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ABSTRACT

This paper considers an international oligopoly where firms simultaneously choose both the amount of output produced and the proportion of R&D investment to output. The model captures the links between the exchange rate, market power, innovative activity and price, which are important for the determination of the optimal degree of exchange rate pass-through. It is found that in the long run the pass-through elasticity can be less than, equal to or greater than one depending on R&D effectiveness but in any case it is higher than in models that do not endogenise innovation decisions. The empirical implications of the model are tested using data for Japanese firms exporting to the US market and applying the Johansen multivariate cointegration technique. Particular attention is given to the estimation and identification of the equilibrium price and R&D-intensity equations. The empirical results indicate that price-setting and R&D-intensity decisions of firms are jointly determined in the long run. This interdependence must be taken into account if an accurate estimate of the exchange rate pass-through is to be obtained.

Keywords: Exchange rate pass-through; market power; innovative activity; multivariate cointegration
JEL classification: C32; F39; L13; O31

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1. Introduction

A central question in international economics relates to whether traded goods prices respond proportionately or less than proportionately to exchange rate changes. Recent evidence indicates that exchange rate movements do not necessarily lead to a proportional change in traded goods prices even after a prolonged period of time. This puzzling empirical phenomenon − referred to as incomplete exchange rate pass-through - has been extensively analysed in the literature (for a survey of the empirical literature see Menon, 1995; Goldberg and Knetter, 1997).

Most of the studies on pass-through focus on the micro-foundations of firms' pricing and analyse the determinants of incomplete exchange rate pass-through in the context of imperfectly competitive markets. Specifically, incomplete pass-through is regarded as the endogenous outcome of the profit maximising strategy of firms that sell their products in international markets rather than as a short-run phenomenon caused by the contractual stickiness of prices, as earlier work had assumed. As to the empirical literature, there is conclusive evidence showing that the existence of market power by firms plays a central role in the determination of the optimal degree of exchange rate pass-through (e.g. Feenstra *et al*., 1996).

An issue that has not attracted much attention in the literature relates to the impact of exchange rates on exporting firms' market power and through that on their cost structure and competitiveness, and the implications for the exchange rate pass-through. Recent studies have accounted for the impact of the exchange rate on exporting firms' market power. This endogeneity is an important result derived from the Cournot oligopolistic model in which a depreciation of the importer's currency by increasing the cost of foreign firms, expressed in the currency of the importer, shifts their reaction function inwards and contracts their market share[1,2] - the converse holds for appreciations of the currency of the importer. The impact of the exchange rate on firms' market power should be taken into account if accurate estimates of pass-through are to be obtained. However, Bernhofen and Xu (2000), even after controlling for the effect of this endogeneity in their analysis, cannot conclude that market power

[1] For a theoretical foundation and a detailed discussion see Shy (1996).
[2] The market share of the exporter is defined as the ratio of its exports to the destination country to the latter's total imports.

is the only factor on which to base the analysis of incomplete exchange rate pass-through in the case of Japanese firms exporting to the US market.

This paper introduces innovative activity of oligopolistic firms engaging in international trade in addition to market power as a determinant of pass-through. Recent advances in the theory of industrial organisation point to the importance of innovative activity, and particularly process innovation, for the quantity and pricing decisions of oligopolistic firms. Most of this work, however, examines the impact of innovation on firms' decisions in a closed economy framework (e.g. Dasgupta and Stiglitz, 1980; D'Aspremont and Jacquemin, 1988; Yi, 1999; Lin and Saggi, 2002). In this paper we extend this framework to analyse the impact of cost-reducing investment in R&D on the pricing behaviour of firms that operate in international markets and are subject to exchange rate-induced cost changes. Specifically, we develop a model in which exporting firms' pricing and innovation decisions are endogenously and simultaneously determined. Thus, two optimal relationships are derived and estimated. One relates to the pricing strategy of the exporting firms that are subject to cost changes caused by exchange rate changes, and the other to the innovation strategy of these firms. The model introduces process innovation in a way similar to that of Dasgupta and Stiglitz (1980), in the sense that the unit cost of production is dependent on the level of R&D expenditure and that output and innovation decisions are determined simultaneously. In this context, the interaction between cost changes related to exchange rate changes and cost reductions induced by innovative activity is crucial for the analysis of the optimal degree of pass-through.

The model developed predicts that exporting firms' technological sophistication, along with market power, is an important factor that influences the exchange rate pass-through elasticity, which can be not only less than or equal to one but also greater than one depending on R&D effectiveness[3]. This is a novel result since most previous studies were mainly concerned with explaining incomplete exchange rate pass-through and did not consider innovative activity and its effect on the degree of pass-through. Moreover, our model further predicts that, by accounting for the links between the exchange rate, market power and innovative activity, the bias in the

[3] R&D effectiveness measures the success of R&D investment. Pricing decisions are not affected by the amount of R&D investment but by its output, namely the cost reduction achieved.

estimate capturing the direct impact of exchange rate changes on import prices − which can no longer be interpreted as the exchange rate pass-through coefficient − is likely to be eliminated, since potential endogeneities among the variables are accounted for.

The role of innovative activity is tested using aggregate quarterly data for Japanese firms exporting to the US market for the period 1978-2002. Following common practice in empirical work, innovative activity is proxied by labour productivity and market power by market share. The estimation method used is the Johansen multivariate cointegration technique. A multivariate approach in estimation is adopted since in the presence of indirect effects of exchange rates on firms' market power and innovative activity, single estimations techniques are not appropriate. To anticipate the results, we find that the price and innovation decisions of the Japanese firms exporting to the US market are jointly determined. Also, the pricing and innovation relationships are subject to the restrictions implied by the theoretical model. Finally, we find that when we account for the relationships between the exchange rate, market power and innovative activity, the estimate of the exchange rate effect on price can be considered as bias-free.

The rest of the paper is structured as follows. Section 2 presents a brief literature review. Section 3 describes the theoretical model. Section 4 provides a discussion of the empirical results motivated by the theoretical model. Finally, Section 5 provides concluding remarks.

2. Literature review

The available evidence on the unresponsiveness of import prices to exchange rate changes, which persists for a long time period, motivated a lot of theoretical and empirical work examining the determinants of incomplete exchange rate pass-through.

