BANK OF GREECE

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Sophocles N. Brissimis
Theodora S. Kosma

Working Paper

No. 51 December 2006

BANK OF GREECE
Economic Research Department – Special Studies Division
21, E. Venizelos Avenue
GR-102 50 Athens
Tel: +30210-320 3610
Fax: +30210-320 2432

www.bankofgreece.gr

*Printed in Athens, Greece*
*at the Bank of Greece Printing Works.*


ISSN 1109-6691

# MARKET CONDUCT, PRICE INTERDEPENDENCE AND EXCHANGE RATE PASS-THROUGH

Sophocles N. Brissimis
Bank of Greece and University of Piraeus

Theodora S. Kosma
Bank of Greece

**ABSTRACT**

This paper develops an international oligopoly model where foreign and domestic firms simultaneously choose their pricing strategies under the assumption of non-zero conjectural variations. The model captures the links between domestic and foreign producers' prices and establishes a relationship between the price of domestically-produced goods and the exchange rate, which appears to be important for the determination of exchange rate pass-through. It is also found that the equilibrium pass-through elasticity can be less than, equal to or greater than one depending on exporting and domestic firms' conjectural variations. The empirical implications of the model are tested with the Johansen multivariate cointegration technique using data for Japanese firms' exports to the US market. The results indicate that US producer prices are indeed influenced by the prices of their Japanese competitors and that the pass-through elasticity is less than one.

*Keywords*: Exchange rate pass-through; Conjectural variations; Translog expenditure function; Multivariate cointegration
*JEL classification*: C32; F39; L13

*Acknowledgements:* We are grateful to Heather Gibson and Tassos Anastasatos for helpful comments. The views expressed in the paper are of the authors and do not necessarily reflect those of the Bank of Greece.

**Correspondence:**
Sophocles N. Brissimis,
Economic Research Department,
Bank of Greece, 21 E. Venizelos Ave.,
102 50 Athens, Greece,
Tel. +30 210-320 2388
Fax: +30 210 320 2432
E-mail: sbrissimis@bankofgreece.gr

## 1. Introduction

The issue of the unresponsiveness of traded good prices to exchange rate changes has been extensively analyzed in the literature. Most of the existing theoretical and empirical studies focus on the analysis of the micro-foundations of firms' pricing and attribute this puzzling empirical phenomenon – referred to as incomplete exchange rate pass-through – to imperfectly competitive market structures and the existence of market power by firms that sell their products in international markets (e.g. Dornbusch, 1987; Feenstra *et al.*, 1996).

The majority of these studies examine pass-through in an international oligopoly setting (Feenstra *et al.*, 1996; Bernhofen and Xu, 2000; Bodnar *et al.,* 2002). In this context, the existence of domestic competitors is recognized but their interaction with foreign producers is not fully integrated in the models. Thus, the possible impact of the exchange rate on domestic producers' pricing behavior and its implications for the exchange rate pass-through have not been adequately analyzed.

The exchange rate pass-through estimates obtained from the above studies correspond to partial pass-through, namely to the impact of the exchange rate on the price setting of foreign firms, excluding the effect through domestic producers' behavior. This approach cannot therefore provide an accurate estimate of total pass-through, i.e. the one accounting for all channels of influence of the exchange rate (cf. Adolfson, 2001). Total and partial pass-through are identical only to the extent that the effect of the exchange rate on other variables, such as domestic producers' prices, is unimportant.

In fact, the impact of the exchange rate on domestic producers' prices can be very important. Feinberg (1986, 1989) finds that the exchange rate affects domestic producers' prices in the US and Germany and argues that international financial influences on domestic markets must be seriously taken into account. Feinberg (1989) attributes the responsiveness of domestic producers' prices to the exchange rate to these producers' reliance on imported inputs. Subsequent studies (Allen, 1998; Olive, 2004) allow for the interaction between producers of imported goods and domestic producers when analyzing the latter's pricing strategy. These studies establish a direct relationship between domestic producers' prices and the prices of imported goods, which is taken into account in the estimation[1]. This price interdependence originates from two factors. First, domestic and imported goods are considered as imperfect substitutes in demand. Thus, a change in the price of the imported good affects the demand for the domestically-produced good and this leads to a change in its price. Second, both domestic and foreign producers develop perceptions regarding each other's response to their own price changes. Such interdependence has implications for exchange rate pass-through, which have not as yet been analyzed in the literature.

Our paper attempts to fill this gap by developing a model[2], which examines the pricing behavior of foreign firms that produce a differentiated product and compete with domestic producers in the domestic market. Foreign and domestic firms simultaneously choose their pricing strategies and are assumed to have non-zero conjectural variations. The two price relationships derived, which correspond to exporting and domestic firms' reaction functions, indicate that the prices of these producers are interdependent and this simultaneity establishes an indirect link between domestic producers' prices and the exchange rate. Thus, the interaction between foreign and domestic producers' prices and the exchange rate appears to be a key element in the determination of the exchange rate pass-through elasticity, which can be not only less than one but also equal to or greater than one, depending on these producers' conjectural variations. The paper therefore contributes to the literature by providing a richer pattern for exchange rate pass-through; models that assume zero conjectural variations typically come up with a pass-through elasticity, which is lower than one.

To preview the results, we find evidence of a relationship between US producer prices and the price of imports from Japan. This establishes an indirect link between US producer prices and the dollar/yen exchange rate. However, even after allowing for this indirect influence, pass-through is still found to be incomplete, although it is higher than that reported in other studies e.g. Faruquee (2004).

The remainder of the paper is structured as follows. Section 2 presents a literature review. Section 3 describes the model that motivates our empirical analysis.

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[1] Feinberg (1986, 1989) argues that the effect of the exchange rate on domestic producers' prices is influenced by the degree of import competition. He does not, however, derive an explicit relationship between the prices of domestically-produced and imported goods.

[2] The model is similar to the one that Allen (1998) uses as a benchmark for his estimations. It is, however, extended to account for the influence of the exchange rate.

Section 4 provides a brief description of the econometric method and discusses the empirical results. Finally, Section 5 provides concluding remarks.

## 2. Literature review

The responsiveness of traded goods prices to exchange rate changes, namely the degree of exchange rate pass-through, has been extensively analyzed in the literature. Most empirical studies find that pass-through is incomplete, and this is not just a short-run phenomenon but one that persists over time. The evidence of incomplete pass-through has motivated a lot of theoretical research examining its determinants.

