-through. However, the results obtained are very general and do not hinge on particular assumptions for the exact values of the parameters and therefore do not explain differences in pricing behaviour between sectors which differ in the degree of substitutability between products, the reservation price relative to marginal costs or the importance of consumers' switching costs. In order to give an account of either single component, γ is set to zero in order to reduce the complexity of derivatives.

The elasticities are then restricted as follows:

$$[53] \quad -E(p_1^{AB}, e) \Big|_{\gamma=0} = E(p_1^{AB}, c^A) \Big|_{\gamma=0} = E(p_1^{AA}, c^A) \Big|_{\gamma=0} = \frac{8}{(4 + \sigma)[2 + \alpha(2 - \sigma)]}$$

Exchange rate pass-through to export prices is again negative and of the same amount as domestic cost pass-through, with absolute values in the interval $[0, 2/3)$. Whereas in the limit of perfect substitutability, the value of the elasticity is always approaching $2/3$, the monopoly result also depends on α and thus on the elasticity of demand.

For exchange rate pass-through to domestic prices it holds that

$$[54] \quad E(p_1^{AA}, e)_{\gamma=0} = E(p_1^{AB}, c^B)_{\gamma=0} = E(p_1^{AA}, c^B)_{\gamma=0} = \frac{2\sigma}{(4+\sigma)[2+\alpha(2-\sigma)]}$$

which is zero for the monopolist and 1/3 for perfect substitutability.

2. Relative export price

The significance of price discrimination between the export and home market can be measured in terms of the ratio of export to domestic sales price in the producer's currency. Pricing-to-market occurs if both prices evolve differently to exogenous shocks. Since domestic prices are not independent to variations in the exchange rate, contrary to the monopolistic pricing schedule, the conclusions with regard to pricing-to-market are no longer trivial. It is now required to compare the magnitude of the export price and domestic price elasticities in order to tell if the export price rises, falls or remains unaltered relative to the domestic price if the exporter's currency depreciates. In order to be able to compare both prices in the same currency units (here the exporter's currency), export price pass-through is recalculated in domestic currency. As the export price elasticity in producer prices is simply the foreign currency export price elasticity of the domestic exporter augmented by one, it holds that

$$[55] \quad E(q_1^{AB}, e)_{\gamma=0} = \frac{\alpha(4-\sigma)(2-\sigma) + 2\sigma}{(4+\sigma)[2+\alpha(2-\sigma)]}, \text{ which is in the interval } (1/3, 1].$$

For values of σ smaller than 2, one obtains the expression

$$[56] \quad E(q_1^{AB} / p_1^{AA}, e)_{\gamma=0} = \frac{\alpha(2-\sigma)}{2+\alpha(2-\sigma)} > 0,$$

which is between zero (perfect substitutability) and one. A depreciation of the exporter's currency thus makes export prices rise more than domestic ones as long as products are imperfect substitutes.

3. Relative producer price

As argued in the introduction, the law of one price can be interpreted either to apply to the prices one and the same producer gets from sales in different markets, or to the prices different producers charge in the same market. The latter concept relates to the price differential of the foreign competitor relative to the domestic producer in the same market, say the market of country A. Its elasticity with respect to the exchange rate is:⁶

$$[57] \quad E\left(\frac{p_1^{BA}}{p_1^{AA}}, e\right)_{\gamma=0} = \frac{2(4-\sigma)}{(4+\sigma)[2+\alpha(2-\sigma)]} > 0 .$$

The import price in country A relative to the domestic price always rises if country A's currency depreciates. In the following it will be investigated in what how the parameters act on the magnitude of all these elasticities.

4. Effect of σ

The findings for a monopolist in the last section can now be generalized to values of σ higher than zero. A rise in σ signifies a higher substitutability between products. The derivatives of the elasticities evaluated at $\sigma=0$ show how pass-through changes when a former monopolist now faces the competition of substitutable products. One can not tell a priori whether this effect increases or decreases pass-through. On the one hand, more competition could mean that a producer is less able to hand over cost increases to his customers. On the other hand, the mark-up component of the price, which is reflected in the ratio of price to marginal costs greater than one, is hypothesized to be lower under competition and can therefore to a lesser extent compensate for marginal cost changes in order to limit the effect on prices. In other words, under more competitive price setting, prices would be more closely oriented at marginal cost so that pass-through increases.

⁶ Note that with zero γ the value of the price elasticity with respect to the exchange rate for the foreign supplier is simply minus one times the elasticity for the domestic producer, so that calculation of the relative producer price reaction is straightforward.