Most of the theoretical studies link pass-through to deviations from perfectly competitive market structures. One strand of these studies focuses on the interaction between firms exporting to a foreign market and their domestic competitors and obtains pass-through from the industry equilibrium defined by the intersection of the supply functions of foreign and domestic firms, both derived from profit maximisation. Dornbusch (1987) [4] is the most representative study in this category. Dornbusch expresses the degree of exchange rate pass-through to the industry equilibrium price[5] in terms of the relative number of foreign firms that compete in the importer's market (the market share of foreign firms) and the degree to which foreign exporters exercise their market power in the importer's market (measured as the ratio of marginal cost, in the importer's currency, to the price the foreign supplier faces in the importer's market).

The other strand of the theoretical literature recognises the existence of domestic firms but concentrates on the determinants of the import price pass-through. These studies analyse the supply function of foreign firms only, also derived from profit maximisation, from which the optimal degree of pass-through is obtained (e.g. Bernhofen and Xu, 2000; Feenstra, 1989; Feenstra *et al.,* 1996).

In contrast to the industry equilibrium price pass-through, which is always less than one, since it depends on the relative number of firms that experience cost changes related to exchange rate changes, the import price pass-through can be complete. This will be the case when the mark-up and the marginal cost of firms are constant and thus unaffected by the exchange rate. On the other hand, if either of those varies with the exchange rate, the pass-through will be incomplete. The mark-up varies when the price elasticity of demand, a component of the mark-up, is not constant along the demand curve[6] (Feenstra *et al.,* 1996). Moreover, market share, another component of the mark-up, may depend on the exchange rate (see Bernhofen and Xu, 2000) [7]. As for marginal cost, this will be related to the exchange rate to the extent that firms rely on imported inputs (see, Menon, 1996). Furthermore, if the marginal cost is not constant with respect to output and output varies with the exchange rate, the pass-through will be incomplete (see Yang, 1997; Adolfson, 1999).

The large empirical work on the exchange rate pass-through generally shows that Japanese and, in some cases, German firms adopt a pricing strategy that results in less than full pass-through of exchange rate changes into traded goods prices

[4] The work by Menon (1995) and Venables (1990) is in the same direction.
[5] It is implicitly assumed that for homogeneous products there is a common price for both the imported and import-competing goods. Consequently, exchange rate changes are assumed to affect the price of both categories of goods. The extent of the influence is determined by the interaction between the two groups of producers.
[6] This result is derived from studies that adopt a Bertrand framework.
[7] As already mentioned, this is a property of Cournot competition.

(Marston, 1990; Athukorala and Menon, 1994; Feenstra *et al.,* 1996; Kikuchi and Sumner, 1997; Tange, 1997; Yang, 1997; Klitgaard, 1999; and recently Bernhofen and Xu, 2000 and Gross and Schmitt, 2000). On the other hand, UK and US firms do pass through a larger amount of exchange rate movements to the price of their goods sold in foreign markets. The majority of these studies analyse pass-through under the assumption of imperfectly competitive markets and attribute the finding of incomplete pass-through to deviations of the market structure from perfect competition and to the existence of market power by firms. However, these studies do not take into account the dependence of exporting firms' market share, used as proxy for market power, on the exchange rate, mentioned above. If this endogeneity is not accounted for, the estimates of the exchange rate impact on import prices are likely to be downward biased. This misspecification problem is more serious when a two-step approach is followed in estimation, where in the first step the degree of exchange rate pass-through is estimated for different countries (or sectors within a country) from time series regressions relating import prices to the exchange rate[8]. In the second step, the significance of various determinants of pass-through is evaluated from cross-section regressions with the estimated, in the first stage, pass-through coefficients for individual countries used as the dependent variable. In this case, exporting firms' market share, which determines both the optimal import price and the degree of exchange rate pass-through, is not usually taken into account in the first-step regressions. Thus, such regressions suffer from an omitted-variable bias, which influences the reliability of the second-step estimation. Nonetheless, Bernhofen and Xu (2000) in a study that adopts the one-step procedure, even after controlling for the endogeneity of market share (by using instrumental variables estimation) do not find evidence that the bias is eliminated in the case of Japanese firms exporting to the US petrochemical market[9]. This finding implies that the bias may be related to other factors not taken into account in empirical work.

[8] If the competition foreign suppliers face in the importer's market is proxied by the domestic competitors' price (i.e. Bertrand competition is assumed) the bias may still be present if domestic competitors' prices also depend on the exchange rate, through their interaction with foreign exporters (cf. Gross and Schmitt, 2000).

[9] This study analyses static long-run equilibrium import price equations. It defines the exchange rate coefficient as the direct effect of exchange rates on prices (sometimes this is also referred to as partial pass-through cf. Adolfson, 1999). This coefficient must be unity once all adjustments related to pricing decisions have taken place. If this coefficient is not unity, there is indication of omitted variables or omitted interactions among variables.

Thus, the existing framework of analysis may not be appropriate for identifying all possible determinants of exchange rate pass-through. Recent advances in the industrial organisation literature show that innovative activity constitutes, along with market power, an important determinant of firms' pricing decisions. In this area of research, as Lin and Saggi (2002) argue, the bulk of the theoretical literature focuses on process innovation − on cost-reducing investment in R&D.

Studies on process innovation analysing the incentive to innovate under alternative market structures suggest that a larger market share may lead to greater R&D expenditure (Bester and Petrakis, 1993; Yi, 1999; Lin and Saggi, 2002). Market structure can thus affect the pricing behaviour of firms in two ways. One is through its impact on firms' mark-up and the other through its impact on firms' innovative activity, which in turn influences the cost and price of their product. Such an extended framework can capture the links between market structure, process innovation and firms' decisions in the product market (quantity and price setting decisions). Recently, Petit and Sanna-Randaccio (2000) derived the optimal price charged by firms that successfully introduce cost-reducing investment in R&D. Their results suggest that prices depend inversely on R&D effectiveness, although this conclusion is not sufficiently emphasised, as it is not related to the main objective of their analysis.

A key characteristic of most of the above-mentioned work is that it refers to a closed economy and focuses on the analysis of the decisions of firms, which serve only one market, their home market. An exception to this, is the work of Petit and Sanna-Randaccio (2000), which takes into account the firms' external orientation but concentrates on the interaction between innovative activity and the choice of the mode of foreign expansion i.e. whether firms will expand through exporting abroad or through foreign direct investment. Even though the study of the firms' foreign expansion strategy is important, it would be interesting to extend the analysis to the interaction between innovative activity and the quantity and pricing decisions of firms that have a presence in a foreign market. This extension is warranted since the number of firms engaging in international transactions is growing over time.

