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ABSTRACT

This paper represents one of the first analyses of exchange rate pass-through in a dynamic context. It explores the impact of exchange rate fluctuations in a duopoly where firms interact over an indefinite period of time. In these circumstances there exists an incentive for the duopolists to tacitly collude. The paper investigates the manner in which exchange rate changes influence the inherent tension that exists between the incentives to collude and compete. It is shown that the sign and degree of exchange rate pass-through depends critically upon: the expected duration of a change in the exchange rate and the relative competitive strengths of the firms. The predictions of the model closely accord with the empirical evidence on exchange rate pass-through.

Keywords: imperfect competition, oligopoly, foreign exchange

JEL Classification Codes: D4, F3

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1. Introduction

The responsiveness of import prices to fluctuations in the exchange rate is an issue which has generated considerable interest in recent years. Much of this literature has been motivated by the observation that changes in the exchange rate do not pass-through in to prices. For instance, a number of empirical studies have discovered that the degree of exchange rate pass-through in to prices depends on both the source and the destination of exports. Thus, in a widely quoted study Knetter (1989) found that US exporters tended to adjust prices in a manner which amplified the effects of exchange rate variations on local currency prices, while German export prices were varied in a way which stabilized the local currency price in the destination market[i].

It has frequently been suggested that this asymmetry in the pattern of pricing across destination markets may be indicative of tacitly collusive pricing behavior[ii]. While there are a profusion of theoretical models which seek to explain incomplete exchange rate pass-through, there have been no attempts to formally explore this phenomenon in the context of a tacitly collusive oligopoly. Accordingly, this paper seeks to augment the existing literature by investigating the impact of exchange rate variations in an infinitely repeated supergame.

The analysis is based on a simple price setting duopoly with a domestic firm and a foreign rival who produce a differentiated product and compete over an indefinite period of time. It is widely recognised that when firms interact over an infinite horizon, then at least some degree of tacit collusion is rendered individually rational (Friedman, 1989). However, collusion gives rise to the familiar problem that each firm has an incentive to defect, given that its rival abides by the collusive agreement. To deter such defection we assume that firms employ the familiar "grim trigger strategy" to deter cheating. Specifically, a firm abandons collusion and reverts to the noncooperative one-shot Nash equilibrium when its rival defects.[iii] The duopolists will have no incentive to defect if the future losses brought about by dissolution of the tacitly collusive agreement exceed the immediate gains from defection.

In what follows we focus upon the sign of exchange rate pass-through to prices in the constrained tacitly collusive equilibria.[iv] It is demonstrated that the response of prices to variations in the exchange rate depends crucially upon two factors: the expected duration of a change in the exchange rate, and the relative competitiveness of the foreign and domestic firms.

To see why, consider a permanent depreciation of the exchange rate. *Ceteris paribus*, this lowers the future collusive profits accruing to the foreign firm and hence diminishes its incentive to collude. Thus, a permanent depreciation of the exchange rate induces the foreign firm to compete more aggressively and this leads to an equilibrium with lower prices.

Exchange rate variations are, however, typically transitory in nature. Hence, Section 4 explores the impact of random fluctuations in the exchange rate. It is demonstrated that if exchange rate changes are expected to be random, then a depreciation raises the foreign firm's incentive to collude. This occurs because a depreciation lowers the current gains accruing to the firm from defection. On the other hand, by colluding the firm expects to earn higher future collusive profits when the exchange rate appreciates. It follows that the foreign firm has a greater incentive to collude during a temporary depreciation. Thus, if the foreign firm is the dominant competitor, a temporary depreciation provides it with an incentive to establish a more collusive equilibrium with higher prices. Conversely, when the domestic firm is the more aggressive competitor, a depreciation by weakening the position of the foreign rival, allows the domestic firm to establish a more competitive equilibrium with lower prices. Thus, the response of prices to exchange rate movements is found to depend not only on the expected duration of the change, but also the relative competitiveness of the firms.