This research attributes incomplete pass-through to deviations from perfectly competitive market structures and the existence of market power by foreign firms. More specifically, they focus on the interaction between profit maximizing firms exporting to a foreign market and their domestic competitors and obtain pass-through from the industry equilibrium, which is defined by the intersection of the supply relationships of foreign and domestic producers. In this context, pass-through is found to depend on the degree to which foreign producers exercise their market power in the importer's market (measured by the ratio of their marginal cost, in the importer's currency, to the price they face in this market) and by their market share – measured by the ratio of exporting firms to the total number of firms in the importer's market (Dornbusch, 1987 and subsequently Venables, 1990 and Menon, 1995). Thus, the industry equilibrium price pass-through is always less than one since it depends on the relative number of foreign firms that are subject to exchange rate-induced cost changes.

Another strand of the literature accounts for the interaction between profit maximizing foreign and domestic firms but concentrates on the analysis of the supply relationship of foreign firms only and therefore analyzes import price pass-through. It is found that import price pass-through can be complete if the mark-up and marginal cost of foreign firms are constant and unaffected by the exchange rate, while if either of those varies with the exchange rate, pass-through will be incomplete. Specifically, the mark-up varies when the price elasticity of demand is not constant along the demand curve[3] (Feenstra *et al.*, 1996) and/or the market share varies with the exchange rate[4,5] (Bernhofen and Xu, 2000). As to the marginal cost, this will depend on the exchange rate to the extent that foreign exporters rely on imported inputs (cf. Menon, 1996) and if this cost is not constant with respect to output and the latter varies with the exchange rate (see, Yang, 1997 and Adolfson, 1999).

As to the empirical studies, they document a different pricing behavior among different groups of exporters. Japanese and, in some cases, German firms adopt a pricing strategy of incomplete pass-through of exchange rate changes to the price of their goods sold in foreign markets (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). UK and US firms, on the other hand, pass-through a larger proportion of exchange rate changes to their prices.

It should be mentioned, however, that most of these studies analyze exchange rate pass-through in an international oligopoly setting by focusing on the link between exporting firms' pricing behavior and market power and assume that foreign exporters take the prices of their domestic rivals as given when they formulate their pricing strategies. However, recent advances in the literature of industrial organization point out that the relationship between firms' market power and their pricing strategy may be more multidimensional than it may initially appear. In the Cournot model of oligopolistic competition – widely used in the exchange rate pass-through literature (e.g. Dornbusch, 1987 and Bernhofen and Xu, 2000) – firms with high market shares are thought to be able to charge higher prices. In reality, though, firms may find themselves unable to charge high prices, if their competitors are not expected to follow their price increases. High market share alone does not guarantee higher prices; firms' pricing strategy will be conditioned by their anticipation of their rivals' reaction to this strategy, namely, their conjectural variations. Market conduct, hence, matters for price determination.

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[3] This result is derived from a Bertrand differentiated products oligopoly, in which the price elasticity of demand is a component of the mark-up.

[4] In a Cournot framework a firm's mark-up is dependent on this firm's market share.

[5] This relationship is expected to hold in a Cournot oligopolistic framework, since a depreciation of the importer's currency, by increasing the cost of foreign exporters, shifts their reaction functions inwards and thus reduces their market share (cf. Shy, 1996).

Conjectural variations are a basic element of duopoly theory. What firms conjecture, affects the way they react. Cournot recognized that firms' choice of production levels depends on their expectation about their rivals' reaction to their output changes. He assumed, however, that they consider their rivals' output behavior as given when they determine their production levels. The analysis of non-zero conjectural variations and their relation to firms' profitability and price-cost margins, has largely been confined to the closed economy framework, i.e. to the analysis of firms that produce solely for their home market (cf. Clarke and Davies, 1982 and Machin and Van Reenen, 1993). The studies published so far can be classified into two broad categories. The first involves studies that try to identify the way conjectural variations are formed. Conjectures are formulated rationally when they are consistent with their competitors' reaction functions (for a discussion see Boyer and Moreaux, 1983 and Bresnahan, 1981); these are known as consistent conjectural variations. Also firms' conjectures about their competitors' reactions may depend on the latter's ability to react, which is usually related to their capacity utilization and financial distress. Specifically, firms with spare capacity are assumed to be more flexible and able to react. On the other hand, firms in financial distress are expected to follow a less aggressive strategy than firms with healthy balance sheets. The results of Haskel and Scaramozzino (1997) confirm these arguments. The other category of studies try to empirically measure conjectural variations (e.g. Allen, 1998).

As already mentioned, most of the oligopoly models that are applied to an open economy setting assume zero conjectural variations. However, there are some studies that adopt the assumption of a non-zero conduct parameter. Turnovsky (1986) analyses the determination of an optimal tariff under the assumption of consistent conjectural variations in the interaction between countries. Further, Allen (1998) assumes non-zero conjectures in his analysis of the interaction between US producers and producers of the imported goods. Finally, Bernhofen and Xu (2000) assume non-zero conjectural variations when solving their theoretical model but the relationship between the pass-through elasticity derived and conjectural variations is not analyzed. Thus, since in real world situations firms never regard the strategies of their rivals as given, non-zero conjectural variations must be explicitly taken into account in the analysis of exchange rate pass-through. The ability of exporting firms to pass-through exchange rate-induced cost changes to their prices depends on their expectations about the reaction of their domestic competitors to their price changes.

It must also be noted that most of the above-mentioned empirical studies on pass-through, apart from assuming zero conjectural variations, focus on the reaction functions of foreign firms only, and even though they include variables that account for domestic firms' price competition, they implicitly assume that the pricing behavior of domestic competitors is not influenced by the pricing strategy of exporting firms. The price of domestic competitors is assumed to influence import prices but the reverse is not true. However, this latter assumption may not be reasonable given that recent evidence indicates that the interrelationship between exporting and domestic firms' prices is very important and that economies with greater exposure to international markets have domestic industry prices that are more responsive to international competition (Olive, 2004).

Allen (1998) is one of the very few studies that explicitly accounts for the simultaneity between domestic and import prices[6]. He estimates import and domestic price equations of various US manufacturing industries and finds a significant degree of interdependence among the pricing strategies of the two groups of producers; not only domestic prices exert a statistically significant impact on import prices, as already noted in the literature, but also the latter influence the former. Thus the estimation of the import price equation should account for the interrelationship between the pricing strategies of exporting and domestic firms through the adoption of an appropriate estimation technique (cf. Allen, 1998 and Olive, 2004). As Allen (1998) argues, studies that fail to account for the impact of import prices on domestic firms' pricing behavior may obtain inaccurate estimates of pricing to market. Consequently, the exchange rate pass-through literature could be extended to account also for this channel of influence.

Finally, most of the analysis of pass-through so far focuses on its relationship with exporting firms' market power, by examining mainly the nature of their interaction with domestic competitors. However, firms' market power also depends on the degree to which consumers regard their product to be differentiated from other firms' products, i.e. on consumers' utility function (e.g. Taylor, 2000). Most of the

[6]Even though import price equations are estimated, the issue of exchange rate pass-through is not examined.

studies on pass-through consider preferences that are of the CES form (cf. Bodnar *et al.*, 2002). These preferences, however, result in a pricing rule in which prices are just a mark-up over marginal cost, and thus competitors' prices do not feature explicitly. This specific demand structure, therefore, fails to replicate the documented interrelationship between exporting and domestic firms' prices mentioned above.