The adoption of the new industrial organisation framework in the analysis of the quantity and price setting behaviour of export-oriented firms is further supported by the well-documented evidence that exporting firms tend to be more innovative and more technologically sophisticated[10] than firms that produce solely for the home market (for a detailed discussion on the issue see Bernard and Jensen, 1999; Basile, 2001; Wagner, 2002)[11]. Consequently, innovative activity should explicitly be taken into account in the analysis of firms' decisions regarding their pricing behaviour in international markets when they face various adverse cost changes, and in particular cost changes induced by exchange rate changes.

3. The model

In this section we develop an oligopolistic model that examines the pricing behaviour of foreign firms competing with domestic firms in the importer's market. We consider the case of a small number of innovative foreign firms that produce a homogeneous product and face two kinds of decisions. One relates to the amount of output to be produced and the other to the amount of cost-reducing investment in R&D – investment that reduces the cost of producing existing products (process innovation). As to the sequence of decisions, we employ the simplest possible one-period game, i.e. we assume that firms choose simultaneously both the output level and the amount of real resources directed towards innovative activity.

The model developed assumes that firms are homogeneous with respect to their main characteristics, i.e. cost structure, conjectural variations[12], proportion of R&D investment to output and effectiveness of R&D investment. In the analysis that follows we assume that domestic producers are unaffected by exchange rate changes. Thus, we analyse pass-through by focusing our attention on the examination of the pricing and innovation policies of foreign firms only[13].

[10] Wakelin (2001) argues that more technologically sophisticated firms are characterised by a better productivity performance.

[11] Most of the studies on this issue examine whether better and more technologically sophisticated firms become exporters or whether export orientation leads to superior performance in all respects, technology included. Even though this direction of research lies beyond the scope of this paper, it should be kept in mind that exporting firms appear in general to be technologically superior.

[12] The notion of conjectural variation is an essential feature of oligopolistic interdependence. It captures the firm's beliefs concerning the reaction of other firms to its decisions.

[13] Most of the studies on pass-through implicitly assume that domestic producers are unaffected by exchange rate changes and thus the channel through which exchange rates affect the equilibrium price is the foreign firms' marginal cost (expressed in the importer's currency). Accordingly, pass-through is obtained from the analysis of foreign firms' pricing

Let the unit cost of production[14] of the foreign firm be defined as:

$c_j^* = c_j^*(x_j^*)$, where $x_j^* = a_j^* q_j^*$, or $c_j^* = c_j^*(a_j^* q_j^*)$ $\qquad (j = 1, ..., n^*)$

x_j^* corresponds to total resources committed to innovative activity and α_j^* to their proportion to the foreign firm's output q_j^*[15]. According to this specification, only part of the firm's total output is sold in the market, i.e. $(1-\alpha_j^*)q_j^*$.

The specification adopted introduces process innovation in a way similar to that of Dasgupta and Stiglitz (1980). Specifically, the unit cost of production depends on the amount of cost-reducing investment in the sense that a higher commitment of resources to R&D leads to greater cost reductions for the firm. This formulation emphasises the fact that cost does not depend directly on the amount of output produced but indirectly through the impact of the latter on the amount of R&D investment. Output, as a determinant of the amount of this cost-reducing investment, is a factor that shifts the unit cost of production curve downwards.

We define the following profit function of the firm:

$$\Pi_j^* = p(X)(1-\alpha_j^*)q_j^* - ec_j^*(a_j^* q_j^*)q_j^*, \qquad (j = 1, ..., n^*) \tag{1}$$

where p is the industry price, e is the exchange rate defined as the home currency price of foreign currency, $X = Q + \sum_{j=1}^{n^*} q_j^*$ corresponds to total supply in the importer's market and Q and $\sum_{j=1}^{n^*} q_j^* = Q^*$ to domestic and foreign firms' supply, respectively.

The term $\alpha_j^* p q_j^*$, represents revenue foregone and could thus be interpreted as the total cost of innovative activity and as such it is subtracted from the firm's total revenue. Since the firm simultaneously chooses the quantity of output q_j^* and the

equations only, which are derived from their profit maximisation (e.g. Bernhofen and Xu, 2000; Feenstra, 1989 and Feenstra *et a*l., 1996).

[14] The unit cost of production is assumed to be constant for every output level and equal to the marginal cost.

[15] To abstract from the analysis of the impact of alternative ways of investment financing on the firm's innovation decisions, we assume that the firm finances R&D from its own resources – i.e. using a proportion of its output.

fraction of output α_j^* devoted to innovative activity, the two first-order conditions for profit maximisation are[16]:

$$\partial\Pi_j^* \big/ \partial q_j^* = 0 \text{ and } \partial\Pi_j^* \big/ \partial\alpha_j^* = 0$$

The first condition can be written as:

$$(1-\alpha_j^*)p + (1-\alpha_j^*)(\partial p/\partial X)(\partial X/\partial q_j^*)q_j^* - ec_j^*(\alpha_j^* q_j^*) - e[\partial c_j^*(\alpha_j^* q_j^*)/\partial(\alpha_j^* q_j^*)][\partial(\alpha_j^* q_j^*)/\partial q_j^*]q_j^* = 0$$

Defining $\theta_j^* = (\partial X/\partial q_j^*)$, a parameter which captures how market supply reacts to the firm's own supply decisions[17], and $\mu_j^* = -[\partial c_j^*(\alpha_j^* q_j^*)/\partial(\alpha_j^* q_j^*)][(\alpha_j^* q_j^*)/c_j^*(\alpha_j^* q_j^*)]$, the (positive) cost elasticity with respect to the amount of output going to R&D[18], we obtain:

$$p - \alpha_j^* p + (\partial p/\partial X)\theta_j^* q_j^* - \alpha_j^*(\partial p/\partial X)\theta_j^* q_j^* - ec_j^*(\alpha_j^* q_j^*) + e\mu_j^* c_j^*(\alpha_j^* q_j^*) = 0 \qquad (2)$$

Expression (2) can be rewritten in the following form:

$$p - \alpha_j^* p + (\partial p/\partial X)\theta_j^* q_j^* - \alpha_j^*(\partial p/\partial X)\theta_j^* q_j^* = ec_j^*(\alpha_j^* q_j^*) - e\mu_j^* c_j^*(\alpha_j^* q_j^*) \qquad (3)$$

which states that the perceived marginal revenue is equal to the marginal cost. The right-hand side shows that the marginal cost is equal to the initial marginal cost (the term $ec_j^*(\alpha_j^* q_j^*)$) minus the cost reduction achieved through investment in R&D (the term $e\mu_j^* c_j^*(\alpha_j^* q_j^*)$). The third and fourth terms on the left hand side represent the effect on marginal revenue of producing an extra unit of output and capture the firm's beliefs regarding how the other firms react to its output decisions. However, the impact on marginal revenue is lower than in the models without innovation, since a proportion of the increase in output is directed towards innovative activity.