The role of market structure in determining pass -through has long been recognised in the theoretical literature. For instance, Fisher (1989a) demonstrated that in a one-shot homogenous duopoly the extent and direction of pass-through depends critically upon the relative market structure of the domestic and foreign industries. It is shown that a depreciation of the exchange rate will lead to a greater increase in prices if the domestic industry is highly monopolised relative to the foreign rivals. This is because firms use their market power to set prices when the exchange rate moves in their favour. The results in this paper suggest that in an infinitely repeated game the outcome is somewhat more complicated and depends on both relative market power and the duration of the exchange rate change.

2. The Model

The analysis is based on a simple model with two firms labeled F and H who produce a differentiated product. Firm H is assumed to be a domestic firm and F a spatially separated rival located in a foreign country. It is supposed that the duopolists compete in country H, using prices as the strategic variable. The price of the domestic firm's product in home currency units is denoted p_H and that of the foreign rival also denominated in country H's currency, is p_F. The demand function for firm i in each period is given by:

$$q_i = q_i(p_H, p_F) \qquad (i = H, F) \qquad (1a)$$

where p_i is the price set by firm i (i =H,F) denominated in the currency of the domestic country H.

We assume that the demand function q_i is bounded and continuous in p_i and p_j with:

$$\partial q_i/\partial p_i < 0; \quad \partial q_i/\partial p_j > 0 \quad \text{and} \quad \partial q_i/\partial p_i \; > \; \partial q_i/\partial p_j \qquad (1b)$$

These conditions imply that the goods produced are imperfect substitutes, with the own price effects on demand exceeding the cross price effects.

For simplicity it is supposed that production costs are zero. Thus, the profit function of firm H is given by:

$$\Pi_H = p_H q_H \qquad (2a)$$

Similarly the profit function of firm F, denominated in country H's currency units, is:

$$\overline{\Pi}_F = (p_F q_F) \qquad (2b)$$

In contrast, the profits of firm F in its own currency is:

$$\Pi_F = (p_F q_F)/e \qquad (2c)$$

where: e is the exchange rate defined as units of home currency per unit of foreign exchange.

It is further supposed that the profit functions are single peaked in p_i and p_j in the relevant range. Finally, we assume that:

$$(\partial^2\Pi_i / \partial p_i \partial p_j) > 0 \qquad (3a)$$

$$(\partial^2\Pi_i / \partial p_i \partial p_j) + \partial q_i / \partial p_i > 0 \qquad (3b)$$

Condition (3a) asserts that prices are strategic complements (Bulow et al, 1985) so that the best response curves are positively sloped. In contrast, (3b) is the dual of the familiar "Hahn condition" which is evoked to ensure stability of the one-shot Nash equilibrium (Shapiro, 1990).

The solution of the one-shot price setting game is obtained by differentiating the profit functions in (2a) and (2c) and solving the first order conditions:

$$q_i + p_i (\partial q_i/\partial p_i) = 0 \qquad (i = H, F) \qquad (4)$$

Equation (4) implicitly defines each firm's best response function. Solving yields the one shot Nash equilibrium prices and profits denoted p_i^N and Π_i^N respectively (i = H, F).

It is supposed that the firms interact over an indefinite period of time and therefore have an incentive to tacitly collude by restricting output levels (see Friedman (1989)). For completeness we define the joint profit maximising outcome. The most collusive outcome is defined by the vector of prices $\tilde{p}^c = (\tilde{p}_H^c, \tilde{p}_F^c)$ which maximise joint collusive profits[v]. That is:

$$\tilde{p}^c \in \text{Argmax } \Pi^c \equiv \overline{\Pi}_F + \Pi_H \qquad (5a)$$

where: superscript C is used to denote collusion.

Collusion, however, gives rise to the familiar problem that each firm has an incentive to defect when its rival sets the collusive price. More formally, suppose that firm i (i = H, F) sets some collusive price $p_i^c > p_i^N$. Then its rival j ≠ i maximizes its one period profits by defecting and producing at a price:

$$p_H^D = \text{Argmax } \Pi_H^D \equiv p_H^D q_H (p_H^D, p_F^c,) \qquad \text{for } j = H \text{ and } i = F \qquad (5b)$$

$$p_F^D = \text{Argmax } \Pi_F^D \equiv p_F^D q_F(p_H^c, p_F^D)/e \quad \text{for j = F and i = H} \qquad (5c)$$

where: superscript D denotes defection and C collusion.

