A UNIFIED FRAMEWORK FOR ANALYSING PRICE INTERDEPENDENCE, INNOVATIVE ACTIVITY AND EXCHANGE RATE PASS-THROUGH

SOPHOCLES N. BRISSIMIS AND THEODORA S. KOSMA

Abstract

This paper develops an international oligopoly model in which domestic and foreign firms simultaneously choose their price and innovation strategies under the assumption of non-zero conjectural variations in relation to their competitors’ price changes. The model captures the links between the exchange rate, foreign and domestic firms’ prices and investment in process innovation and provides a unified framework for analysing exchange rate pass-through. Estimations allowing for all these exchange rate links and using data relating to Japan’s presence in the US market provide evidence of a pass-through elasticity, higher than reported in studies that do not account for these interactions.

Keywords: Exchange rate pass-through; Conjectural variations; Translog expenditure function; Innovative activity

JEL classification: C32; F39; L13; O31

1 Bank of Greece and University of Piraeus, and Bank of Greece, respectively. The views expressed in the paper are of the authors and do not necessarily reflect those of the Bank of Greece. Corresponding author: Tel.: +(30) 210 3202642; fax: +(30) 210 3233025; Email: tkosma@bankofgreece.gr.
A UNIFIED FRAMEWORK FOR ANALYSING PRICE INTERDEPENDENCE, INNOVATIVE ACTIVITY AND EXCHANGE RATE PASS-THROUGH

1. Introduction

The available evidence on the unresponsiveness of traded goods prices to exchange rate changes has motivated a lot of work on the issue. Many studies adopt an international oligopoly setting as the framework of analysis and regard incomplete exchange rate pass-through as a profit maximising strategy of firms that sell their products in international markets. However, even though these studies recognise the existence of domestic competitors, they restrict their attention to the analysis of foreign firms’ reaction function. They thus examine pass-through by focusing on the impact the exchange rate may have on these firms’ market share, cost structure and investment in process innovation (e.g. Brissimis and Kosma, 2005). The possible impact of the exchange rate on domestic firms’ prices and competitiveness is usually ignored.

It would, however, be unreasonable to assume that domestic producers are unaffected by the exchange rate. First, the available evidence indicates that domestic firms’ pricing strategies depend on their foreign competitors’ prices (Allen, 1998) and are, thus, indirectly linked to the exchange rate. Second, the exchange rate, by influencing the market share of domestic firms, is likely to affect these firms’ incentive to adopt process-improving R&D investment.

Therefore, the pass-through estimates obtained from the above studies correspond to the partial pass-through, i.e. the one working through the foreign firms’ reaction function. Total pass-through, which accounts for all possible channels of influence of the exchange rate, cannot be obtained in this context.

---

2 In the Cournot model, widely used in the literature, the market share of the foreign firms is negatively related to the exchange rate. A depreciation of the importer’s currency increases the marginal cost of foreign firms (expressed in the currency of the importer) and shifts their reaction function inwards. Thus, their market share in the importer’s market is reduced (for a discussion see Shy, 1996).

3 The translog demand structure adopted in many recent studies (Allen, 1998; Bergin and Feenstra, 2001 and Feenstra, 2004) suggests that domestic firms’ market share depends not only on their prices but also on the prices of their foreign competitors. Since the latter prices depend on the exchange rate, the domestic firms’ market share will be indirectly linked to the exchange rate.
This paper develops an international oligopoly model, where a foreign firm that produces a slightly differentiated product competes with a domestic firm in the importers’ market. These two firms simultaneously decide on their pricing and innovation strategies. The model produces four equilibrium relationships that describe the foreign and domestic firm’s price and innovation decisions. The model, by endogenising the price and innovation decisions of the foreign and the domestic firm, captures all possible exchange rate links and thus provides a unified framework for obtaining accurate estimates of pass-through.

The implications of the model are tested using monthly data for the Japanese firms’ exports to the US market over the period 1993 through 2004 and applying the Johansen multivariate cointegration technique. To preview the results, we find evidence of a pass-through elasticity that is greater than that obtained from studies that do not allow for the impact of the exchange rate on foreign and domestic firms’ process-innovation decisions.

The rest of the paper is structured as follows. Section 2 describes the theoretical model. Section 3 provides a brief description of the econometric method and discusses the empirical results. Finally, Section 4 provides concluding remarks.

2. Model

In this section we develop an ologopolistic model, which examines the pricing behaviour of foreign firms that produce a slightly differentiated product and compete with domestic firms in the importer’s market. These firms face two kinds of decisions. One relates to their pricing strategy and the other to their investment in 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 their pricing strategy\(^5\) and the amount of real resources directed towards innovative activity\(^6\), given

\(^4\) In the literature it is argued that market structures that guarantee a larger market share to firms are likely to lead to more investment in process innovation (Bester and Petrakis, 1993; Yi, 1999; Lin and Saggi, 2002).