The second condition for profit maximisation can be written as:

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[16] For the domestic firms, the profit maximisation problem can be formulated in a similar way, but without the presence of the exchange rate variable. However, the analysis here focuses on the supply decisions of foreign firms only.

[17] $\theta_j^* = \partial X / \partial q_j^*$, can be regarded as a measure of the degree of market power. It can be decomposed in the following two terms: $\partial X / \partial q_j^* = \partial q_j^* / \partial q_j^* + \sum_{j \neq i} \partial q_i^* / \partial q_j^* = 1 + \sum_{j \neq i} \partial q_i^* / \partial q_j^*$.
The second term corresponds to the conjectural variations mentioned above.

[18] This elasticity can be interpreted as a measure of the success of innovative activity or as a measure of the effectiveness of R&D investment.

$$-e[\partial c_j^*(a_j^* q_j^*)/\partial(a_j^* q_j^*)][\partial(a_j^* q_j^*)/\partial a_j^*]q_j^* - pq_j^* = 0 \tag{4}$$

or

$$p = ec_j^{*\prime}(\alpha_j^* q_j^*)q_j^*$$

The above expression states that the firm should continue investing in R&D until the unit cost of further expenditure on R&D (given by the revenues foregone p) is equal to the benefit from the increased expenditure (given by the cost-reduction achieved times the output produced $ec_j^{*\prime}(\alpha_j^* q_j^*)q_j^*$). This interpretation is similar to that given by Dasgupta and Stiglitz (1980).

Rearranging (4) and using the definition of μ_j^* given above − the cost elasticity with respect to the amount of R&D investment − we obtain the following expression for the proportion of the firm's output committed to innovative activity:

$$\alpha_j^* = e\mu_j^* c_j^* / p \tag{5}$$

Each of the two optimality conditions (3) and (5) can be summed-up over n^* in order to derive the profit-maximising conditions for the industry as a whole. Given the homogeneity assumptions adopted, c_j^*, θ_j^*, α_j^* and μ_j^*, must be independent of j for $j = 1, 2, \ldots . n^*$. Thus, the first condition becomes:

$$n^* p - n^* \alpha^* p + (\partial p/\partial X)\theta^* Q^* - (\partial p/\partial X)\alpha^* \theta^* Q^* - n^* ec^* + n^* ec^* \mu^* = 0 \tag{6}$$

or, defining $\beta^* = \frac{\eta\theta^*}{n^*}$[19], η the (positive) elasticity of market demand, i.e. η=-$\left(\partial X/\partial p\right)\left(p/X\right)$, and s^* the foreign firms' market share, i.e. $s^* = Q^*/X$, it becomes:

$$p = \frac{ec^*(1-\mu^*)}{(1-\alpha^*)(1-\beta^* s^*)} \tag{7}$$

which is the industry supply relationship.

[19] This definition implicitly assumes that the conjectural variations and the price elasticity of demand are constant for all price and exchange rate values.

Similarly, summing up the second first-order condition (eq. 5) over n^*, yields the corresponding condition for the industry as a whole:

$$\alpha^* = e\mu^* c^* / p \tag{8}$$

Equations (7) and (8) show that the price and the proportion of R&D investment to output are jointly determined. Recognising that R&D intensity is likely to change with movements in the exchange rate, which affect the equilibrium condition (5) − i.e. the equality between the marginal cost and the marginal benefit of R&D investment − we should control for such an indirect effect when calculating the pass-through elasticity from equation (7). For this purpose, the system of equations (7) and (8) is solved to yield the reduced-form solution:

$$p = ec^* \frac{(1-\mu^*\beta^* s^*)}{(1-\beta^* s^*)} \tag{9}$$

and

$$\alpha^* = \mu^* \frac{(1-\beta^* s^*)}{(1-\mu^*\beta^* s^*)} \tag{10}$$

Taking logarithms of both sides of (9) and (10) and using linear approximations to the Taylor series expansion of the logarithms, we obtain estimable equations for the industry price (p) and R&D intensity (α^*):

$$\ln p = \ln e + \ln c^* + (1-\mu^*)\beta^* s^* \tag{11}$$

and

$$\ln \alpha^* = \ln \mu^* - (1-\mu^*)\beta^* s^* \tag{12}$$

Both industry price and R&D intensity are seen to depend on the effectiveness of R&D investment (i.e. the parameter μ^*). In particular, the more effective R&D investment is, the greater the reduction of cost and price (for a similar result, see Petit and Sanna-Randaccio, 2000). Also the effectiveness of R&D investment, by influencing the size of the output effect, influences the incentive to adopt this cost-reducing investment for a given market share[20].

A further characteristic of equations (11) and (12) is that they include a market share variable and thus explicitly account for market power. As indicated in the previous section, it has been argued that market power induces innovative activity since it creates a favourable climate for innovation and technical progress (cf. Dasgupta and Stiglitz, 1980). This result holds true in (12) only to the extent that there is a large payoff to innovative activity $\left(\mu^* > 1\right)$.

The exchange rate pass-through elasticity can be obtained by differentiating equation (11) with respect to the exchange rate:

$$\varphi = \frac{\partial \ln p}{\partial \ln e} = 1 + \left(1 - \mu^*\right)\beta^* \frac{\partial s^*}{\partial \ln e} \tag{13}$$

There are two features of the pass-through elasticity that need to be discussed: how it varies with the market share and how large it is. In the Cournot model the market share is negatively related to the exchange rate. A depreciation of the importer's currency increases the marginal cost of foreign firms and shifts their reaction functions inwards. Thus, their market share in the importer's market is reduced – the converse holds for appreciations of the currency of the importer – consequently, $\partial s^* / \partial \ln e < 0$. This result critically depends on the assumption that domestic producers are unaffected by exchange rate changes. However, if domestic producers are subject to exchange rate-induced changes in competitiveness, due to their reliance on imported inputs and/or their interaction with foreign producers (see Marston, 2001), this result may not hold.