In effect, the amount of pass-through of exchange rates and domestic costs to foreign market prices increases in σ , so the second effect dominates. Exchange rate pass-through thus becomes more negative when σ rises:

$$[58] \quad \left. \frac{\partial E(p_1^{AB}, e)}{\partial \sigma} \right|_{\gamma=0} = \frac{16[\alpha(1+\sigma)-1]}{(4+\sigma)^2[2+\alpha(2-\sigma)]^2} < 0$$

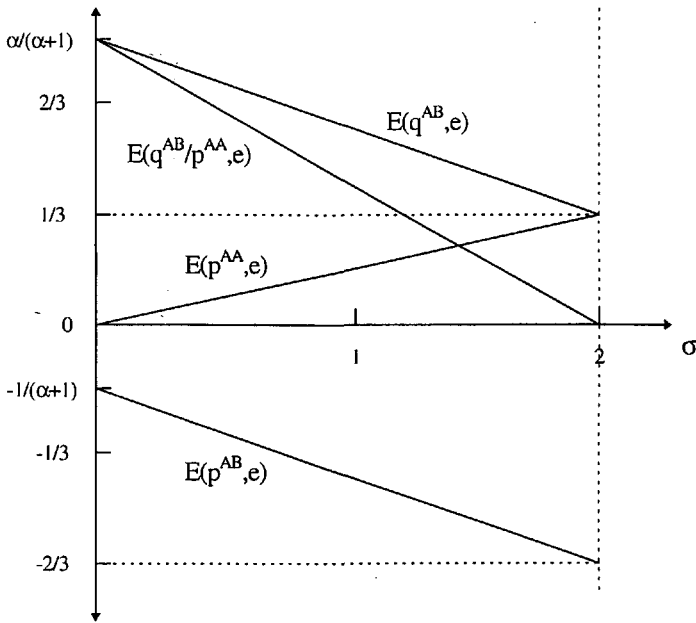
Analogously, the elasticity relating to the home market also rises with σ . A higher substitutability therefore increases both the effect of exchange rate changes on domestic prices and the effect foreign costs have on both prices the domestic producer sets:

$$[59] \quad \left. \frac{\partial E(p_1^{AA}, e)}{\partial \sigma} \right|_{\gamma=0} = \frac{2[\alpha(8+\sigma^2)+8]}{(4+\sigma)^2[2+\alpha(2-\sigma)]^2} > 0$$

The ability to price-discriminate between markets is reduced to the degree that σ rises, since it holds that

$$[60] \quad \left. \frac{\partial E(q_1^{AB}/p_1^{AA}, e)}{\partial \sigma} \right|_{\gamma=0} = \frac{-2\alpha}{[2+\alpha(2-\sigma)]^2} < 0$$

In the limit of nearly perfect substitutability ($\sigma \rightarrow 2$) the value for the pricing-to-market expression approaches zero.

Figure 5 — Pass-through elasticities with increasing σ ¹

¹ In order to simplify the graphical presentation all curves have been linearized.

For the relative producer prices (i.e. the relative import price) in market A however, the effect of σ is ambiguous:

[61]

$$\left. \frac{\partial E(p_1^{BA} / p_1^{AA}, e)}{\partial \sigma} \right|_{\gamma=0} = \frac{2[\alpha\sigma(8-\sigma) - 16]}{\{(4+\sigma)[2+\alpha(2-\sigma)]\}^2} \begin{cases} < 0 \Leftrightarrow \alpha < 16/[\sigma(8-\sigma)] \\ > 0 \Leftrightarrow \alpha > 16/[\sigma(8-\sigma)] \end{cases}$$

The role of the exchange rate for creating that differential impact is more likely to be strengthened the larger are both α and σ . If one starts from a situation with very

high monopolistic market power (σ near 0) and introduces more competition, the effect is always reduced, irrespective of α :

$$[62] \quad \left. \frac{\partial E(p_1^{BA} / p_1^{AA}, e)}{\partial \sigma} \right|_{\gamma=0, \sigma \rightarrow 0} = \frac{-1}{2(\alpha+1)^2} < 0 .$$

With a larger degree of competition, i.e. when sigma is strictly positive, the elasticity may begin to increase, if demand is sufficiently inelastic, brought about by high values of α . Otherwise, with a moderate reservation price α , a higher degree of substitutability always reduces that price gap caused by an exchange rate change. It is the last case that one intuitively would expect to be the role of σ . To sum up, a higher substitutability reduces exchange rate induced price differentials both across export markets and across producers (the latter only if α is small). The general result is ambiguous however.

5. Effect of α

A rise in the reservation price α can be conjectured to have the same effect on the elasticities as a fall in sigma, since both reduce the own price elasticity of demand. This is indeed the case for pass-through and pricing-to-market, but not for the intra-market producer price differential as the following derivatives show. More inelastic demand, accomplished via a higher reservation price, reduces pass-through to foreign and domestic prices since price setting is mostly demand determined and therefore more specific to the relevant market. Note that [63] is just a generalization of the monopoly outcome with $\sigma=0$ as shown in [30].

$$[63] \quad \left. \frac{\partial E(p_1^{AB}, e)}{\partial \alpha} \right|_{\gamma=0} = \frac{8(2-\sigma)}{(4-\sigma)[2+\alpha(2-\sigma)]^2} > 0$$

$$[64] \quad \left. \frac{\partial E(p_1^{AA}, e)}{\partial \alpha} \right|_{\gamma=0} = \frac{-2(2-\sigma)\sigma}{(4+\sigma)[2+\alpha(2-\sigma)]^2} < 0$$

Since the export price in the exporter's currency is then necessarily more responsive to exchange rate changes as opposed to the domestic price, the phenomenon of pricing-to-market is increasing in the value of the reservation price.