\(^5\) When firms produce differentiated products, price competition can be assumed. In this case price competition is profitable since imperfect substitutability does not lead to marginal cost pricing as in the case of homogeneous products (Hay and Morris, 1991, p.116).

\(^6\) When dynamic elements in either demand or supply are not assumed, a single-period game can be adopted (Kandiyali, 1997). The impact of dynamic demand and supply effects on pass-through have been analysed elsewhere (Gross and Schmitt, 2000; Froot and Klemperer, 1989 and Kasa, 1992) and their examination is beyond the focus of the present study.
expectations about the reaction of their rivals to their price changes – these expectations are captured by a non-zero conjectural variation term for price changes. It is also assumed that firms in each country are identical (Yang, 1997) and we can therefore consider a game between two firms – one foreign and one domestic.

The specification adopted in this model introduces process innovation in a way similar to that of Dasgupta and Stiglitz (1980). Specifically, the unit cost of production of the foreign and the domestic firm is defined as:

\[ c_j = c_j(x_j), \quad \text{where} \quad x_j = a_j q_j, \quad \text{or} \quad c_j = c_j(a_j q_j) \quad j = 1, 2 \]

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

This specification assumes that the unit cost of production depends on the amount of cost-reducing investment in process innovation in the sense that a higher commitment of resources to process innovation leads to greater cost reductions for the firms. This formulation further, assumes that cost does not depend directly on the amount of output produced but indirectly through the impact of the latter on the amount of investment in process innovation. Thus, output as a determinant of the amount of this cost-reducing investment, is a factor that shifts the unit cost of production curve downwards.

The demand for the firms’ products is derived from a homothetic expenditure function of the translog form (cf. Diewert, 1974; Bergin and Feenstra, 2001 and Feenstra, 2003):

\[ \ln X = \ln U + \beta_0 + \sum_{i=1}^{n} \beta_i \ln p_i + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} \ln p_i \ln p_j, \quad \text{with} \quad \gamma_{ij} = \gamma_{ji} \quad (1) \]

---

7 For expositional purposes we assume that firms have non-zero conjectural variations in relation to their competitors’ pricing strategies but zero conjectural variations in relation to their competitors’ innovation strategies.

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

9 We assume that the firms finance investment in process innovation from their own resources, i.e. using a proportion of their output, and we thus abstract from the analysis of the impact of alternative ways of investment financing on the firms’ innovation decisions.
where $X$ is the minimum expenditure necessary to obtain a specific utility level at given prices, $U$ is the level of utility and $p_i, p_j$ are the prices of good $i$ and $j$, respectively. For our two-firm model, $n = 2$. From the logarithmic differentiation of (1) with respect to the price of good $i$, we can obtain demand functions in budget share form, namely the share of good $i$ in total expenditure.

Thus, $s_i = \frac{\partial \ln X}{\partial \ln p_i} = \beta_i + \sum_{j=1}^{n} \gamma_{ij} \ln p_j$ (2)

where $s_i$ is the share of good $i$. The term $\beta_i$ in eq. (2) represents the so-called basic market share, i.e. the market share that each firm could attain if prices were equalised and which depends on tastes, advertising, past market shares and switching costs (Allen, 1998).

Firms, therefore, maximise profits – expressed in the currency of the importer – by choosing their prices and the proportion of investment under the constraint of the above demand structure.

Therefore the profit function of the foreign firm can be defined as follows:

$$\Pi_i = p_i (1 - \alpha_i) q_i - ec_i (a_i q_i)q_i$$ (3)

where $p_i$ corresponds to the price of the imported good, $q_i$ to the foreign firm’s supply, $e$ to the exchange rate defined as the home currency price of foreign currency, $c_i$ to the foreign firm’s marginal cost and $\alpha_i$ to the proportion of foreign firm’s output devoted to innovative activity – the foreign firm’s process-innovation intensity. The term $\alpha_i p_i q_i$, 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.

---

10 To ensure that the expenditure function will be homogeneous of degree one, it is assumed that: $\sum_{i=1}^{n} \beta_i = 1$ and $\sum_{i=1}^{n} \gamma_{ij} = \sum_{j=1}^{n} \gamma_j = 0$.