We turn now to the size of the pass-through elasticity. Equation (13) shows that the higher the effectiveness of R&D investment, the more pass-through will occur. For $\mu^* < 1$ the pass-through is incomplete, since $\beta^* > 0$ and the market share decreases following a depreciation of the exchange rate. In this case though the pass-through elasticity is larger than that obtained from models not assuming process

[20] The output effect of R&D investment is measured as the cost reduction achieved times the output produced. Thus, this effect depends both on the amount of output produced and the effectiveness of R&D investment (see Bester and Petrakis, 1993).

innovation. Bernhofen and Xu (2000), for example, derive the following elasticity from a homogeneous-product oligopoly model:

$$\varphi = \frac{\partial \ln p}{\partial \ln e} = 1 + \beta^* \frac{\partial s^*}{\partial \ln e} \tag{14}$$

which differs from (13) in the factor $(1-\mu^*)$. The intuition behind this result is straightforward: a depreciating exchange rate increases cost and decreases market share but process innovation reduces cost. The latter effect tends to weaken the exchange rate-induced impact of market share on the pass-through elasticity. If $\mu^* = 1$, there will be complete pass-through. Finally, if $\mu^* > 1$, the price will rise proportionately more than the exchange rate change. This result reflects the fact that greater R&D effectiveness leads to greater cost reductions. This effect tends to outweigh the exchange rate-induced impact of market share on the pass-through elasticity and thus reinforces the direct cost effect of exchange rate changes.

Thus, it can be concluded that, depending on the parameter μ^* of R&D effectiveness, the pass-through elasticity can be not only less than or equal to one but also greater than one. Indeed, as μ^* goes from $\mu^* < 1$ to $\mu^* = 1$ and $\mu^* > 1$, the pass-through elasticity rises commensurately and for $\mu^* > 1$ becomes greater than one. This is a novel result since most previous studies have not examined innovative activity and its interaction with market power and the exchange rate, and thus have not estimated its effect on the degree of exchange rate pass-through.

Given the interactions among the variables discussed in this section, pass-through cannot be obtained from the estimation of equilibrium relationship (11), since an estimate of the impact of the exchange rate on market share is also required. The estimate of the coefficient of the exchange rate in (11) gives us an estimate of the direct effect of the exchange rate on prices – the partial pass-through – which ignores the effects working through the other variables (cf. Adolfson, 1999). Total pass-through, i.e. the total effect of changes in the exchange rate working through all interactions in the system can only be obtained from a full system dynamic estimation.

4. Empirical investigation

In this section we provide empirical evidence on the relationship between the exchange rate, market share, innovative activity and price. We draw on the experience of Japanese firms exporting to the US market during the period 1978-2002 as it appears that the pricing behaviour of these firms cannot be adequately explained in terms of market power alone (see e.g. Bernhofen and Xu, 2000). In fact, Japanese export-oriented industries besides being oligopolistic (see Bodnar *et al.*, 2002) are characterised by a high degree of R&D intensity, which may also impact on their cost and pricing behaviour (see Cohen *et al.,* 2002) [21]. These two features accord well with the structure and hypotheses of the theoretical model developed above.

The two reduced-form equations (11) and (12), which were derived from the firms' profit maximisation and determine their optimal pricing and research intensity respectively, will be tested empirically as equilibrium relationships using the Johansen multivariate cointegration technique. This method allows us to account for the possible interactions, discussed above, between the exchange rate, market share, innovative activity and price and thus eliminate the endogeneity bias that is likely to have affected the estimates of the exchange rate coefficient in the price equations of previous studies that were used as the basis for obtaining estimates of the exchange rate pass-through. Moreover, since eqs (11) and (12) are the outcome of the firms' simultaneous choice of the profit maximising levels of output and their research intensity, the Johansen technique, by allowing for their joint estimation, can take into account the possible short-run and long-run links between the two equations.

The Johansen technique involves the estimation of a vector error correction model (VECM) of the following form:

$$\Delta z_t = \Gamma_1 \Delta z_{t-1} + ... + \Gamma_{k-1} \Delta z_{t-k+1} + \Pi z_{t-k} + \Psi D_t + u_t \qquad (15)$$

which may be considered as a reparameterisation of an initial VAR model. Δ is the first-difference operator, z_t the vector of endogenous variables and D_t the vector of deterministic and/or exogenous variables. The above specification contains

[21] Data on Japanese R&D expenditure as a percent of value added in industry indicate that Japanese firms spend a lot on R&D. In particular, in the period 1995 through 2001, Japanese R&D expenditure as percent of value added in industry was higher than in the US, UK and Germany. These data are available from the *Main Science and Technology Indicators* of the OECD.

information for both the short-run and the long-run relationships via the estimates of Γ_i and Π respectively. The matrix Π can be expressed as $\Pi = \alpha\beta'$, where α represents the matrix of the speed of adjustment parameters and β the matrix of long-run coefficients. The rank of the Π matrix – the number of cointegrating vectors – is determined by the trace and the maximum eigenvalue statistics proposed by Johansen (1988).

Testing for the number of long-run relationships is carried out by estimating a five-dimensional VAR, such as (15), where the vector of the endogenous variables is: $z = \begin{bmatrix} p & e & c^* & s^* & \alpha^* \end{bmatrix}$ and p corresponds to import prices, e to the US dollar/ Japanese yen nominal exchange rate, c^* to the Japanese producer price index used as a measure of foreign marginal cost, s^* to the ratio of US imports from Japan to US final sales[22] measuring market share and α^* [23,24] to productivity used as a proxy for Japanese firms' R&D intensity [25, 26]. Table 1 reports the estimated trace test statistics and the respective critical values at the 95 percent significance level[27]. According to the trace test there is evidence for two cointegrating vectors. Note that a trend was included in the cointegrating vectors to account for any deterministic trend component of productivity (related for example to factors such as structural reforms – for a discussion see Salgado, 2002; Fukao *et al*., 2003) that would make the long-run combination of variables trend stationary (Johansen, 1995). Failure to correctly model the deterministic component could have biased the results towards rejecting cointegration (Zhou, 2003).

[22] Final sales are defined as GDP minus net exports

[23] We use productivity as a proxy given the lack of data on R&D expenditure at high frequencies.

[24] Our choice of the proxy is based on the fact that process innovation is usually defined as a reduction in the unit labour requirement i.e. an improvement in productivity (see Calabuig and Gonzalez-Maestre, 2002). There is also evidence of a positive and significant relationship between firms' R&D expenditure and productivity growth (see e.g. Wakelin, 2001).

[25] A detailed analysis of data definitions and sources is provided in the Appendix.

[26] All series are I(1) as suggested by the ADF test and the lag length was chosen to be five on the basis of misspecification tests and in order to avoid overparameterisation. The test results are not reported here but are available upon request.

[27] Misspecification tests indicate the presence of non-normal errors. However, this may not be a serious problem, as the trace test statistic is robust in the presence of non-normal errors (for a discussion see Cheung and Lai, 1993 and Garratt *et al*., 2003).