Recently, the open economy macroeconomics literature models consumers' preferences by adopting a translog demand structure. Bergin and Feenstra (2001), conclude that, while models that adopt the standard CES preferences cannot replicate the observed real exchange persistence, those that assume a translog demand structure perform better in predicting real exchange rate persistence. Apart from that, and for the purpose of the analysis of import prices, translog preferences have some other useful properties. As Feenstra (2003) argues, translog preferences lead to the establishment of a direct link between the price of each product and the corresponding competitors' price. Hence, given the evidence, translog preferences may provide a good approximation of the demand constraint exporters and domestic producers face. So far, Allen (1998) is the only study that assumes preferences of the translog form in the analysis of import and domestic price equations of various US manufacturing industries.

## 3. Model

In this section we develop an ologopolistic model, which examines the pricing behavior of foreign firms that produce a slightly differentiated product and compete with domestic firms in the importer's market. The theoretical model is similar to that of Allen (1998) but it is extended to account for the influence of the exchange rate on foreign producers' cost. It is assumed that firms in each country are identical (cf. Yang, 1997) and we can therefore consider a game between two firms – one foreign and one domestic. The firms are assumed to compete in price strategies[7] given their expectations about the reaction of their rivals – these expectations are captured by a

[7] When firms produce differentiated products, price competition can be assumed. In this case price competition is profitable for firms since imperfect substitutability does not lead to marginal cost pricing as in the case of homogeneous products (cf. Hay and Morris, 1991 p.116). On the other hand, for homogeneous products it is reasonable to assume that firms compete in quantities (cf. Dornbusch, 1987 and Bernhofen and Xu, 2000) since this behaviour results to less output and higher prices (see Hay and Morris, 1991, p. 66).

non-zero conjectural variation term[8]. As to the structure of the game, we employ the simplest possible one-period game, i.e. we assume that foreign and domestic firms simultaneously choose their pricing strategies[9].

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):

$$\ln X = \ln U + \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln p_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_{ij} \ln p_i \ln p_j \text{ , with } \gamma_{ij} = \gamma_{ji} \qquad (1)$$

where $X$ is the minimum expenditure necessary to obtain a specific utility level at given prices, $U$ is the level of utility, $p_i, p_j$ the price of good $i$ and $j$, respectively. For our two-firm model, $n = 2$. To ensure that the expenditure function will be homogeneous of degree one, it is further assumed that: $\sum_{i=1}^{n} \alpha_i = 1$ and $\sum_{i=1}^{n} \gamma_{ij} = \sum_{j=1}^{n} \gamma_{ji} = 0$.

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 total expenditure on good $i$.

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

where $s_i$ is the share of total expenditure on good $i$.

It can easily be verified that equation (2) corresponds to the budget share of good $i$. According to Shephard's lemma the partial derivative of the expenditure function with respect to the price of good $i$ gives the expenditure-minimizing demand function for good $i$ (for a discussion see Chung, 1994, p.203). Therefore,

$$\frac{\partial X}{\partial p_i} = q_i \qquad (3)$$

[8] We therefore assume that firms do not take the price strategies of their competitors as given.

[9] A single-period (static) game can be adopted since dynamic elements in either demand or supply are not assumed (cf. Kandiyali, 1997). The impact of dynamic demand-side effects on pass-through has been analyzed by Gross and Schmitt (2000) and Froot and Klemperer (1989) who developed two-period (dynamic) games that are beyond the scope of the present study.

where $q_i$ is the demand for good $i$. Multiplying both sides of (3) by $\frac{p_i}{X}$ yields:

$$\frac{\partial X}{\partial p_i}\frac{p_i}{X} = \frac{q_i p_i}{X} \tag{4}$$

The left-hand side of eq. (4) is equal to $\frac{\partial \ln X}{\partial \ln p_i}$ and the right-hand side corresponds to the share of total expenditure on good $i$, $s_i$. The term $\alpha_i$ in eq. (2) represents the so-called basic market share; it is the market share that each firm could attain if prices equalised and it depends on tastes, advertising, past market shares and switching costs (cf. Allen, 1998).

Accordingly, firms maximise their profits – expressed in the currency of the importer – by choosing their prices subject to the constraint of the above demand structure.

The profit function of the foreign firm is defined as follows:

$$\Pi_1 = p_1 q_1 - e c_1 q_1 \tag{5}$$

where $p_1$ corresponds to the price of the imported good, $q_1$ to the foreign firm's supply, $e$ to the exchange rate defined as the home currency price of foreign currency and $c_1$ to the foreign firm's marginal cost, which is assumed to be constant.

If eq. (5) is rewritten in terms of market share we obtain the following expression for the foreign firm's profits:

$$\Pi_1 = \left(1 - \frac{e c_1}{p_1}\right) s_1 X \tag{6}$$

where $s_1$ is the foreign firm's market share and $X$ is total expenditure, as defined above.

The first-order condition for profit maximization of the foreign firm is:

$$\frac{\partial \Pi_1}{\partial p_1} = 0$$

This condition can be written as follows:

$$\frac{ec_1}{p_1^2}s_1X+\left(1-\frac{ec_1}{p_1}\right)\left[\frac{\partial s_1}{\partial p_1}+\frac{\partial s_1}{\partial p_2}\frac{\partial p_2}{\partial p_1}\right]X=0$$

where $p_2$ is the price of the domestic firm and $\frac{\partial p_2}{\partial p_1}$ is the foreign firm's conjectural variation, i.e. its expectation about the domestic firm's reaction to its own price change[10]. Assuming that $\eta_{s_{11}}=\frac{\partial s_1}{\partial p_1}\frac{p_1}{s_1}$ is the elasticity of foreign firm's market share with respect to its price and $\eta_{s_{12}}=\frac{\partial s_1}{\partial p_2}\frac{p_2}{s_1}$ is the elasticity of foreign firm's market share with respect to the price of the domestic firm, we get the following expression:

$$\frac{ec_1}{p_1^2}s_1X+\left(1-\frac{ec_1}{p_1}\right)\left[\eta_{s_{11}}\frac{s_1}{p_1}+\eta_{s_{12}}\frac{\partial p_2}{\partial p_1}\frac{p_1}{p_2}\frac{s_1}{p_1}\right]X=0 \quad (7)$$

Let us define $\theta_1=\frac{\partial p_2}{\partial p_1}\frac{p_1}{p_2}$ as the conjectural variation of the foreign firm, in elasticity form. 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[11]: $\eta_{s_{11}}=\frac{\gamma_{11}}{s_1}$ and $\eta_{s_{12}}=-\frac{\gamma_{11}}{s_1}$.