11 This result is based on the application of Shephard’s lemma (for a discussion see Chung, 1994, p.203).
If the foreign firm’s profit function is rewritten in terms of market share we obtain the following expression for the foreign firm’s profits\textsuperscript{12,13}:

\[
\Pi_i = \left(1 - \alpha_i\right) - \frac{ec_1(\alpha_i, q_i)}{p_i} s_i X
\]

where \(s_i\) is the foreign firm’s market share and \(X\) is total expenditure, as defined above. Since the firm simultaneously chooses its price \(p_i\) and the fraction of output \(\alpha_i\) devoted to innovative activity, the two first-order conditions for profit maximisation are:

\[
\frac{\partial \Pi_i}{\partial p_i} = 0 \quad \text{and} \quad \frac{\partial \Pi_i}{\partial \alpha_i} = 0
\]

The first condition can be written as:

\[
\left[\frac{ec_1}{p_1^2} - \frac{ec_1(\alpha_i, q_i) \alpha_i}{\partial(\alpha_i, q_i)} \frac{1}{p_i} \right] s_i X + \left(1 - \alpha_i\right) \left[\frac{\bar{c}_{s_i}}{\partial \bar{p}_1} + \frac{\bar{c}_{s_i}}{\partial \bar{p}_2} \frac{p_2}{p_i}\right] X = 0
\]

where \(p_2\) is the price of the domestic firm and \(\frac{\partial p_2}{\partial p_i}\) is the foreign firm’s conjectural variation, i.e. its expectation about the domestic firm’s reaction to its own price change\textsuperscript{14}.

Assuming that \(\eta_{s_i} = \frac{\bar{c}_{s_i}}{\partial \bar{p}_1} \frac{p_1}{s_i}\) is the elasticity of the foreign firm’s market share with respect to its price, \(\eta_{s_i} = \frac{\bar{c}_{s_i}}{\partial \bar{p}_2} \frac{p_2}{s_i}\) is the elasticity of the foreign firm’s market

\textsuperscript{12}Eq. (4) is derived from eq. (3) as follows: by multiplying the first term of eq. (3) by \(\frac{X}{X}\) and the second term by \(\frac{p_i X}{p_i X}\) the following expression is obtained:

\[
\Pi_i = \left(1 - \alpha_i\right) \frac{p_i q_i}{X} X - ec_1(\alpha_i, q_i) \frac{p_i q_i}{X} \frac{p_i X}{p_i}.
\]

Defining, as above, the foreign firm’s market share as \(s_i = \frac{p_i q_i}{X}\), yields eq. (4).

\textsuperscript{13}The profit function is similar as in Allen (1998) but extended to account for the impact of the exchange rate and of the investment in process innovation.
share with respect to the price of the domestic firm, \( \eta_{11} = \frac{\partial q_1}{\partial p_1} \) is the foreign firm’s own price elasticity of demand and \( \eta_{12} = \frac{\partial q_1}{\partial p_2} \) is the cross price elasticity of demand, we get the following expression:

\[
\left( \frac{c_1}{p_1^2} \frac{\partial c_1}{\partial (c q_i)} (a q_i) c}{p_1} \left( \eta_{n_1} + \eta_{n_2} \frac{\partial p_1}{\partial p_1} \right) \right) s_1 X + \left( \frac{c_1}{p_1} \right) \left( \eta_{n_1} \frac{q_1}{p_1} + \eta_{n_2} \frac{\partial p_1}{\partial p_2} \right) s_1 \right] X = 0 \tag{6}
\]

Let us define \( \theta_i = \frac{\partial p_i}{\partial p_1} \frac{p_1}{p_2} \) as the conjectural variation of the foreign firm, in elasticity form and \( \mu_i = \frac{\partial c_1}{\partial (c q_i)} (a q_i)\) as the (positive) cost elasticity with respect to the amount of output going to process innovation\(^{15}\). It can also be proved that the following relations hold for the elasticity of the foreign firm’s market share with respect to its price and the price of the domestic firm\(^{16}\): \( \eta_{s1} = \frac{\gamma_{11}}{s_1} \) and \( \eta_{s2} = -\frac{\gamma_{11}}{s_1} \). Further, the foreign firm’s own and cross price elasticities of demand can also be proved to be equal to\(^{17}\): \( \eta_{11} = \frac{\gamma_{11} - s_1}{s_1} \) and \( \eta_{12} = -\frac{\gamma_{11}}{s_1} \).