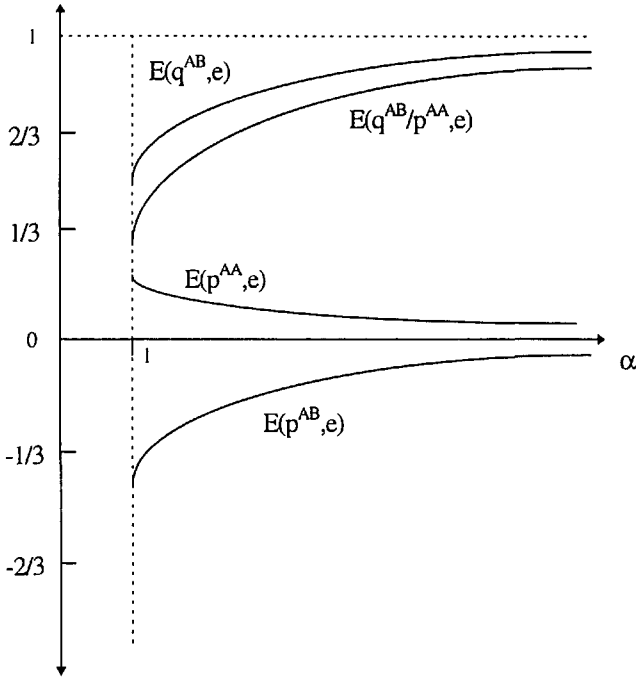
$$[65] \quad \left. \frac{\partial E(q_1^{AB} / p_1^{AA}, e)}{\partial \alpha} \right|_{\gamma=0} = \frac{2(2-\sigma)}{[2+\alpha(2-\sigma)]^2} > 0$$

The result that a comparatively inelastic demand, leading in turn to large markups, reduces the scope for intra-market price differentials from exchange rate changes appears to be counterintuitive:

$$[66] \quad \left. \frac{\partial E(p_1^{BA} / p_1^{AA}, e)}{\partial \alpha} \right|_{\gamma=0} = \frac{2[\sigma(6-\sigma)-8]}{(4+\sigma)[2+\alpha(2-\sigma)]^2} < 0$$

However, an explanation is that a low reservation price which is not much higher than marginal cost forces both producers to follow more closely the path of marginal costs when setting prices. That, in turn, may lead to more divergent prices in the same market, when the competitive position between the producers is altered by means of the exchange rate. High reservation prices, however, make price setting more market-demand oriented and thus reduce the price differential between producers. What we learn from this analysis is that it does not suffice to only measure the price elasticity of demand when it comes to explain intra-market price differentials between producers. It matters whether a larger demand elasticity is induced by a low α or a high σ . In the first case, intra-market price differentials are increased, whereas in the second one, they are generally reduced.

Figure 6 — Exchange rate pass-through and pricing-to-market with increasing α



6. Effect of γ

One can also ask the question of how elasticities are affected if the intertemporal spillover term in demand gains weight in the utility function, which could be accomplished by a larger γ . As stated above, the positive impact of previous period sales on demand in the following period is strengthened by a rise in γ .

Pass-through of permanent exchange rate changes to export prices becomes greater in absolute value with γ . This impact is reversed, however, if the exchange rate shock is perceived to be only temporary. Past market share considerations are then more important and dampen the impact of exchange rate changes on prices. In case of a temporary devaluation, prices are lowered by less if the devaluation is expected to be reversed in the next period. This makes it less valuable for the firm to shift profit to the second period, and the firm is more inclined to increase current profits by means of setting a relatively higher current price, so the price fall becomes less marked. The single effect of expected devaluations lowers export prices if γ rises above zero due to an analogous reasoning. Note that these results hold irrespective of whether export prices are measured in the exporter's or importer's currency since their derivatives are identical:

$$[67] \quad \left. \frac{\partial E(p_1^{AB}, e)}{\partial \gamma} \right|_{\gamma=0} = \frac{-128\lambda[\alpha(16-2\sigma-3\sigma^2)+2\sigma]}{\beta(2-\sigma)(2+\sigma)(4-\sigma)(4+\sigma)^3[2+\alpha(2-\sigma)]^2} < 0 ,$$

$$[68] \quad \left. \frac{\partial E(p_1^{AB}, e_1)}{\partial \gamma} \right|_{\gamma=0} = \frac{64\lambda(\alpha-1)[\alpha(8-2\sigma-\sigma^2)+2\sigma]}{\beta(2+\sigma)(4-\sigma)^2(4+\sigma)[2+\alpha(2-\sigma)]^2} > 0 ,$$

$$[69] \quad \left. \frac{\partial E(p_1^{AB}, e_2)}{\partial \gamma} \right|_{\gamma=0} = \frac{-64\lambda[\alpha(32-6\sigma^2-\sigma^3)+2\sigma]}{\beta(2-\sigma)(2+\sigma)(4-\sigma)^2(4+\sigma)^3[2+\alpha(2-\sigma)]^2} < 0 .$$