The estimated coefficients of the two cointegrating vectors have the theoretically expected signs. However, further testing is required in order to assess whether these relationships are subject to the restrictions implied by the theoretical model. Identification of the relationships can be attempted without imposing any restrictions on the matrices of short-run responses – Γ_i – or the speed of adjustment parameters – α – (see Pesaran and Shin, 2002). Thus, only over-identifying restrictions are imposed and tested on the long-run structure. These restrictions are the unit restriction on the exchange rate coefficient in the price vector and the exclusion restrictions on the coefficients of the exchange rate and the foreign marginal cost in the R&D-intensity vector. The restricted structure thus reads as follows:

$$\beta' = \begin{bmatrix} \beta_1' \\ \beta_2' \end{bmatrix} = \begin{bmatrix} 1 & -1 & \beta_{13} & \beta_{14} & 0 \\ 0 & 0 & 0 & \beta_{24} & 1 \end{bmatrix}$$

The LR test statistic reported in Table 1 suggests that the restrictions are not rejected at the 5 percent significance level. The unit exchange rate coefficient in the price vector indicates that, by accounting for the dependence of market share and R&D intensity on the exchange rate, we are able to eliminate the downward bias in the estimate of the direct exchange rate effect on price. Also, the exclusion restriction on the exchange rate coefficient in the second vector indicates that the impact of the exchange rate on R&D intensity is not direct but transmitted through its impact on market share.

A further prediction of the theoretical model is that the market share coefficients in the two vectors should be equal in magnitude but of opposite sign. Thus, in addition, a cross-equation restriction is tested on these coefficients and the new restricted structure becomes:

$$\beta' = \begin{bmatrix} \beta_1' \\ \beta_2' \end{bmatrix} = \begin{bmatrix} 1 & -1 & \beta_{13} & \beta_{14} & 0 \\ 0 & 0 & 0 & -\beta_{14} & 1 \end{bmatrix}$$

The outcome of the LR test, presented in Table 1, shows that this restriction, along with the previous restrictions, is validated by the data.

Note that in both cases (i.e. in the model with or without the cross-equation restriction) the relationship between market share and price is negative, while that between market share and R&D intensity is positive. These results seem to imply that R&D effectiveness of Japanese exporting firms is large (i.e. $\mu^* > 1$) and thus the incentive to adopt cost-reducing investment in R&D is also strong.

As a final step, we perform robustness tests on the estimated model. Thus, we first examine the stability properties of the long-run structure. Two types of tests can be applied here. One looks at the stability of the cointegrating vectors. In this test, we examine the plotted values of the recursively estimated eigenvalues. Since a relationship exists between the eigenvalues and α and β, i.e. the matrices of the speed of adjustment parameters and of the cointegrating vectors respectively, any shifts or trends in the time path of the eigenvalues can be regarded as an indication of instability of α and/or β (see Hansen and Johansen, 1999). The other test investigates the stability of the over-identifying restrictions over time. It involves the recursive estimation of the LR test statistic for the over-identifying restrictions, which is plotted at each point in time against the respective critical value. Since the stability of the imposed long-run structure does not exclude shifts in the freely varying parameters, the constancy of the individual unrestricted coefficients will also be tested by plotting the recursively estimated coefficients against their +/- 2SE bands.

Considering that Japan experienced a productivity slowdown in the 1990s, we have chosen the year 1990 as the starting point of our recursive estimation. The slowdown in Japanese productivity growth is a well-documented fact. Salgado (2002) reports that labour productivity growth in the Japanese business sector has declined substantially during this decade. Total factor productivity (TFP) growth has followed a similar pattern. According to Fukao *et al.* (2003), the slowdown in the Japanese TFP growth occurred in the manufacturing sector, while TFP growth in the non-manufacturing sectors has accelerated in the 1990s. Thus, through this recursive estimation, we shall investigate if these developments in productivity have affected the stability of the estimated system.

The paths of the plotted values of the two recursively estimated eigenvalues are smooth providing evidence of stability of the cointegrating vectors (see Figure 1).

Further, the recursively estimated LR test statistic[28] for the over-identifying restrictions does not indicate any serious instability. The acceptance of these restrictions appears to be sample-independent except for three observations in the period 1999-2000 where the restrictions are rejected at the 1 percent significance level (see Figure 2). As to the cross-equation restriction on the market share coefficients, this is generally accepted for every time period except for 1995Q3 (see Figure 3). Also, the plots of the recursively estimated unrestricted coefficients support the stability of these coefficients. In particular, the bands for the estimate of the market share coefficient in the R&D-intensity vector are quite narrow and do not cross the horizontal axis at any point in time. This implies that the market share coefficient retains its sign in all time periods (see Figures 4 and 5).

Overall, the above results indicate that Japanese firms' pricing and R&D-intensity decisions are adequately described by the model consisting of equations (11) and (12). In addition, tests on the cointegrating vectors suggest that the estimated system is fairly stable and that the theoretical restrictions derived in the previous section are data-consistent. Thus, it can be concluded that pricing and innovation decisions are jointly determined and that both market power and innovative activity are important determinants of the optimal pricing behaviour of Japanese exporting firms to the US market. This must be taken into account for the determination of total pass-through – the total effect of changes in the exchange rate working through all interactions in the system. However, an estimate of the pass-through cannot be obtained from the above analysis since here we have focused on the long-run identification of the system and not on the full system's dynamics.

5. Conclusions

In this paper we considered exporting firms' pricing and innovation decisions in the context of a Cournot model of oligopolistic competition, where firms simultaneously choose both the amount of output produced and the proportion of R&D investment to output. The endogenisation of R&D intensity, which is absent in traditional models of the exchange rate pass-through, makes it possible to address

[28] The recursive estimation is performed by conditioning on the full-sample estimates of the short-run parameters, which gives us sufficient degrees of freedom (cf. Hansen and Johansen, 1999).

issues such as the impact of innovation on firms' pricing behaviour in international markets and the size of the exchange rate pass-through elasticity.

The model developed predicts that the relationship between the exchange rate, market power and innovative activity is important for the determination of both the firms' pricing strategy and the degree of exchange rate pass-through. An innovative feature of our work is the theoretical finding that, under the assumption that domestic producers are unaffected by the exchange rate, in the long run the pass-through elasticity can be less than, equal to or greater than one depending on R&D effectiveness. This adds to the literature on exchange rate pass-through where the debate so far has largely been confined to the distinction between incomplete and complete pass-through.

The predictions of the model have been tested empirically using data for Japanese firms exporting to the US market over the last 25 years. The results indicate that the pricing and innovation decisions of Japanese firms are jointly determined in the long run. This interdependence should be taken into account if an accurate estimate of pass-through is to be obtained.