The first-order condition can therefore be written as:

\(^{14}\) Conjectural variations are assumed to be constant, as is usual in oligopoly models (cf. Boyer and Moreaux, 1983, p. 97).
\(^{15}\) This elasticity can be interpreted as a measure of the success of innovative activity or as a measure of the effectiveness of investment in process innovation.
\(^{16}\) For our two-firm model, eq. (2) can be written as: \( s_i = \beta_i + \gamma_{11} \ln p_1 + \gamma_{12} \ln p_2 \). Thus, the elasticities of the foreign firm’s market share can be obtained from the latter equation:

\( \eta_{s1} = \frac{\partial s_1}{\partial \ln p_1} \frac{1}{s_1} = \gamma_{11} \) and similarly, \( \eta_{s2} = \frac{\partial s_1}{\partial \ln p_2} \frac{1}{s_1} = \gamma_{12} \). As already mentioned, in order to ensure that the expenditure function is homogeneous of degree one, we assume that \( \sum_{i=1}^n \gamma_i = 0 \), which for our model is equivalent to \( \gamma_{12} = -\gamma_{11} \) and thus, \( \eta_{s2} = -\frac{\gamma_{11}}{s_1} \).

\(^{17}\) Since \( q_1 = \frac{s_1 X}{p_1} \), it can easily be proved that \( \eta_{11} = \eta_{s1} - 1 = \frac{\gamma_{11} - s_1}{s_1} \) and \( \eta_{12} = \eta_{s2} = -\frac{\gamma_{11}}{s_1} \), based on the derivation for the foreign firm’s elasticity of market share with respect to its own price and the price of the domestic firm described in fn 16.
\[
\left[ \frac{e_{c1} + e_{c2} \mu_i \left( \gamma_{11} - \frac{s_i}{s_1} - \frac{\gamma_{11} \theta_i}{s_1} \right)}{p_i^2} \right] s_i + \left( \frac{1 - \alpha_i}{p_i} \right) \left[ \frac{\gamma_{11} (1 - \theta_i)}{p_i} \right] X = 0
\]  

(7)

From eq. (7) we get the foreign firm’s price reaction function:

\[
p_i = e_{c1} \left( \frac{1 - \mu_i}{1 - \alpha_i} \right) \left( 1 - \frac{s_i}{\gamma_{11} (1 - \theta_i)} \right)
\]  

(8)

Eq. (8) shows that the price the foreign firm sets in the importer’s market is a mark-up over marginal cost. This mark-up, evidently, depends on the firm’s conjectural variations, its market share, the effectiveness of investment in process innovation, \( \mu_i \) and the proportion of investment in process innovation to output.

By taking logarithms of both sides of (8) and substituting the demand constraint\(^8\) defined by equation (2) the following log-linear expression for the firm’s reaction function can be obtained:

\[
\ln p_i = -\frac{\beta_i}{\gamma_{11} (2 - \theta_i)} + \left( \frac{1 - \theta_i}{2 - \theta_i} \right) \ln e + \left( \frac{1 - \theta_i}{2 - \theta_i} \right) \ln c_i - \left( \frac{1 - \theta_i}{2 - \theta_i} \right) \mu_i + \left( \frac{1 - \theta_i}{2 - \theta_i} \right) \alpha_i + \frac{1}{2 - \theta_i} \ln p_2
\]  

(9)

The distinctive characteristic of this reaction function is that it establishes a relationship between the foreign firm’s price and the proportion of investment in process innovation to output. It further, establishes an explicit relationship between foreign and domestic firm’s prices. This is in contrast to the findings of previous studies on pass-through, which derive reaction functions for the foreign firms that do not explicitly include foreign firm’s process-innovation intensity or their domestic competitors’ prices.

The second condition for profit maximisation can be written as:

\[
\left[ -1 - \frac{e_{c1} (\alpha_i, q_i) \partial (\alpha_i, q_i) \partial \alpha_i}{\partial (\alpha_i, q_i) \partial \alpha_i} \frac{1}{p_i} \right] s_i X = 0
\]  

(10)

\(^8\)For our two-firm model the demand constraint that the foreign firm faces is equivalent to

\[s_i = \beta_i + \gamma_{11} \ln p_i + \gamma_{12} \ln p_2\]
Rearranging (10) and using the definition of $\mu_i$, given above, we obtain the following expression for the proportion of the foreign firm’s output committed to innovative activity:

$$\alpha_i = e^{\mu_i c_i / p_i}$$  \hspace{1cm} (11)

Evidently, foreign firm’s process-innovation intensity changes with movements in the exchange rate and this must be allowed for when calculating exchange rate pass-through from eq. (9).

By taking logarithms of both sides of eq. (11) the following expression is obtained for the foreign firm’s process-innovation intensity:

$$\alpha_i = \mu_i + \ln e + \ln c_i - \ln p_i$$  \hspace{1cm} (12)

As equation (12) shows foreign firm’s process-innovation intensity depends on the exchange rate.

The profit function of the domestic firm is defined as:

$$\Pi_2 = p_2(1 - \alpha_2)q_2 - c_2(\alpha_2 q_2)q_2$$  \hspace{1cm} (13)

where $p_2$ corresponds to the price of the domestically-produced good, $q_2$ to the domestic firm’s supply, $c_2$ to the domestic firm’s marginal cost and $\alpha_2$ to the proportion of the domestic firm’s output devoted to innovative activity. Again, the term $\alpha_2 p_2 q_2$ represents revenue foregone and as such it is subtracted from the firm’s total revenue.