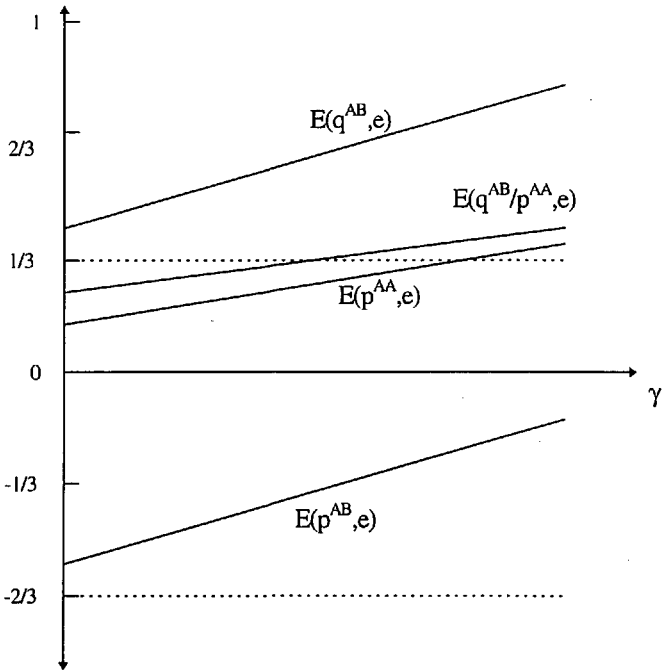
Regarding prices of domestic sales, the effect of a rise in γ on pass-through leads to some ambiguous results. Therefore I start by interpreting the unambiguous effect of γ on first period exchange rate pass-through to domestic prices, which is

$$[70] \quad \left. \frac{\partial E(p_1^{AA}, e_1)}{\partial \gamma} \right|_{\gamma=0} = \frac{128\lambda(\alpha-1)\sigma}{\beta(2+\sigma)(4-\sigma)^2(4+\sigma)^2[2+\alpha(2-\sigma)]^2} > 0 .$$

It was already concluded that a temporary depreciation leads the domestic enterprise to also raise its price in its own home market. This effect is strengthened by a positive γ .

Since the competitive position of the domestic enterprise redeclines in the future, past sales are less valuable for the firm, so the current price is raised even more. Note that this fact stands in sharp contrast to what was obtained for export prices, where γ reduced the absolute effect of temporary exchange rate changes due to dynamic considerations.

Figure 7 — Pass-through elasticities with increasing σ^1



¹ In order to simplify the graphical presentation all curves have been linearized.

Concerning future exchange rate changes, a positive γ implies that expected exchange rate or competitor cost changes now affect domestic prices negatively since past sales are more valuable for the firm in the future:

$$[71] \quad \left. \frac{\partial E(p_1^{AA}, e_2)}{\partial \gamma} \right|_{\gamma=0} = \frac{-64\lambda\sigma^2}{\beta(2-\sigma)(2+\sigma)(4-\sigma)^2(4+\sigma)^3[2+\alpha(2-\sigma)]^2} < 0 .$$

As opposed to export prices, this mechanism now acts to reduce the absolute value of pass-through to home market prices. If the overall effect of permanent exchange rate changes is split into the pure first and second period effects both counteracting each other, one can not tell a priori what the total outcome is:

$$[72] \quad \left. \frac{\partial E(p_1^{AA}, e)}{\partial \gamma} \right|_{\gamma=0} = \frac{64\lambda\sigma[\alpha(4-\sigma^2)-4]}{\beta(2-\sigma)(2+\sigma)(4-\sigma)(4+\sigma)^3[2+\alpha(2-\sigma)]^2} \begin{matrix} > \\ < \end{matrix} 0 .$$

The expression [72] is positive for $\alpha > 4/(4-\sigma^2)$. The larger is σ and the more we approach the limiting case of perfect substitutability, the larger has to be α in order to make that elasticity positive. For perfect substitutability, α has to be infinity, so for any finite value of α , the influence of past sales via γ decreases pass-through. Since both a low σ and a high α are indicative of high mark-ups, it can be conjectured that the effect of past market share only increases pass-through to domestic prices in high mark-up sectors.

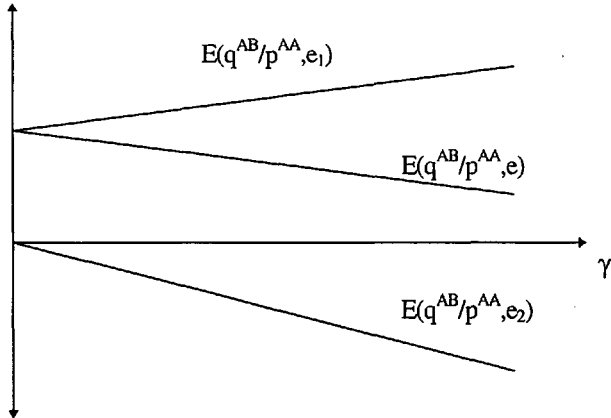
For the phenomenon of pricing-to-market one gets the unambiguous result that switching costs decrease pricing-to-market if exchange rate changes are permanent, and increase pricing-to-market if they are temporary. This is also equivalent to saying that the effect of an expected depreciation leads to negative pricing-to market, i.e. the domestic price falls more than the export price. The effects of γ on pricing-to-market are:

$$[73] \quad \left. \frac{\partial E(q_1^{AB}/p_1^{AA}, e)}{\partial \gamma} \right|_{\gamma=0} = \frac{-64\lambda\alpha}{\beta(2+\sigma)(4-\sigma)(4+\sigma)[2+\alpha(2-\sigma)]^2} < 0 ,$$