As is well established in the literature, such defection can be deterred by adopting a credible threat of future retaliation. We assume that firms adopt the familiar "grim trigger strategy" to deter cheating. Specifically, this requires that both firms set some tacitly collusive price so long as there is no defection. However, if any firm defects, the collusive agreement is abandoned and all firms revert to the one-shot Nash equilibrium price. For collusion to be feasible the following incentive compatibility constraint must hold for each firm:

$$\Pi_i^D - \Pi_i^C \leq \frac{\delta}{1-\delta}(\Pi_i^C - \Pi_i^N) \quad \text{(i = H, F)} \qquad (6a)$$

where: δ is the discount factor, Π_i^D denotes defection profits, $\Pi_H^C \equiv p_H^c q_H(p_H^c, p_F^c)$; $\Pi_F^C \equiv p_H^c q_F(p_H^c, p_F^c)/e$ are the collusive profits of firm's H, and F respectively and Π_i^N is one-shot Nash equilibrium profits.

The left hand side of (6a) represents the one period gains from defection, while the right hand side defines the net present value of future collusive profits foregone when the punishment is delivered and the firms revert to the one-shot Nash equilibrium. Recall that firm F's profits are denominated in the foreign currency and are thus directly affected by exchange rate variations, while those of firm H are not. This therefore introduces an asymmetry in the payoffs from tacit collusion, even when both firms confront identical cost and demand conditions. Accordingly, solving equation (6a) for δ we define a function which captures the relative gains from defection:

$$a_i(p_H^C, p_F^C, e) \equiv (\Pi_i^D - \Pi_i^C)/(\Pi_i^D - \Pi_i^N) \quad \text{(i = H, F)} \qquad (6b)$$

Observe that if the prevailing discount factor $\delta \geq a_i(p_H^C, p_F^C, e)$ then the incentive compatibility constraint in (6a) is satisfied, so that firm i has no incentive to defect. Conversely, if $\delta < a_i(p_H^C, p_F^C, e)$ the payoffs from defection exceed the discounted profits from collusion so that defection is the individually rational strategy for firm i. It follows, that $a_i(p_H^C, p_F^C, e)$ defines the threshold level of the discount factor at which tacit collusion is sustainable. Specifically, firm i has an incentive to collude, if and only if, the prevailing discount factor $\delta \in [a_i(p_H^C, p_F^C, e), 1]$.

Equations (2a) and (2c) reveal that *ceteris paribus* firm F's profits are directly influenced by exchange rate changes, while those of firm H are not. To take account of the differential impact of exchange rates on the firms' incentives to collude we implicitly define a level of the exchange rate (denoted e*) at given collusive prices (p_H^c, p_F^c) such that:

$$a_F(p_H^C, p_F^C, e^*) = a_H(p_H^C, p_F^C, e^*) \tag{6c}$$

When (6c) holds, then at the prevailing exchange rate e* the two firms are symmetric in the sense that they both have the same incentive to collude.[vi] If instead, the exchange rate is such that: $a_F(p_H^C, p_F^C, e) > a_H(p_H^C, p_F^C, e)$ (for $e \neq e^*$) then, *ceteris paribus*, firm H has a greater incentive to collude than its rival F. This is because higher levels of $a_i(p_H^C, p_F^C, e)$ correspond to increases in the incentive to defect. Thus, F may be interpreted as the more aggressive competitor. Conversely, if: $a_F(p_H^C, p_F^C, e) < a_H(p_H^C, p_F^C, e)$ (for $e \neq e^*$) then firm F has a greater incentive to collude than its rival H. Hence, H is the more aggressive competitor. Clearly, tacit collusion is feasible if and only if the prevailing discount rate satisfies:

(6d) $$\delta \geq \text{Max}\,(a_F(p_H^C, p_F^C, e), a_H(p_H^C, p_F^C, e))$$

When condition (6d) holds the payoffs to each firm from collusion are at least as great as the gains from defection. Tacit collusion is therefore sustainable.