If the domestic firm’s profit function is rewritten in terms of market share we obtain the following expression for the domestic firm’s profits$^{19}$:

$$\Pi_2 = \left(1 - \alpha_2 - \frac{c_2(\alpha_2 q_2)}{p_2}\right)s_2 X$$  \hspace{1cm} (14)

where $s_2$ is the domestic firm’s market share and $X$ is total expenditure, as defined above.

$^{19}$ The derivation is similar to that described in fn.12 for the case of the foreign firm.
Since the firm simultaneously chooses its price $p_2$ and the fraction of output $\alpha_2$ directed to innovative activity, the two first-order conditions for profit maximisation are:

$$\frac{\partial \Pi_2}{\partial p_2} = 0 \quad \text{and} \quad \frac{\partial \Pi_2}{\partial \alpha_2} = 0$$

The first condition for profit maximisation yields:

$$\left[ \frac{c_2}{p_2^2} - \frac{\partial c_2(\alpha_2 q_2)}{\partial (\alpha_2 q_2)} \frac{1}{p_2} \right] s_2 X + \left[ \frac{c_2}{p_2} - \frac{\partial c_2(\alpha_2 q_2)}{\partial p_2} \right] \left[ \frac{\partial s_2}{\partial p_2} + \frac{\partial s_2}{\partial p_1} \frac{\partial \alpha_2}{\partial p_2} \right] X = 0 \quad (15)$$

where $\frac{\partial p_1}{\partial p_2}$ is the domestic firm’s conjectural variation.

Let us define $\theta = \frac{\partial p_1}{\partial p_2}$ as the conjectural variation of the domestic firm, in
elasticity form and $\mu_2 = \left[ \frac{\partial c_2(\alpha_2 q_2)}{\partial p_2} \right] \left[ \frac{c_2(\alpha_2 q_2)}{c_2(\alpha_2 q_2)} \right]$ as the (positive) cost elasticity with respect to the amount of output going to process innovation. Again, it can easily be proved that the following expressions hold for the elasticities$^{20}$ of the
domestic firm’s market share with respect to its price and the price of its foreign rival:

$$\eta_{s_2} = \frac{\partial s_2}{\partial p_2} \frac{p_2}{s_2} = \frac{\gamma_{22}}{s_2}, \quad \eta_{s_1} = \frac{\partial s_2}{\partial p_1} \frac{p_1}{s_2} = -\frac{\gamma_{22}}{s_2}$$

and the domestic firm’s own and cross price elasticities of demand: $\eta_{s_2} = \frac{\gamma_{22} - s_2}{s_2}, \quad \eta_{s_1} = -\frac{\gamma_{22}}{s_2}$. Therefore, by following similar
steps as in the case of the foreign firm, we get the domestic firm’s reaction function:

$$p_2 = c_2 \left[ \frac{1 - \mu_2}{1 - \alpha_2} \left( 1 - \frac{s_2}{\gamma_{22} (1 - \theta)} \right) \right] \quad (16)$$

By taking logarithms of both sides of eq. (16) and imposing the demand constraint
described by eq. (2), which for the domestic firm is equivalent to
$s_2 = \beta_2 + \gamma_{22} \ln p_2 + \gamma_{21} \ln p_1$, yields the following log-linear form for the domestic
firm’s reaction function:

$^{20}$ The derivations are similar to those described in fn. 16.
Thus, the domestic firm’s reaction function, in addition to an explicit relationship between the foreign and the domestic firm’s prices, also establishes a relationship between the domestic firm’s price and the proportion of its investment in process innovation to output. Since the price of the imported good depends on the exchange rate, the price of the domestically-produced good will be indirectly linked to the exchange rate.

The second condition for profit maximisation of the domestic firm can be written as:

\[
\begin{bmatrix}
-1 - \frac{\partial c_2(\alpha, q_2)}{\partial \alpha} \frac{\partial (\alpha, q_2)}{\partial \alpha} \frac{1}{p_1} \\
\end{bmatrix}
\begin{bmatrix}
s_2 X = 0
\end{bmatrix}
\]  

Rearranging (18), using the definition of \( \mu_2 \), and taking logarithms, the following expression is obtained for the foreign firm’s process-innovation intensity:

\[
\alpha_2 = \mu_2 + \ln c_2 - \ln p_2
\]  

The domestic firm’s process-innovation intensity depends on its price, which as noted earlier, is indirectly linked to the exchange rate. This is likely to establish another indirect channel of influence of the exchange rate working through domestic firm’s process-innovation intensity.