$$[74] \quad \left. \frac{\partial E(q_1^{AB}/p_1^{AA}, e_1)}{\partial \gamma} \right|_{\gamma=0} = \frac{64\lambda\alpha(\alpha-1)(2-\sigma)}{\beta(2+\sigma)(4-\sigma)^2(4+\sigma)[2+\alpha(2-\sigma)]^2} > 0 ,$$

$$[75] \quad \left. \frac{\partial E(q_1^{AB}/p_1^{AA}, e_2)}{\partial \gamma} \right|_{\gamma=0} = \frac{-64\lambda\alpha}{\beta(2+\sigma)(4-\sigma)^2(4+\sigma)[2+\alpha(2-\sigma)]^2} < 0 .$$

Figure 8 — Pricing-to-market with various natures of exchange rate changes¹



¹ In order to simplify the graphical presentation all curves have been linearized.

Concerning the elasticity of intra-market price differentials across producers, results hinge upon the assumption governing the discount rate, since they evolve differently for the producers under the assumption of perfect capital mobility. What is sure however, is that with a temporary exchange rate change, switching costs work towards a stabilization of the local price for the exporter from country *A* in country *B* as was just argued, and that effect should partially lead to lower price spread across producers in the target market.

C. Oligopoly

It is straightforward to study as a generalization of the previous section the case where the number of domestic and foreign enterprises can also be greater than one. I also allow for the possibility that these numbers can differ between both markets. Therefore, n^{rs} indicates the number of enterprises in country *r* which are selling to market *s*. The aim of this generalization is twofold: Firstly, one is able to arrive at statements about the role of market share for pass-through. If one starts from a situation where domestic and foreign firms have equal costs measured in the same currency, sales of each firm would be identical, and the market share of firms of country *r* in the market of country *s* can be represented by the ratio of the number of country *r*'s firms to all firms which sell in that market, i.e. by the ratio

$$[76] \quad s^{rs} = \frac{n^{rs}}{n^{rs} + n^{ss}}.$$

In equilibrium, a country's market share in a national market is thus identical to the proportion of its firms in that market.

To begin with, one first has to restate the demand function [2] for the particular case where the rest of the firms, the number of which is $N-1$, is distributed between the home and the foreign country *s* from the point of view of the representative firm in country *r*. That is, if the focus is on demand in the home market, the relevant figures are $n^{rr} - 1$ for the number of rival firms from the same country as the representative firm and n^{rf} for

the number of external competitors. If one turns to the export market, the respective figures are $n^{rs} - 1$ and n^{st} respectively. Of course, it must hold that

$$n^{sr} + n^{rr} = N^r, \text{ which is the total number of firms which serve market } r, \text{ and}$$

$$n^{ss} + n^{rs} = N^s, \text{ which is the total number of firms which serve market } s.$$

The demand for the representative firm from country r in market s depends on its own price p_i^{rs} , the prices of its competitors from the same country p_{-i}^{rs} , and the prices their foreign competitors set, p^{st} . Because of symmetry, all firms from the same country have the same price. For simplicity, γ is set to zero since the mechanism behind the dynamics of x_i can be conjectured to work in a similar fashion as in the duopoly model.

$$[77] \quad x_i^{rs} = \frac{\alpha(2-\sigma) + \sigma(n^{rs} - 1)p_{-i}^{rs} + \sigma n^{ss} p^{ss} - p_i^{rs}(2 + \sigma(N^s - 2))}{\beta(2-\sigma)(2 + \sigma(N^s - 2))}, \quad r=A,B, s \neq r$$

An analogous demand function exists for the representative firm's home sales x_i^{rr} :

$$[78] \quad x_i^{rr} = \frac{\alpha(2-\sigma) + \sigma(n^{rr} - 1)p_{-i}^{rr} + \sigma n^{sr} p^{sr} - p_i^{rr}(2 + \sigma(N^r - 2))}{\beta(2-\sigma)(2 + \sigma(N^r - 2))}, \quad r=A,B, s=r$$

In price equilibrium the optimality condition for both representative firms of either country must hold and it is also required that $p_i^{rs} = p_{-i}^{rs}$ for $r=A,B$ and $s=A,B$. Equilibrium prices can be determined from profit maximization for the domestic and foreign producers leading to the respective reaction functions and then computing the reduced form for prices. The resulting prices for the supplier from country A in markets A and B

[79]

$$p^{AA} = \frac{\left[(N^A - 2)\sigma + 2 \right] \left\{ \left[(N^A + n^{AA} - 3)\sigma + 4 \right] c^A + n^{BA} \sigma e c^B \right\} + \alpha(2 - \sigma) \left[(2N^A - 3)\sigma + 4 \right]}{\left[(N^A - 3)\sigma + 4 \right] \left[(2N^A - 3)\sigma + 4 \right]}$$

[80]

$$p^{AB} = \frac{\left[(N^B - 2)\sigma + 2 \right] \left\{ \left[(N^B + n^{AB} - 3)\sigma + 4 \right] c^A / e + n^{BB} \sigma c^B \right\} + \alpha(2 - \sigma) \left[(2N^B - 3)\sigma + 4 \right]}{\left[(N^B - 3)\sigma + 4 \right] \left[(2N^B - 3)\sigma + 4 \right]}$$