Therefore, the first-order condition can be written as:

[10] As is usual in oligopoly models, conjectural variations are assumed to be constant (cf. Boyer and Moreaux, 1983, p. 97).

[11] For our two-firm model, eq. (2) can be written as: $s_1=\alpha_1+\gamma_{11}\ln p_1+\gamma_{12}\ln p_2$. Thus, the elasticities of the foreign firm's market share can be obtained from the latter equation: $\eta_{s_{11}}=\frac{\partial s_1}{\partial \ln p_1}\frac{1}{s_1}=\frac{\gamma_{11}}{s_1}$ and similarly, $\eta_{s_{12}}=\frac{\partial s_1}{\partial \ln p_2}\frac{1}{s_1}=\frac{\gamma_{12}}{s_1}$. However, as noted above, in order to ensure that the expenditure function is homogeneous of degree one, we assume that $\sum_{i=1}^{n}\gamma_{ij}=0$, which for our model is equivalent to $\gamma_{12}=-\gamma_{11}$ and thus, $\eta_{s_{12}}=-\frac{\gamma_{11}}{s_1}$.

$$\frac{ec_1}{p_1^2}s_1X+\left(1-\frac{ec_1}{p_1}\right)\left[\frac{\gamma_{11}}{p_1}\left(1-\theta_1\right)\right]X=0 \tag{8}$$

From eq. (8) we get the foreign firm's reaction function:

$$p_1=ec_1\left(1-\frac{s_1}{\gamma_{11}\left(1-\theta_1\right)}\right) \tag{9}$$

Eq. (9) 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 and on its market share.

By taking logarithms of both sides of (9), the following log-linear expression for the firm's reaction function can be obtained:

$$\ln p_1=\ln e+\ln c_1-\frac{s_1}{\gamma_{11}\left(1-\theta_1\right)} \tag{10}$$

The demand constraint[12] defined by equation (2) can be substituted into (10) and the following form for the foreign firm's reaction function is obtained:

$$\ln p_1=-\frac{\alpha_1}{\gamma_{11}\left(2-\theta_1\right)}+\left(\frac{1-\theta_1}{2-\theta_1}\right)\ln e+\left(\frac{1-\theta_1}{2-\theta_1}\right)\ln c_1+\frac{1}{2-\theta_1}\ln p_2 \tag{11}$$

The distinctive characteristic of this reaction function is that it establishes an explicit relationship between foreign and domestic firm's prices, which holds even in the case of zero conjectural variation, i.e. $\theta_1=0$, and is due to the structure of the demand functions reflecting imperfect substitutability of the two products in consumption[13]. The assumption of non-zero conjectural variation simply gives rise to a richer pattern of responses. 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 their domestic competitors' prices (cf. Bodnar *et al.*, 2002; Yang, 1997).

[12] As noted earlier, for our two-firm model the demand constraint that the foreign firm faces is equivalent to $s_1=\alpha_1+\gamma_{11}\ln p_1+\gamma_{12}\ln p_2$.

The profit function of the domestic firm is defined as:

$$\Pi_2 = p_2 q_2 - c_2 q_2 \tag{12}$$

where $p_2$ corresponds to the price of the domestically-produced good, $q_2$ to the firm's supply and $c_2$ to its marginal cost, which is assumed to be constant. The profit function of the domestic firm is similar to that of the foreign firm except for the presence of the exchange rate.

The domestic firm's profit function can similarly be rewritten in terms of its market share:

$$\Pi_2 = \left(1 - \frac{c_2}{p_2}\right) s_2 X \tag{13}$$

where $s_2 = \frac{p_2 q_2}{X}$ is the domestic firm's market share and $X$ is total expenditure, as defined above.

The first-order condition for profit maximization of the domestic firm yields:

$$\frac{c_2}{p_2{}^2} s_2 X + \left(1 - \frac{c_2}{p_2}\right)\left[\frac{\partial s_2}{\partial p_2} + \frac{\partial s_2}{\partial p_1}\frac{\partial p_1}{\partial p_2}\right] X = 0 \tag{14}$$

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

By following similar steps as in the case of the foreign firm, we get the domestic firm's reaction function:

$$p_2 = c_2 \left(1 - \frac{s_2}{\gamma_{22}(1-\theta_2)}\right) \tag{15}$$

where $\eta_{s_{22}} = \frac{\partial s_2}{\partial p_2}\frac{p_2}{s_2} = \frac{\gamma_{22}}{s_2}$ and $\eta_{s_{21}} = \frac{\partial s_2}{\partial p_1}\frac{p_1}{s_2} = -\frac{\gamma_{22}}{s_2}$ are the elasticities[14] of domestic

[13] Equation (2) shows that the budget share of each good depends not only on its own price but also on the price of the competing good.
[14] The derivations are similar to those described in fn. 11.

firm's market share with respect to its price and the price of its foreign rival and $\theta_2 = \frac{\partial p_1}{\partial p_2}\frac{p_2}{p_1}$ is the conjectural variation of the domestic firm, in elasticity form.

By taking logarithms of both sides of eq. (15) and imposing the demand constraint described by eq. (2), which for the domestic firm is equivalent to $s_2 = \alpha_2 + \gamma_{22} \ln p_2 + \gamma_{21} \ln p_1$, yields the following log-linear form for the domestic firm's reaction function:

$$\ln p_2 = -\frac{\alpha_2}{\gamma_{22}\left(2-\theta_2\right)} + \left(\frac{1-\theta_2}{2-\theta_2}\right)\ln c_2 + \frac{1}{2-\theta_2}\ln p_1 \tag{16}$$

Evidently, this reaction function depends on the foreign competitor's price, an issue that has largely been ignored in the pass-through literature. Thus, since the price of the foreign firm depends on the exchange rate, the domestic firm's price will also be linked to the exchange rate, although indirectly.

The indirect channel of influence of the exchange rate, working through the domestic firm's price raises an issue as regards the accurate estimation of the exchange rate pass-through. The exchange rate coefficient in the foreign firm's reaction function, equation (11), captures only the partial exchange rate pass-through (cf. Adolfson, 2001); total pass-through, i.e. the total effect of the exchange rate working through all interactions in the system, can only be obtained if we allow for the indirect impact of the exchange rate on the domestic producer's price. For this purpose, the system of equations (11) and (16) can be solved to yield reduced-form equilibrium price equations for the domestic and foreign firms' prices.