Therefore, the unified framework described by equations (9), (12), (17) and (19), corresponds to the foreign and the domestic firm’s price reaction functions and process-innovation intensity.

The exchange rate coefficient in the foreign firm’s reaction function equation (9) yields only the partial pass-through. The total effect of the exchange rate, i.e. total pass-through, can only be obtained if the above-discussed interactions have been allowed for. For this purpose the system of equations (9), (12), (17) and (19) must be solved to yield the reduced-form equations for these variables. The following set of reduced-form equations for the foreign and the domestic firm’s price and process-innovation intensity is therefore derived:
\[
\ln p_1 = A + \left( \frac{(2-2\theta_1)(3-2\theta_2)}{F} \right) \ln e + \left( \frac{(2-2\theta_1)(3-2\theta_2)}{F} \right) \ln c_1 + \frac{(2-2\theta_2)}{F} \ln c_2 \tag{20}
\]

where \( A = -\frac{\beta_1(3-2\theta_2)}{\gamma_{11}F} - \frac{\beta_2}{\gamma_{22}F} \) and \( F = \left[ (3-2\theta_1)(3-2\theta_2) - 1 \right] \).

\[
\ln p_2 = B + \left( \frac{(2-2\theta_1)}{F} \right) \ln e + \left( \frac{(2-2\theta_1)}{F} \right) \ln c_1 + \frac{(2-2\theta_2)(3-2\theta_1)}{F} \ln c_2 \tag{21}
\]

where \( B = -\frac{\beta_1}{\gamma_{11}F} - \frac{\beta_2(3-2\theta_1)}{\gamma_{22}F} \) and \( F \) is as defined above.

\[
\alpha_1 = H + \left[ \frac{(3-2\theta_2)-1}{F} \right] \ln e + \left[ \frac{(3-2\theta_2)-1}{F} \right] \ln c_1 - \frac{(2-2\theta_2)}{F} \ln c_2 \tag{22}
\]

where \( H = \mu_1 + \frac{\beta_1(3-2\theta_2)}{\gamma_{11}F} + \frac{\beta_2}{\gamma_{22}F} \) and \( F \) is as defined above.

\[
\alpha_2 = G - \frac{(2-2\theta_1)}{F} \ln e - \frac{(2-2\theta_1)}{F} \ln c_1 + \left[ \frac{(3-2\theta_1)-1}{F} \right] \ln c_2 \tag{23}
\]

where \( G = \mu_2 + \frac{\beta_1}{\gamma_{11}F} + \frac{\beta_2(3-2\theta_1)}{\gamma_{22}F} \) and \( F \) is as defined above.

The total pass-through can now be obtained from the foreign firm’s reduced-form price equation (20), as the exchange rate coefficient, which is found to be equal to \( \phi = \left( \frac{(2-2\theta_1)(3-2\theta_2)}{(3-2\theta_1)(3-2\theta_2)-1} \right) \). Its size can be seen to depend on the foreign and the domestic firm’s conjectural variations. An interesting case emerges when firms have divergent conjectural variations, e.g. the foreign firm has a zero conjectural variation and the domestic firm a positive one. This happens when there is a dominant domestic firm that acts as a Stackelberg-type price leader and a foreign firm that acts as a follower in the market and thus takes the price of its domestic competitor as given. In such a case, as \( \theta_2 \) goes from \( \theta_2 < 1 \) to \( \theta_2 = 1 \) and \( \theta_2 > 1 \), the pass-through elasticity rises commensurately and for \( \theta_2 > 1 \) it becomes greater than one (Table 1). In the special case where \( \theta_1 = \theta_2 = 0 \), i.e. each firm takes its competitor’s price as given, and
the Nash solution to the strategic game is obtained, the pass-through is incomplete (Table 1).

An interesting issue relates to the implications for exchange rate pass-through of the exchange rate effect on the foreign and the domestic firm’s process-innovation intensity. We thus compare the pass-through elasticity obtained from this general framework to that obtained from a restricted version of the model in which the foreign and the domestic firm decide only on their pricing strategies. In such case, the foreign firm’s profit function is given by \( \Pi_1 = p_1 q_1 - ec_1 q_1 \) and that of the domestic firm by \( \Pi_2 = p_2 q_2 - c_2 q_2 \). The solution of this simple game\(^{21}\) yields the following expression for the pass-through elasticity:

\[
\varphi = \frac{\partial \ln p_1}{\partial \ln e} = \left( \frac{(1-\theta_1)(2-\theta_2)}{(2-\theta_1)(2-\theta_2)} - 1 \right)
\]

This elasticity captures only the exchange rate effect working through foreign and domestic producers’ prices but not the one through these producers’ innovation policies. As Table 1 shows, the same values of the parameters \( \theta_1 \) and \( \theta_2 \) always result in higher pass-through estimates when process-innovation decisions are endogenised. Thus, the analysis of models that ignore the impact of the exchange rate on the foreign and the domestic firm’s investment in process innovation is likely to yield inaccurate pass-through estimates.