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Appendix: Data definitions and sources

The US import price data are taken from the OECD's International Trade and Competitiveness Indicators. They are import unit values expressed in US dollars (1995=100). The Japanese yen / US dollar exchange rate is the period average and is taken from the International Financial Statistics (IFS) of the IMF. The Japanese producer price index (1995=100) is from the OECD's Main Economic Indicators. Market share is the ratio of US imports from Japan to US final sales (OECD's Monthly International Trade and Main Economic Indicators). Labour productivity is the ratio of Japanese GDP to civilian employment (index, 1995=100. Source: IFS and OECD's Quarterly Labour Force Statistics).

Table 1: Estimates of the long-run structure

A. Number of cointegrating vectors[1]	Trace test	
0	105.80 (87.30)	
1	66.90 (63.00)	
2	42.40 (42.40)	
B. Over-identifying restrictions implied by eqs (11) and (12) – No restriction imposed on market share coefficients		
Coefficients on cointegrating vector variables[2]	Price vector	R&D-intensity vector
p	1	
e	-1	
c*	-5.736 (0.796)	
s*	6.589 (2.394)	-1.710 (0.259)
α^*		1
LR test for the over-identifying restrictions[3]	$X^2(3) = 7.117(0.068)$	
C. Over-identifying restrictions implied by eqs (11) and (12) – Restriction imposed on market share coefficients		
Coefficients on cointegrating vector variables[2]	Price vector	R&D-intensity vector
p	1	
e	-1	
c*	-8.064 (1.390)	
s*	1.955 (0.00)	-1.955 (0.246)
α^*		1
LR test for the over-identifying restrictions[3]	$X^2(4) = 9.288(0.054)$	

Notes: 1. Numbers in parentheses are critical values at the 5 percent significance level
2. Numbers in parentheses are asymptotic standard errors
3. Numbers in parentheses are p-values to accept the over-identifying restrictions

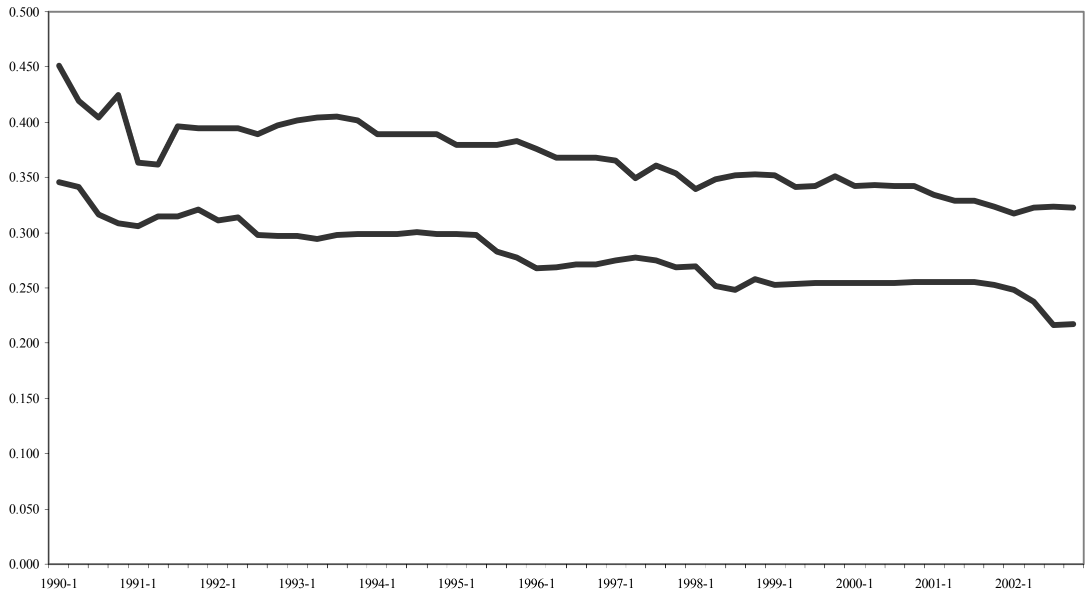

Figure 1: Recursively estimated eigenvalues

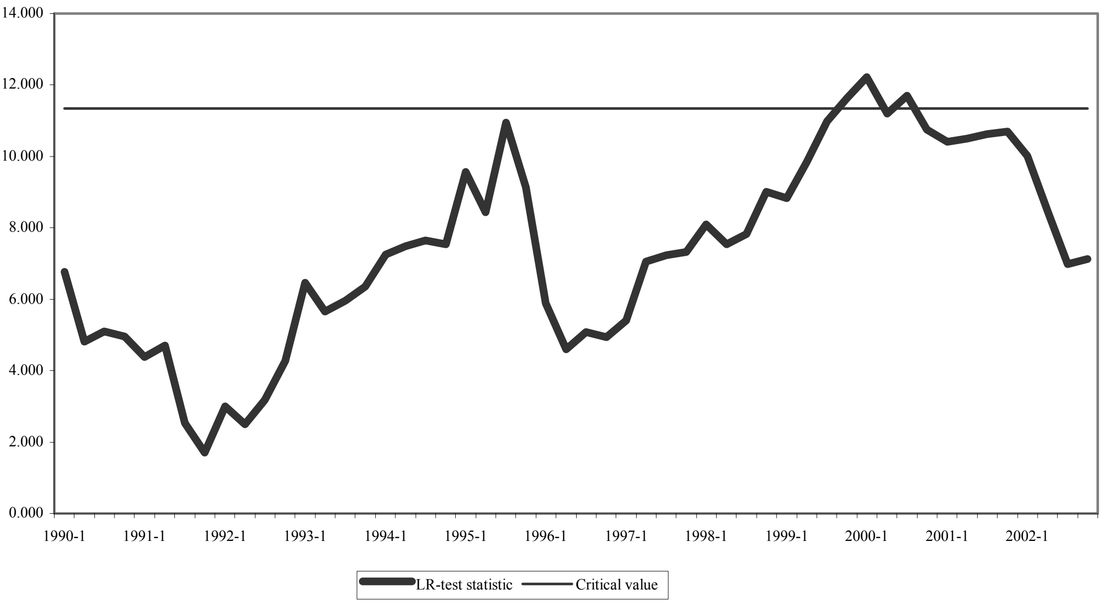

Figure 2: Recursively estimated LR test statistic for the over-identifying restrictions – No cross-equation restriction imposed on market share coefficients