The corresponding pass-through elasticities are:

[81]

$$E(p^{AA}, e) = E(p^{AA}, c^B) = \frac{n^{BA} \sigma \left[(n^{AA} + n^{BA} - 2)\sigma + 2 \right]}{4 + (2n^{AA} + n^{BA} - 3)\sigma \left[(n^{AA} + n^{BA} - 1)\sigma + (\alpha + 1)(2 - \sigma) \right]} > 0$$

[82]

$$-E(p^{AB}, e) = E(p^{AB}, c^A) = \frac{8 + (n^{AB} + n^{BB} - 1)\sigma + (n^{AB} + n^{BB} - 2)(2n^{AB} + n^{BB} - 3)\sigma^2}{4 + (2n^{AB} + n^{BB} - 3)\sigma \left[(n^{AB} + n^{BB} - 1)\sigma + (\alpha + 1)(2 - \sigma) \right]} > 0$$

As in the duopoly framework, a foreign cost increase or depreciation of the domestic currency ($e \uparrow$) raises the price in the home market, and the quantitative impact of both shocks is identical. Furthermore, concerning export prices, a domestic cost rise and an exchange rate appreciation both lead to the same upward adjustment of local prices in the target country. Note that p^{AB} is country A 's export price measured in currency of country B . For the export price elasticity in the exporter's currency the expression is:

[83]

$$E(q^{AB}, e) = \frac{4\alpha(2-\sigma) + (2-\sigma)\sigma \left[\alpha(2n^{AB} + n^{BB} - 3) + n^{BB} \right] n^{BB} (n^{AB} + n^{BB} - 1) \sigma^2}{\left[4 + (2n^{AB} + n^{BB} - 3)\sigma \right] \left[(n^{AB} + n^{BB} - 1)\sigma + (\alpha + 1)(2 - \sigma) \right]} \geq 0$$

When [81] is compared with [83], we see that pricing-to-market still occurs. The pricing-to-market elasticity is only shown for the particular case when both markets are identical in their structure of suppliers, i.e. when $n^{AA} = n^{AB} = n^A$ and $n^{BA} = n^{BB} = n^B$.⁷

[84]

$$E\left(q^{AB}/p^{AA}, e\right) \Big|_{n^{AA}=n^{AB}=n^A, n^{BA}=n^{BB}=n^B} = \frac{\alpha(2-\sigma)}{(n^A + n^B - 1)\sigma + (\alpha + 1)(2 - \sigma)} \geq 0$$

Note that $n^A + n^B = N$.

As a usual result, the export price rises above the home market price if the domestic currency depreciates, and the more so the higher the degree of substitutability between products since it holds that

$$[85] \quad \left. \frac{\partial E(q^{AB}/p^{AA}, e)}{\partial \sigma} \right|_{n^{AA}=n^{AB}=n^A, n^{BA}=n^{BB}=n^B} < 0.$$

1. The role of the number of firms

The pricing-to-market elasticity is also declining in the total number of suppliers from both countries, again assumed to be identical in both target markets ($N^A = N^B = N$). This can be seen by realizing that

$$[86] \quad \left. \frac{\partial E(q^{AB}/p^{AA}, e)}{\partial N} \right| < 0$$

⁷ Concerning the total number of suppliers, it then holds that $N^A = N^B = N$

Thus, all else equal, a fragmentation of the market in the sense that more firms are competing against each other for the consumer's choice, has the effect that the scope for pricing-to-market is becoming smaller. For $n^A = n^B = 1$ the duopoly case applies, and for $n^A = 1, n^B = 0$ we have the monopolistic outcome.

2. The role of market share

In the following the derivatives of pass-through elasticities with respect to the share of domestic firms in the relevant market are calculated. This is done by substituting all n^x by the respective expression for share s and the total number N^x and then deriving. For the home market the following outcome holds:

$$[87] \quad \frac{\partial E(p^{AA}, e)}{\partial s^{AA}} = \frac{-\sigma[\sigma(N^A - 2) + 2]N^A}{\sigma(N^A - 2) + \alpha(2 - \sigma) + 2} < 0$$

The larger the share of domestic firms in the home market, which is equivalent to saying that import penetration is lower, the smaller is the effect of exchange rate changes on domestic prices.