By substituting (16) into (11), we obtain the reduced-form equilibrium price equation for the foreign firm, in which the simultaneity between foreign and domestic prices, established in eqs. (11) and (16), has been accounted for.

$$\ln p_1 = -\frac{\alpha_1\left(2-\theta_2\right)}{\gamma_{11}F} - \frac{\alpha_2}{\gamma_{22}F} + \left(\frac{G}{F}\right)\ln e + \left(\frac{G}{F}\right)\ln c_1 + \frac{\left(1-\theta_2\right)}{F}\ln c_2 \tag{17}$$

where $F = \left(2-\theta_1\right)\left(2-\theta_2\right) - 1$ and $G = \left(1-\theta_1\right)\left(2-\theta_2\right)$.

Also, by substituting (17) into (16), the following reduced-form equation for the domestic firm's price as a function of the exchange rate is obtained:

$$\ln p_2 = -\frac{\alpha_2(2-\theta_1)}{\gamma_{22}F} - \frac{\alpha_1}{\gamma_{11}F} + \left(\frac{H}{F}\right)\ln c_2 + \left(\frac{(1-\theta_1)}{F}\right)\ln c_1 + \frac{(1-\theta_1)}{F}\ln e \tag{18}$$

where $H = (1-\theta_2)(2-\theta_1)$ and $F$ is as defined above.

The total pass-through elasticity derived from eq. (17) is

$$\varphi = \frac{\partial \ln p_1}{\partial \ln e} = \left(\frac{(1-\theta_1)(2-\theta_2)}{(2-\theta_1)(2-\theta_2)-1}\right) \tag{19}$$

i.e. it is the exchange rate coefficient in the reduced-form price equation of the foreign firm, and can be seen to depend on the conjectural variations of both the domestic and foreign firm. This is an interesting result since pass-through is now found to depend not only on the market conditions the foreign firm faces, as earlier work had assumed, but also on the foreign and domestic firm's market conduct.

As to the size of the pass-through elasticity, eq.(19) shows that it can be less than, equal to or greater than one depending on the combination of the values of the parameters $\theta_1$ and $\theta_2$, i.e. on market structure[15]. An interesting case emerges when firms have divergent conjectural variations, and in particular when the foreign firm has a zero conjectural variation and the domestic firm a positive one. This is the case where 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. The three-dimensional graph (Figure 1), which plots total pass-through as a function of both $\theta_1$ and $\theta_2$, and Table 1 confirm this argument. They show that, as $\theta_1$ approaches zero and $\theta_2$ approaches unity, the pass-through elasticity approaches unity. It further indicates that in the special case where $\theta_1 = \theta_2 = 0$, i.e.

[15] As Allen (1998) argues models with non-zero conjectural variations can characterise a wide variety of market structures depending on the particular assumption about the values of $\theta_1$ and $\theta_2$.

each firm takes its competitor's price as given, and the Nash solution to the strategic game is obtained, pass-through is incomplete.

An interesting result from the above analysis is that, in the case of zero conjectural variations, pass-through will be incomplete. However, with non-zero conjectural variations, the pass-through elasticity can be less than, equal to or greater than one (Table 1). This pattern emerges since foreign producers, when forming their pricing strategy, take into account not only demand conditions in the importer's market but also the response of their competitors.

Total pass-through elasticity can be obtained from the reduced-form equation (17) estimated as an equilibrium relationship. This is a novel approach, since other studies estimate pass-through from the foreign firm's reaction function only, ignoring the simultaneous determination of foreign and domestic prices and thus, the indirect channel of influence of the exchange rate, discussed above.

## 4. Empirical investigation

This section provides empirical evidence on the relationship between the exchange rate and prices by drawing on the experience of Japanese firms exporting to the US market, using monthly data[16] for the period 1993 through 2004. The empirical analysis focuses on the interaction between foreign and domestic producers' prices – as established in the model of the previous section – and its implications for exchange rate pass-through.

Over the sample period, Japanese exports to the US market accounted on average for 13 percent of total US imports[17]. Thus, it would not be unreasonable to assume that US producers' price strategies are influenced by the prices of their Japanese competitors. Indeed, high import shares may strengthen the link between the prices of domestically-produced and imported goods (cf. Feinberg, 1986), since domestic producers are more likely to interact strategically with foreign producers that have a significant presence in the domestic market.

[16] In order to account for seasonality, we include seasonal dummies.
[17] Market shares are calculated on the basis of data obtained from the OECD's Monthly International Trade.

The main empirical implication of the theoretical model is that, in the presence of interdependence between foreign and domestic producers' prices, total pass-through cannot be obtained from the estimation of the foreign firms' reaction function, alone; this would ignore the indirect impact of the exchange rate on domestic producers' prices. The estimation of the foreign firms' reduced-form price equation (17), in which the above simultaneity has been taken into account, is likely to yield a more accurate estimate of total exchange rate pass-through.

The econometric analysis involves two parts. We start by estimating the domestic firms' reaction function given by equation (16). This will reveal any dependence of US producers' pricing policies on their Japanese competitors' prices[18] and thus the existence of an indirect exchange rate effect. Once the interdependence between US and Japanese producers' prices is established, we estimate, in a second step, the Japanese exporters' reduced-form price equation (eq. (17)) from which total exchange rate pass-through can be obtained.

Each of the US producers' reaction function and the Japanese firms' reduced-form price equation is tested as an equilibrium relationship with the Johansen multivariate cointegration technique (Johansen, 1988). This methodology is appropriate for establishing long-run relationships when the data used are non-stationary and has the advantage of accounting for all possible endogeneities among the variables used in estimation. One important issue when testing for cointegration with this technique concerns the correct specification of the model's deterministic components. As Zhou (2003) argues, failure to correctly specify these components and/or capture changes in the data's trend behavior, may bias the results towards rejecting cointegration too often. In this case, the best modeling strategy would be to split the sample into different sub-samples – when there are indications of changes in the trend behavior of the data[19] – specify for each sub-sample the model's deterministic components and then test for cointegration[20].

[18] Allen (1998) follows the same approach in order to test whether domestic producers' prices depend on their foreign competitors' prices – i.e. he estimates the domestic producers' reaction function and tests for the statistical significance of the coefficient on foreign producers' prices.

[19] Changes in the trend behavior of the data – verified by simple inspection of the series – that happen to coincide with significant economic events can be considered as possible subsample endpoints.

[20] For each sub-sample the model's trend components are specified on the basis of the so-called Pantula principle proposed by Johansen (1992), which constitutes a joint test of deterministic components and rank order (see Harris and Sollis, 2003).