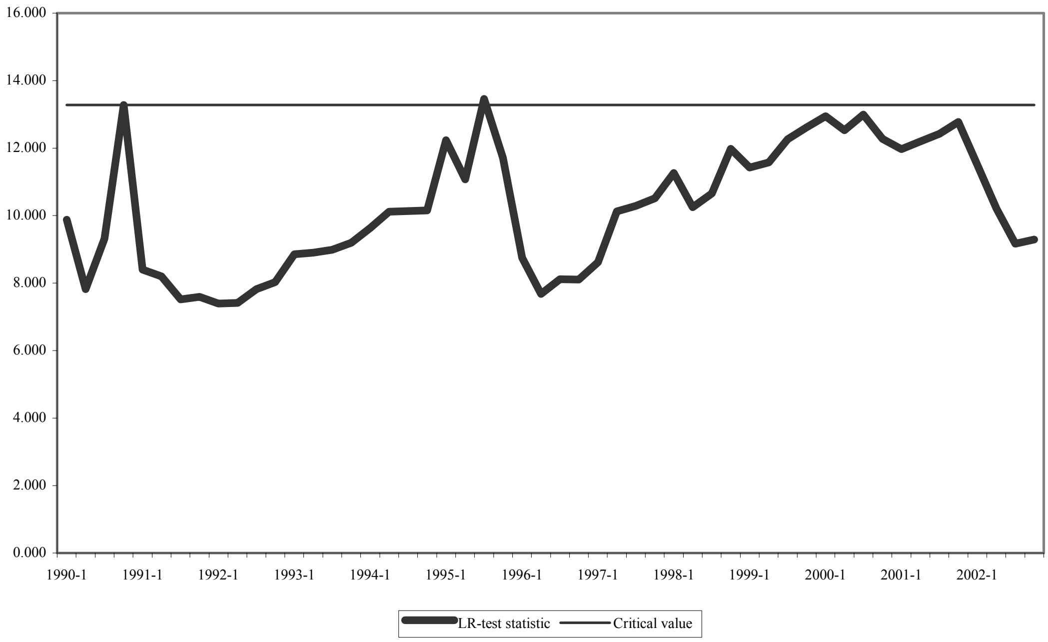

Figure 3: Recursively estimated LR test statistic for the cross-equation restriction on market share coefficients

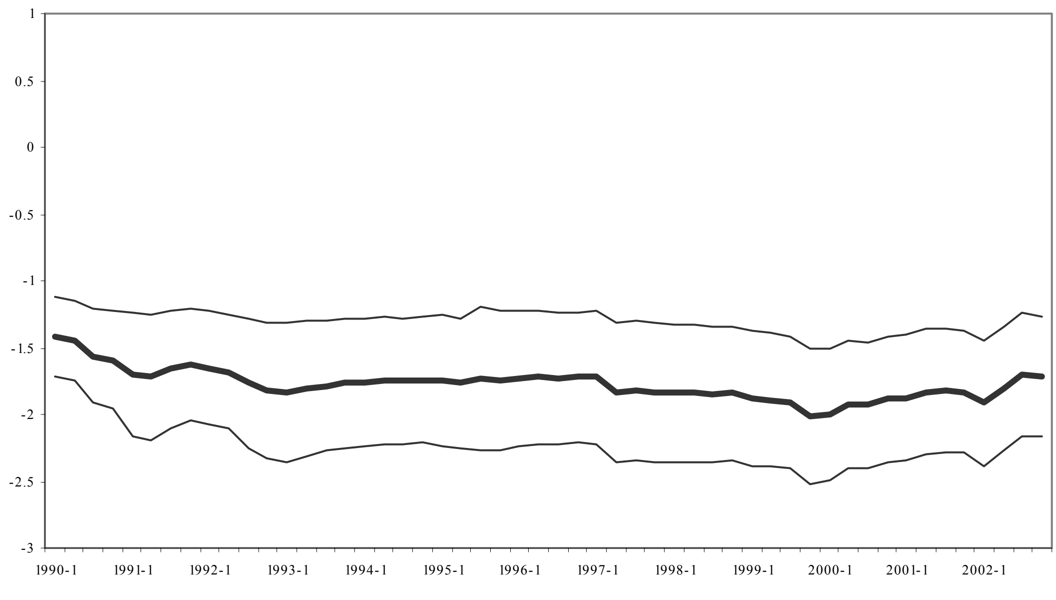

Figure 4: Recursively estimated market share coefficient in the R&D-intensity vector and +/- 2SE bands – No cross-equation restriction imposed

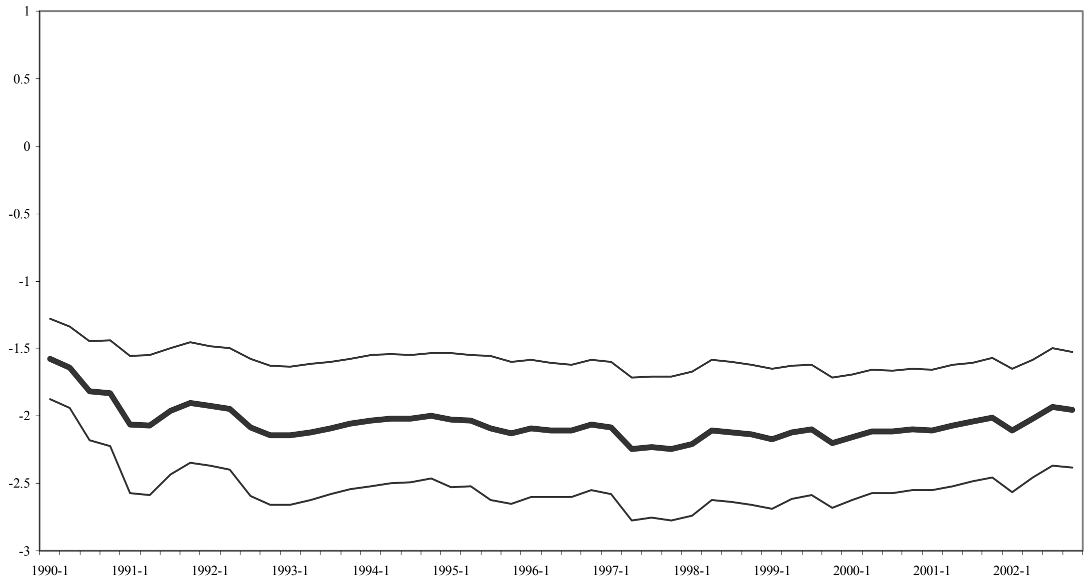

Figure 5: Recursively estimated market share coefficient in the R&D-intensity vector and +/- 2SE bands – Cross-equation restriction imposed

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