In what follows, we assume that given an exogenously determined exchange rate and discount factor, each firm chooses a price which is consistent with the absence of defection by its rival. This implies that firm i's (i = H, F) collusive price is determined by the solution to the following problem[vii]:

$$\underset{p_i^c}{\text{Max}}\, \Pi^c \tag{7}$$

subject to: $\Pi_j^C - \Pi_j^D \leq \dfrac{\delta}{1-\delta}(\Pi_j^C - \Pi_j^N)$ (i = H,F) and ($i \neq j$)

In what follows we focus on cases of constrained collusion in which the joint profit maximising price level cannot be simultaneously sustained by both firms. This implies that the incentive compatibility constraint in (7) binds in equilibrium for at least one firm.[viii] The resulting equilibria are neither as collusive as the joint profit maximising solution, nor as competitive as the one-shot Nash equilibrium. While there are many other equilibria in this model, we deal only with the properties of equilibria where the constraint binds on *at least* one firm.

For future reference we outline a property of the incentive compatibility constraint which is used extensively in what follows. The proof is relegated to the Appendix.

Let p_i^c (i = H, F) denote the solution to the constrained maximisation problem in (7) and define the incentive compatibility constraint for firm j as:

$$\Phi^j = \Pi_j^D - \frac{1}{1-\delta}(\Pi_j^C - \delta\Pi_j^N).$$

Lemma 1: $\dfrac{\partial \Phi^j}{\partial p_i^C} > 0$ (i = H, F) and ($i \neq j$)

Lemma 1 informs us that when a firm raises its collusive price level then this increases its rival's incentive to defect. In particular, the rival's defection profits rise more rapidly than do its collusive profits. This result suggests that a firm can reduce its rival's incentive to defect by simply lowering its own collusive price. Hence, in setting its own collusive price each firm must ensure that its rival also has an incentive to collude. This relationship explains the structure of the maximisation problem outlined in equation (7), where firm i sets a price to maximise collusive profits, subject to the constraint that the rival does not defect.

3. Permanent Changes in the Exchange Rate

Having established the basic properties of the model we now investigate the impact of a permanent shift in the exchange rate. We begin by exploring the effect of changes in the exchange rate on the relative incentives of the firms to collude.

Consider a permanent depreciation of the exchange rate. The profit functions in equation (2a) and (2c) reveal that at given prices a depreciation of the exchange rate lowers the profits accruing to firm F, but has no direct impact on the profits of the domestic firm H. Moreover, it can be shown that a permanent depreciation of the exchange rate decreases the scope for earning future collusive profits and makes defection relatively more attractive than collusion for firm F. This result is summarised with greater accuracy in the following Lemma.

Lemma 2: At given collusive prices (p_H^c, p_F^c) $\Phi_e^F \equiv \dfrac{\partial \Phi^F}{\partial e} > 0$

$\forall \ \delta \in [a_F(p_H^C, p_F^C, e), 1]$

Proof

$\dfrac{\partial \Phi^F}{\partial e} = -\{\Pi_F^D(p_H^D, p_F^C) - \dfrac{1}{1-\delta}(\Pi_F^C(p_H^C, p_F^C) - \delta \Pi_F^N)\} / e$. [ix] Rearranging observe that $\dfrac{\partial \Phi^F}{\partial e}$ >0 iff: $\delta > \dfrac{(\Pi_F^D - \Pi_F^C)}{(\Pi_F^D - \Pi_F^N)}$. However, by equation (6b) we know that collusion is feasible only if: $\delta \geq a_F(p_H^C, p_F^C, e) \equiv \dfrac{\Pi_F^D - \Pi_F^C}{\Pi_F^D - \Pi_F^N}$. It follows that: $\dfrac{\partial \Phi^F}{\partial e} > 0$

$\forall \ \delta \in [a_F(p_H^C, p_F^C, e), 1]$. QED.