In conclusion, the main empirical implication of model developed is that total pass-through can be obtained from the foreign firm’s reduced-form price equation (20), which is estimated as an equilibrium relationship.

3. Empirical investigation

This section provides empirical evidence on the importance of interactions between the exchange rate, foreign and domestic firms’ prices and process-innovation intensity, as derived from the model of the previous section, for the determination of exchange rate pass-through. The empirical investigation draws on the experience of Japanese firms exporting to the US market, using monthly data for the period 1993 through 2004. US and Japanese firms are characterised by a high degree of

\(^{21}\) This model is similar as in Allen (1998) but extended to account for the impact of the exchange rate on the foreign firm’s profits.
technological sophistication. During the 1990s their R&D expenditure as a percentage of GDP was 2.6 percent for the US and 3 percent for Japan\(^{22}\). These features appear therefore to be consistent with the hypotheses of the theoretical model.

Therefore, the Japanese firms’ reduced-form price equation for their exports to the US is tested as an equilibrium relationship with the Johansen multivariate cointegration technique (Johansen, 1988). One important issue when testing for cointegration with this technique concerns the model’s specification as regards the choice of endogenous and weakly exogenous variables and the determination of the number of cointegrating vectors. It has been proved that the tests for the cointegration rank tend to under-reject in small samples (Pesaran et al., 2000; Greenslade et al., 2002) since the number of parameters to be estimated in an unrestricted VAR model is large relative to the sample size. Therefore economic theory should be used at an earlier stage to identify which variables are weakly exogenous and then estimate a conditional VECM model of the following form:

\[
\Delta z_t = \Gamma_0 \Delta x_t + \Gamma_1 \Delta y_{t-1} + \ldots + \Gamma_{k-1} \Delta y_{t-k+1} + \Pi y_{t-k} + \Psi D_t + u_t
\]  

(24)

where \(\Delta\) is the first-difference operator, \(z_t\) is the vector of endogenous variables, \(x_t\) is the vector of weakly exogenous variables, \(y_t = [z_t \ x_t]\) and \(D_t\) is the vector of deterministic and/or exogenous variables, such as seasonal dummies. The above specification contains information for both the short-run and the long-run relationships via the estimates of \(\Gamma\) and \(\Pi\) respectively. The matrix \(\Pi\) can be expressed as \(\Pi = \alpha \beta'\), where \(\alpha\) represents the matrix of the speed of adjustment parameters and \(\beta\) the matrix of long-run coefficients. The rank of the \(\Pi\) matrix – the number of cointegrating vectors – in this conditional system can be at most equal to the number of endogenous variables. It should be mentioned, however, that the asymptotic distribution of the rank test statistic in the conditional model differs from that in the full model (for a discussion see Harris and Sollis, 2003). Pesaran et al.,

\(^{22}\) R&D expenditure data, at annual frequencies, are from the Main Science and Technology Indicators of the OECD.
(2000) computed the rank test statistic allowing for exogenous $I(1)$ regressors in the long-run model$^{23}$.

We thus estimate Japanese firms’ reduced-form price equation, as described by eq. (20). The number of stationary long-run relationships is determined from the estimation of a VAR model in four variables: US import prices of goods imported from Japan, Japanese and US unit labour cost and the dollar/yen exchange rate$^{24}$. In order to give reasonable power to the cointegration tests, we use economic theory to identify which variables can be considered as weakly exogenous and then determine the cointegration rank from the conditional VAR model (Greenslade et al., 2002). It is usually assumed that unit labour costs are unaffected by exchange rate changes (Gross and Schmitt, 2000). We will therefore test for the weak exogeneity of Japanese and US producers’ unit labour costs$^{25}$. As Table 2 indicates these variables can be treated as weakly exogenous. This leaves us with a VAR model in two endogenous and two weakly exogenous variables. As is evident from the trace test statistic reported in Table 2, the hypothesis of the existence of one cointegrating vector among the variables of this model cannot be rejected$^{26}$. Therefore a long-run relationship appears to exist between US producers’ prices, their costs and the prices of goods imported from Japan. Total exchange rate pass-through can now be obtained from the exchange rate coefficient in the normalised vector. This coefficient is estimated at 0.56, which is higher than the estimate of 0.3 reported by Faruquee (2004) for the pass-through of changes in the US dollar effective exchange rate to US import prices; Faruquee’s model, however, does not endogenise foreign and domestic firms’ innovation decisions.