Another issue relates to the model's specification as regards the endogenous and weakly exogenous variables and to the correct 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 (cf. Pesaran *et al.*, 2000; Greenslade *et al.*, 2002) – the estimation is not efficient, since the number of parameters to be estimated in an unrestricted VAR model is large relative to the sample size. It is therefore argued that 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 (cf. Pesaran *et al.*, 2000; Greenslade *et al.*, 2002):

$$\Delta z_t = \Gamma_0 \Delta x_t + \Gamma_1 \Delta y_{t-1} + ...... + \Gamma_{k-1} \Delta y_{t-k+1} + \Pi y_{t-k} + \Psi D_t + u_t \qquad (20)$$

where $\Delta$ is the first-difference operator, $z_t$ is the vector of endogenous variables, $x_t$ is the vector of weakly exogenous variables, $y_t = \left[ z_t \quad x_t \right]'$ and $D_t$ 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 $\Gamma_i$ 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.,* (2000) computed the rank test statistic allowing for exogenous $I(1)$ regressors in the long-run model. Appropriate critical values for testing for cointegration are reported in Pesaran *et al.,* (2000), Table 6.

We start by focusing on the relationship between US producers' prices and the price of their Japanese competitors, as described by eq. (16). The number of stationary long-run relationships is determined by the estimation of a VAR model in three variables, US producer prices, US unit labor cost used as a measure of US producers' cost and US import prices of goods imported from Japan[21,22]. In order to give

[21]All variables are expressed in logs.

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 labor costs are unaffected by exchange rate changes (Gross and Schmitt, 2000). We will therefore test for the weak exogeneity of US producers' unit labor costs[23]. As Table 2 indicates this variable can be treated as weakly exogenous. This leaves us with a VAR model in two endogenous variables and one weakly exogenous variable. 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[24,25,26]. It therefore appears that a long-run relationship exists between US producers' prices, their costs and the prices of goods imported from Japan. In particular, the coefficient on import prices in the normalised vector is 0.37 and significant at the 5 percent level, further confirming the interdependence between the US and Japanese producers' prices (Table 2).

This suggests that estimation of the exporters' reaction function alone would not yield an accurate estimate of the pass-though. This can be done if we estimate the exporters' reduced-form price equation, which takes into account the above simultaneity. The empirical analysis in this case involves the estimation of a VAR model in four variables, the two already mentioned in relation to the previous VAR (US import prices and unit labor cost), and also the dollar/yen exchange rate and Japanese unit labor cost, measuring Japanese producers' cost[27]. Following similar steps as above, we initially test for the weak exogeneity of the Japanese and US

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[22] ADF tests confirm that all variables used in estimation are $I(1)$. These tests are not reported but are available upon request.

[23] Before testing we must decide about the cointegration rank of the system. We will 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).

[24] Our sample covers the period of the recent US dollar depreciation that started in 2002. Reasonable results could not be found for the full sample. We thus, test for cointegration in the period 1993-2002, taking into account the fact that this prolonged depreciation may have caused a structural shift in the trend characteristics of the data – the choice of the sample endpoint is also supported by the visual inspection of the data.

[25] A conditional model with five lags, a linear trend in the cointegrating vector and a constant in VAR is used as the basis for our estimations. Pretesting indicates that this is the correct specification.

[26] Misspecification tests indicate that the model performs well except for the presence of non-normal errors. However, this is not a serious problem, as Cheung and Lai (1993) have shown that the trace test statistic is robust in the presence of non-normal errors.

[27] All variables are again expressed in logs. Also ADF tests confirm that they are all $I(1)$.

producers' cost variables[28]. As Table 3 indicates, the weak exogeneity restriction on Japanese producers' cost is rejected[29] while that on US producers' cost is accepted. Therefore we proceed with the estimation of a conditional VECM in three endogenous variables and one weakly exogenous variable[30,31]**.** The trace test statistic presented in Table 3 confirms the existence of one cointegrating vector among the system's variables. Total exchange rate pass-through can now be obtained from the exchange rate coefficient in the normalised vector. This coefficient is estimated at 0.42, which is comparable to the estimate of 0.3 reported by Faruquee (2004) for the pass-through of changes in the US dollar effective exchange rate to the US import prices[32]. These low estimates of the pass-through elasticity may reflect the fact that estimations in both studies do not account for the impact of the exchange rate on the relative non-price competitiveness of exporters and domestic firms.

As a final step, in order to test for the robustness of our results we perform stability tests on the long-run relationships estimated above. Initially, the plotted values of the recursively estimated eigenvalues are investigated. If there are shifts or trends in the plotted values further testing is required[33]. This testing involves the recursive estimation of the coefficients of the cointegrating vectors which are then plotted against their +/-2SE bands. If the bands of the recursively estimated coefficients are quite narrow and do not cross the horizontal axis at any point in time, stability is ensured.

The graphs of the recursively estimated eigenvalues of both models –the one analyzing the US producers' reaction function and the other focusing on the Japanese

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[28] When testing for the weak exogeneity restrictions we again assume the existence of one cointegrating vector among the variables of the system, as predicted by the theoretical model.

[29] This finding is consistent with the argument that exchange rate-induced changes in the cost of living may lead to wage and thus unit labour cost adjustment, if wage setters try to keep real wages constant.

[30] A model with eight lags and a constant in the VAR is used as the basis for our estimation. Specification tests indicate that this is the correct specification. Furthermore, cointegration was found for the full sample and there are no indications of changes in the trend behaviour of the data.

[31] Misspecification tests show that the estimated model performs well. It should be mentioned though that the null hypothesis that the errors are normally distributed is rejected at the 5 percent level of significance; however, it cannot be rejected at the 1 percent level. Jacobson *et al*. (2002) argue that these specification tests are asymptotic and may thus suffer from size distortions in small samples. Inference at the 1 percent significance level is therefore justified.

[32] Faruquee accounts for the interdependence between US and foreign producers' prices in his estimations although he does not explicitly derive price equations that display this interdependence.

[33] It has been proved that a simple relationship exists between the eigenvalues, $\beta$ - the cointegrating vector and $a$ - the vector of adjustment coefficients. Thus, if the graphs of the recursively estimated

producers' reduced-form price equation – are not smooth (see Figures 2 and 3). Specifically, in the former model there appears to be a shift in the plotted values of the recursively estimated eigenvalue in 2001; this may be related to the US inflationary conditions at the time[34]. In the latter model the shift appears to have taken place in 2002; this coincides with the beginning of the period of US dollar depreciation. The recursively estimated coefficients of the cointegrating vectors in both models further confirm these findings[35]. Interestingly, the point of instability of the pass-through coefficient, obtained from the recursive estimation of the Japanese firms' reduced-form price equation, appears to coincide with that of the recursively estimated coefficient of US import prices in the US producers' reaction function (Figures 4 and 5), both being located in the period between 1999 and 2001. This finding lends support to the argument that total exchange rate pass-through is influenced by the extent to which US producer prices depend on the prices of their Japanese competitors.