On the other hand, a larger share of domestic suppliers in the export market increases pass-through to export prices in the foreign currency (a depreciation, for example, reduces prices in the export country to a larger extent), therefore limiting the reaction of prices in the exporter's currency.

$$[88] \quad \frac{\partial E(p^{AB}, e)}{\partial s^{AB}} = \frac{\partial E(q^{AB}, e)}{\partial s^{AB}} = \frac{-\sigma[\sigma(N^B - 2) + 2]N^B}{\sigma(N^B - 2) + \alpha(2 - \sigma) + 2} < 0$$

As to pricing-to-market, it is straightforward to conclude that this effect is more prevalent the smaller the share of domestic exporters in the foreign market and the larger their home market share:

$$[89] \quad \frac{E(q^{AB}/p^{AA}, e)}{\partial s^{AB}} = \frac{-\sigma N^B [\sigma(N^B - 2) + 2]}{[(N^B - 2)\sigma + \alpha(2 - \sigma) + 2][(2N^B - 3)\sigma + 4]} < 0$$

$$[90] \quad \frac{E(q^{AB}/p^{AA}, e)}{\partial s^{AA}} = \frac{\sigma N^A [\sigma(N^A - 2) + 2]}{[(N^A - 2)\sigma + \alpha(2 - \sigma) + 2][(2N^A - 3)\sigma + 4]} > 0.$$

As long as markets are not fully integrated, meaning that there exists a home bias for domestic producers which makes their share in the domestic market larger than in the export market, the tendency for pricing to market would be even greater than with identical market shares.

The consequence is that if the number of export markets increases because more and more distant markets are delivered due to globalization of product markets, reducing the average home exporter's share across markets, pricing-to-market becomes more important. Of course, this reasoning implies the ceteris-paribus assumption of holding the shares in the exporter's home market constant. If, on the other hand, the predominant effect of globalization is an increase in import penetration in the domestic market, implying that s^{AA} is reduced, pricing-to market effects would decline. It is thus an empirical question which effect is the dominant one when the focus is on evolution of pricing-to-market over time.

3. Cost changes

For investigating the price sensitivity with respect to costs, the two remaining elasticities have to be given first:

$$[91] \quad E(p^{AA}, c^A) = \frac{8 + (n^{AA} + n^{BA} - 1)\sigma + (n^{AA} + n^{BA} - 2)(2n^{AA} + n^{BA} - 3)\sigma^2}{[4 + (2n^{AA} + n^{BA} - 3)\sigma][(n^{AA} + n^{BA} - 1)\sigma + (\alpha + 1)(2 - \sigma)]} > 0$$

$$[92] \quad E(p^{AB}, c^B) = \frac{n^{BB}\sigma[(n^{AB} + n^{BB} - 2)\sigma + 2]}{[4 + (2n^{AB} + n^{BB} - 3)\sigma][(n^{AB} + n^{BB} - 1)\sigma + (\alpha + 1)(2 - \sigma)]} > 0$$

A domestic cost increase not only lets the export price rise (as shown above), but also the home market price. In addition, a foreign cost increase also induces an upward adjustment of export prices in addition to that of home prices.

Note that the functional form for $E(p^{AA}, c^r)$ is identical to $E(p^{AB}, c^r)$, $r = A, B$, with the only modification that the former elasticity contains variables referring to market A, whereas the second one refers to market B.

It is straightforward to conclude that for differential price responses in the export versus domestic market, differences in market shares of domestic producers between both market are fundamental:

$$[93] \quad E(q^{AB}, c^r) < E(p^{AA}, c^r) \Leftrightarrow E(q^{AB}/p^{AA}, c^r) < 0 \Leftrightarrow s^{AB} < s^{AA}$$

If market integration is not perfect, so that domestic producers retain a larger share at home than abroad, cost changes at home can be passed on more easily in the home market. The same holds for the effect of foreign cost changes. They affect prices in the export market more than in the home market if domestic producers have a relatively large home market share. In general, if shares in different markets tend to equalize each other, there will be less ground for differential price reactions between markets.

III. Conclusion

The objective of this paper is to explain exchange rate and cost pass-through and pricing-to-market in a theoretical framework that combines various determinants for

price setting. Among the most influential factors that are relevant in this respect is the price elasticity of demand which is in turn a function of reservation prices and the substitutability between products if a linear demand schedule is assumed. In addition, switching costs on the consumption side are allowed for, which extend the model to an intertemporal one since the producer takes into account the impact of his current price setting on future profits.

It is shown that a depreciation of the exporter's currency generally leads to a less than proportional increase in export prices in the importer's currency, but also an elasticity greater than one may result if consumers' switching costs are sufficiently high. The expected result that a high degree of substitutability or a reservation price near marginal costs lead to a relatively low amount of pass-through and to less price differentiation across markets is derived. The results for the monopoly and perfect competition emerge as special cases of the general framework. For empirical investigation, this implies that estimates of price responses across sectors should be different between high and low mark-up sectors. It is also of interest whether the shock is assumed to be temporary or permanent, or if it is only expected for the future. Consumers' switching costs increase the effects of costs on domestic and foreign-currency export prices and also increase exchange rate pass-through to domestic prices, both for temporary and permanent shocks, but decrease the amount of pass-through of temporary exchange rate shocks to export prices in foreign currency, whereas for a permanent shock the impact is again increased.

Imperfect exchange rate pass-through to foreign prices necessarily affects the export price in the exporter's currency. In addition, it has been shown in the duopolistic framework to what extent also domestic prices are affected by exchange rate changes due to import competition. Both effects compared, export prices are shown to rise more than domestic prices when the exporter's currency depreciates, irrespective of the parameters. The differential impact of exchange rate changes on prices the producer gets for sales in different markets is named pricing-to-market. This phenomenon also applies here where competitive price setting in only two markets is compared, the domestic and the export market. It has been derived that pricing-to-market plays a great role in sectors where concentration is relatively high and in high mark-up sectors, since pricing-to-

market is increasing in the reservation price and decreasing in substitutability of products. Switching costs increase pricing-to-market when the exchange rate change is temporary, but reduce it when the shock is perceived to be permanent. Concerning the differential of prices different producers set in the same market, it is it does not suffice to know if markups are low or high, but it is required to look at each single determinant of mark-ups.