4. Conclusion

In this paper we developed an international oligopoly model that provides a unified framework for analysing exchange rate pass-through. The model, by

---

$^{23}$ Appropriate critical values for testing for cointegration are reported in Pesaran et al., (2000), Table 6.

$^{24}$ All variables are again expressed in logs. Also ADF tests confirm that they are all $I(1)$.

$^{25}$ We base our tests on the assumption of one cointegrating vector among the variables used in estimation, as predicted by the theoretical model of the previous section (for a discussion see Greenslade et al., 2002).
endogenising foreign and domestic firms’ price and process-innovation strategies, captures the complex links between the exchange rate, foreign and domestic producers’ prices and investment in process innovation, which appear to be important for the determination of exchange rate pass-through. Estimations accounting for all these exchange rate links and using monthly observations for Japanese firms’ exports to the US over the last twelve years and the Johansen multivariate cointegration technique, provide evidence of a pass-through elasticity higher than reported in studies that do not consider foreign and domestic firms’ innovation decisions.

26 The specification of the conditional model includes eight lags, a linear trend in the cointegrating vector and a constant in VAR. Pretesting indicates that this is the appropriate specification.
Appendix. Data sources

The US import price index for goods imported from Japan (2000=100) is obtained from the US Bureau of Labor Statistics. The US dollar/Japanese yen nominal exchange rate is the period average and is taken from the International Financial Statistics (IFS) of the IMF. The US and Japanese unit labour cost indices (2000=100) are obtained from the OECD’s Main Economic Indicators. Since the US unit labour cost data is available on a quarterly basis, we converted the quarterly series into monthly by interpolation.
References


<table>
<thead>
<tr>
<th>Conjectural variation parameters</th>
<th>Total pass-through in model with process innovation</th>
<th>Total pass-through in model without process innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta_1 = \theta_2 = 0$</td>
<td>0.75</td>
<td>0.67</td>
</tr>
<tr>
<td>$\theta_1 = 0, \theta_2 = 0.1$</td>
<td>0.76</td>
<td>0.68</td>
</tr>
<tr>
<td>$\theta_1 = 0, \theta_2 = 0.5$</td>
<td>0.80</td>
<td>0.75</td>
</tr>
<tr>
<td>$\theta_1 = 0, \theta_2 = 1$</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$\theta_1 = 0, \theta_2 = 1.1$</td>
<td>1.14</td>
<td>1.13</td>
</tr>
<tr>
<td>$\theta_1 = 0, \theta_2 = 1.2$</td>
<td>1.50</td>
<td>1.33</td>
</tr>
<tr>
<td>$\theta_1 = 0.5, \theta_2 = 0.5$</td>
<td>0.67</td>
<td>0.60</td>
</tr>
</tbody>
</table>
Table 2: Estimates of the Japanese producers’ reduced-form price equation

<table>
<thead>
<tr>
<th></th>
<th>LR test for the weak exogeneity restriction on Japanese producers’ unit labour cost¹</th>
<th>LR test for the weak exogeneity restriction on US producers’ unit labour cost¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$X^2(1) = 1.990 (0.158)$</td>
<td>$X^2(1) = 1.490 (0.222)$</td>
</tr>
</tbody>
</table>

A. Number of cointegrating vectors²

<table>
<thead>
<tr>
<th></th>
<th>Trace test</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>39.6</td>
</tr>
<tr>
<td></td>
<td>(35.3)</td>
</tr>
<tr>
<td>1</td>
<td>11.9</td>
</tr>
<tr>
<td></td>
<td>(18.08)</td>
</tr>
</tbody>
</table>

B. Coefficients on cointegrating vector variables³⁴

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_1$</td>
<td>-0.560</td>
<td>(0.043)</td>
</tr>
<tr>
<td>$e$</td>
<td>-0.326</td>
<td>(0.085)</td>
</tr>
<tr>
<td>$c_1$</td>
<td>-0.043</td>
<td>(0.157)</td>
</tr>
<tr>
<td>$c_2$</td>
<td>-0.0004</td>
<td>(0.0002)</td>
</tr>
</tbody>
</table>

Notes: 1. Numbers in parentheses are p-values to accept the over-identifying restrictions.
2. Numbers in parentheses are critical values at the 5 percent significance level (Pesaran et al., 2000, Table 6).
3. Numbers in parentheses are asymptotic standard errors.
4. $p_1$, $e$, $c_1$, $c_2$ correspond to US import prices of goods imported from Japan, the US dollar/Japanese yen exchange rate, the Japanese producers’ cost and US producers’ cost, respectively, as defined in the theoretical model.