## 5. Conclusions

In this paper we examined the importance of the interactions between domestic and foreign producers' prices for the determination of import price pass-through, in the context of an international oligopoly model where firms simultaneously choose their pricing strategies under the assumption of non-zero conjectural variations. The model developed, by endogenizing domestic producers' pricing behavior, establishes a relationship between the prices of domestically-produced goods and the exchange rate, which must be taken into account when investigating exchange rate pass-through. The model implies a wider range of values for the pass-through elasticity depending on foreign and domestic firms' conjectural variations. The assumption of non-zero conjectural variations is an essential condition for the pass-through elasticity to be greater than one.

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eigenvalues indicate instability, the stability properties of $a$ and $\beta$ should be investigated further (for a discussion see Hansen and Johansen, 1999; Johansen, 1995).

[34] In the period 1998-2000 US CPI inflation was on the rise after having bottomed during the previous years. This is likely to have had an impact on the US producers' pricing strategies that are also influenced by the general macroeconomic environment. This increasing trend was reversed in 2001.

[35] For expositional brevity all graphs are not reported but are available upon request.

The empirical implications of the model have been tested using monthly data for the exports of Japanese firms to the US market over the last twelve years and Johansen's multivariate cointegration technique. The results indicate the existence of a relationship between US producers' prices and the prices of their Japanese competitors. Estimations accounting for this price interdependence still provide evidence of incomplete exchange rate pass-through.

In conclusion, the analysis in this paper has shown that domestic producers are exposed to exchange rate fluctuations through their interaction with their foreign competitors. Future research could focus on investigating further the issue of the exchange rate influence on domestic markets and its implications for exchange rate pass-through.

## 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 labor cost indices (2000=100) are obtained from the OECD's Main Economic Indicators. Since the US unit labor cost data is available on a quarterly basis, we converted the quarterly series into monthly by interpolation. The US producer price index (2000=100) is also obtained from the Main Economic Indicators of the OECD.

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**Table 1. Total pass-through as a function of conjectural variations**

| Conjectural variation parameters | Total pass-through |
|---|---|
| $\theta_1 = \theta_2 = 0$ | 0.67 |
| $\theta_1 = 0, \theta_2 = 0.1$ | 0.68 |
| $\theta_1 = 0, \theta_2 = 0.5$ | 0.75 |
| $\theta_1 = 0, \theta_2 = 1$ | 1 |
| $\theta_1 = 0, \theta_2 = 1.1$ | 1.13 |
| $\theta_1 = 0, \theta_2 = 1.2$ | 1.33 |
| $\theta_1 = 0.5, \theta_2 = 0.5$ | 0.60 |

**Table 2: Estimates of the US producers' reaction function**

*LR* test for the weak exogeneity restriction on US producers' unit labour cost[1]
$X^2(1) = 2.6127\ (0.106)$

| A. Number of cointegrating vectors[2] | Trace test |
|---|---|
| 0 | 35.77<br>(30.77) |
| 1 | 13.71<br>(15.44) |
| **B. Coefficients on cointegrating vector variables[3,4]** | |
| $p_2$ | 1 |
| $c_2$ | -0.530<br>(0.186) |
| $p_1$ | -0.371<br>(0.110) |
| *trend* | -0.001<br>(0.0002) |

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. $p_2$, $c_2$, $p_1$ correspond to US producers' price and cost and US import prices of goods imported from Japan, respectively, as defined in the theoretical model.

**Table 3: Estimates of the Japanese producers' reduced-form price equation**

*LR* test for the weak exogeneity restriction on Japanese producers' unit labour cost[1]
$X^2(1) = 5.931\ (0.015)$

*LR* test for the weak exogeneity restriction on US producers ' unit labour cost[1]
$X^2(1) = 1.874\ (0.171)$

| A. Number of cointegrating vectors[2] | Trace test |
|---|---|
| 0 | 43.64<br>(38.93) |
| 1 | 19.66<br>(23.32) |
| 2 | 1.161<br>(11.47) |

| B. Coefficients on cointegrating vector variables[3,4] | |
|---|---|
| $p_1$ | 1 |
| $e$ | -0.419<br>(0.06) |
| $c_1$ | -0.768<br>(0.120) |
| $c_2$ | -0.134<br>(0.241) |

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.