For many export products of industrialized countries, it generally holds that prices include substantial mark-ups and that switching costs on the demand side often play a role, so the biggest chunk of an exchange rate change is borne by the producer by means of his mark-up adjustment. Short-term exchange rate volatility, when compared to long-lasting misalignments, are also conjectured to increase mark-up adjustment, with a relatively moderate impact on prices in the importer's currency and therefore on trade flows. This is why empirical studies often find a weak role of exchange rates for trade flows relative to other variables explaining demand. Persistent exchange rate misalignments, on the other hand, pose a threat for the international division of labour since they have a relatively large impact on import prices and thus also on trade flows. When a temporary exchange rate and a temporary cost change are compared, the former leads to a larger markup adjustment since the intertemporal discount rate for export earnings is affected, thus reducing pass-through. Cost changes, in turn, are conjectured to lead to more quantity adjustment. Concerning the exposure of the exporter, exchange rate changes, especially if their volatility is short-termed, can be hedged more easily across export regions or over time than cost changes, which affect real exchange rates for all destinations in a uniform way.

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V. Appendix

List of Variables

- x_{it}^{rs} : quantity sold by producer i in country r to a consumer in country s
- p_{it}^{rs} : price in currency of s set by producer i in country r for sale in country s
- q_{it}^{rs} : price in currency of r set by producer i in country r for sale in country s
- Π_i^{rs} : variable profit for producer i in country r from sales to country s in currency of country s
- c^r : unit production costs in country r
- e_t : exchange rate in period t defined as country A currency per unit of country B currency
- s^{rs} : ratio of producers from country r selling in country s relative to all producers selling in country s
- n^{rs} : number of producers from country r selling in country s
- N^s : total number of producers selling in country s

Coefficients

$$k_a = \alpha \left[\beta^2 (4 - \sigma)^2 (4 + \sigma) (2 - \sigma) (2 + \sigma)^2 - 64 \lambda \gamma (\beta (2 + \sigma) + \gamma) \right]$$

$$\times \left[\beta^2 (4 - \sigma) (4 + \sigma)^3 (2 - \sigma)^2 - \lambda (8\gamma)^2 \right]$$

$$k_{aa1} = 8\beta^2 (4 - \sigma) (4 + \sigma) \left\{ b^2 [(4 - \sigma) (4 + \sigma) (2 - \sigma) (2 + \sigma)]^2 - \lambda (16\gamma)^2 \right\}$$

$$k_{ab1} = 2\beta^2 \sigma (4 - \sigma) (4 + \sigma) \left\{ \beta^2 [(4 - \sigma) (4 + \sigma) (2 - \sigma) (2 + \sigma)]^2 - \lambda (8\gamma)^2 (12 - \sigma^2) \right\}$$

$$k_{aa2} = 128\lambda\beta\gamma \left[\beta^2 (4 - \sigma) (4 + \sigma) (2 - \sigma) (2 + \sigma) (16 - 3\sigma^2) - \lambda (8\gamma)^2 \right]$$

$$k_{ab2} = -64\lambda\beta\gamma\sigma \left[\beta^2 \sigma^2 (4 - \sigma) (4 + \sigma) (2 - \sigma) (2 + \sigma) + \lambda (8\gamma)^2 \right]$$

$$k_b = \alpha \left[\beta^2 e_1 (4 - \sigma)^2 (4 + \sigma) (2 - \sigma) (2 + \sigma)^2 - 64 \lambda \gamma (\beta (2 + \sigma) + \gamma) e_2 \right] \\ \times \left[\beta^2 e_1 (4 - \sigma) (4 + \sigma)^3 (2 - \sigma)^2 - \lambda e_2 (8\gamma)^2 \right]$$

$$k_{ba1} = 8\beta^2 (4 - \sigma) (4 + \sigma) \left\{ b^2 e_1 [(4 - \sigma) (4 + \sigma) (2 - \sigma) (2 + \sigma)]^2 - e_2 \lambda (16\gamma)^2 \right\}$$

$$k_{bb1} = 2\beta^2 \sigma (4 - \sigma) (4 + \sigma) \left\{ \beta^2 e_1 [(4 - \sigma) (4 + \sigma) (2 - \sigma) (2 + \sigma)]^2 - \lambda e_2 (8\gamma)^2 (12 - \sigma^2) \right\}$$

$$k_{ba2} = 128\lambda\beta\gamma \left[\beta^2 e_1 (4 - \sigma) (4 + \sigma) (2 - \sigma) (2 + \sigma) (16 - 3\sigma^2) - \lambda e_2 (8\gamma)^2 \right]$$

$$k_{bb2} = -64\lambda\beta\gamma\sigma \left[\beta^2 e_1 \sigma^2 (4 - \sigma) (4 + \sigma) (2 - \sigma) (2 + \sigma) + \lambda e_2 (8\gamma)^2 \right]$$