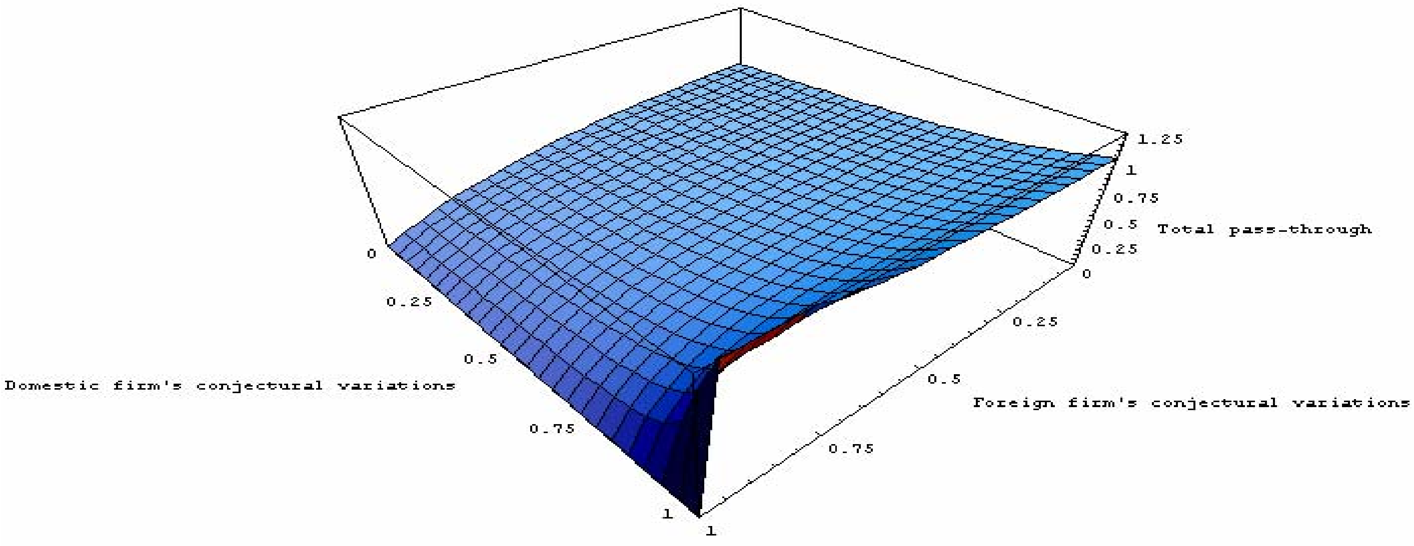


**Figure 1. Total pass-through as a function of conjectural variations**


**Figure 2. Recursively-estimated eigenvalue –US producers' reaction function**

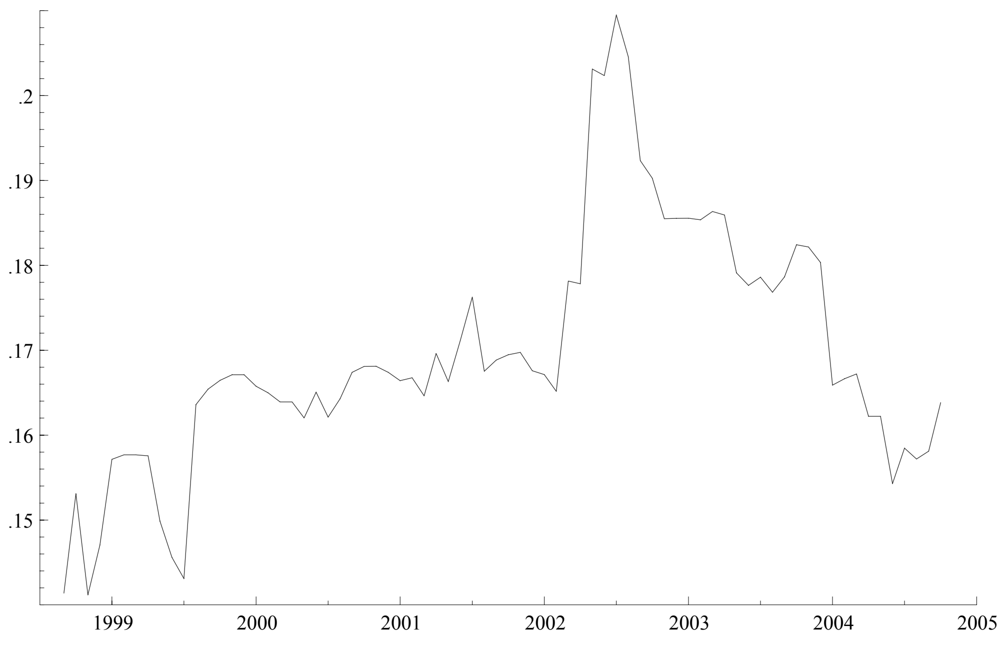


**Figure 3. Recursively-estimated eigenvalue –Japanese producers' reduced-form price equation**

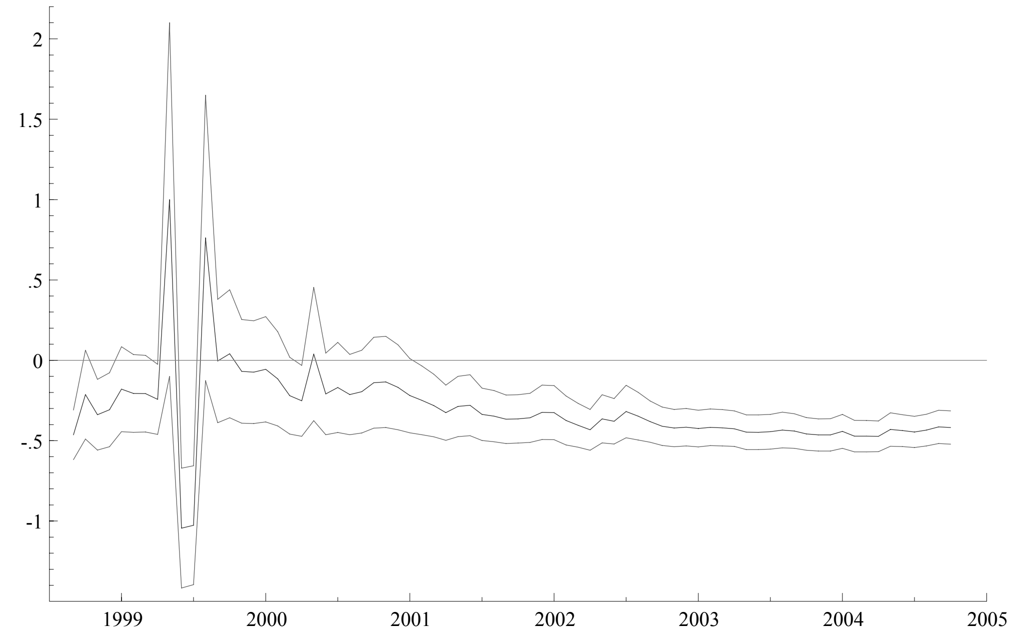


**Figure 4. Recursively-estimated pass-through coefficient in the Japanese producers' reduced-form price equation**

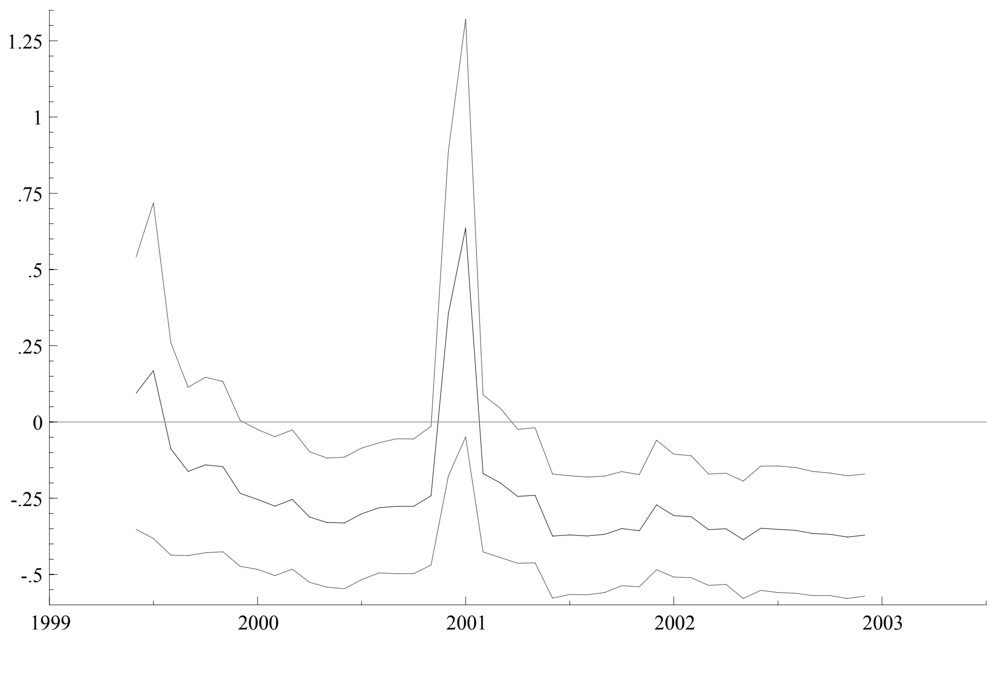


**Figure 5. Recursively-estimated US import price coefficient in the US producers' reaction function**

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