Intuitively, this result may be explained as follows. Recall that equation (6b) reveals that firm F will collude only if it cares sufficiently about future collusive profits. This in turn implies that future earnings are given more weight than current profits in the incentive compatibility constraint. It follows that in this case a depreciation of the exchange rate, by decreasing the scope for earning future profits, makes collusion less attractive for firm F.

An immediate implication of Lemma 2 is that a depreciation of the exchange rate, by lowering the foreign firm's payoffs from collusion, raises the critical level of the discount rate at which F is willing to collude. A depreciation therefore makes the foreign firm a more aggressive competitor relative to its domestic rival. Using Lemma 2 and the definition of e* in equation (6c) it immediately follows that:

$$\text{If } e \geq e^* \text{ then } a_F(p_H^C, p_F^C, e) \geq a_F(p_H^C, p_F^C, e^*) \quad (8a)$$

$$\text{If } e < e^* \text{ then } a_F(p_H^C, p_F^C, e) < a_F(p_H^C, p_F^C, e^*) \quad (8b)$$

Having described the effects of a change in e on the incentive to collude, we now investigate the impact of exchange rate changes on pricing behavior with $a_F(p_H^C, p_F^C, e) \geq (<) a_F(p_H^C, p_F^C, e^*)$.

Consider first the special case when both firms are initially in a symmetric equilibrium at the prevailing discount rate with $\delta = a_F(p_H^C, p_F^C, e^*) = a_H(p_H^C, p_F^C, e^*)$. Observe that in this case at the prevailing exchange rate the firms have the same relative incentive to collude. The equilibrium outcome is given by the solution to the maximisation problem defined in equation (7) with the constraint binding on each firm. That is, each firm i (i= H, F), ($i \neq j$) maximizes profits, subject to the satisfaction of the incentive compatibility constraint of its rival. This in turn yields a mapping from firm i's price into firm j's price and vice-versa. The equilibrium is then defined by the pair of collusive prices that are the fixed point of the two mappings. In the Appendix we solve the system and demonstrate that the impact of a depreciation on equilibrium price levels is given by:

$$\frac{dp_F^C}{de} = \frac{-\Phi_H^H \Phi_e^F}{D} < 0 \quad (9a)$$

$$\frac{dp_H^C}{de} = \frac{\Phi_F^H \Phi_e^F}{D} > 0 \quad (9b)$$

where: $D = \Phi_F^F \Phi_H^H - \Phi_F^H \Phi_H^F > 0$

Equations (9a) and (9b) reveal that the price responses are asymmetric, with the foreign firm lowering its price in response to an exchange rate depreciation, while the domestic rival increases price. This outcome can be seen to arise from Lemma 2 which reveals that a depreciation of the exchange rate lowers the foreign firm's payoffs from collusion and therefore makes defection more attractive. If defection is to be prevented then the foreign firm's collusive payoffs must be increased.

Equations (9a) and (9b) indicate that this is achieved through an increase in the foreign firm's market share and collusive profits.[x]

Consider next the case when the prevailing discount rate is given by $\delta = a_H(p_H^c, p_F^c, e) > a_F(p_H^c, p_F^c, e)$. Recall that higher values of $a_i(p_H^c, p_F^c, e)$ reflect a greater incentive to defect, hence in this equilibrium the domestic firm has less incentive to collude than its foreign rival. Moreover, since $\delta = a_H(p_H^c, p_F^c, e)$ $> a_F(p_H^c, p_F^c, e)$ firm H's incentive compatibility constraint is just satisfied with equality, while that of firm F's holds with slack. Equilibrium prices are thus determined by the solution to the problem:

$$\underset{p_F^c}{\mathrm{Max}}\,\Pi^c \tag{10a}$$

$$\text{subject to:}\quad \Pi_H^C - \Pi_H^D - \frac{\delta}{1-\delta}(\Pi_H^C - \Pi_H^N) = 0$$

$$\underset{p_H^c}{\mathrm{Max}}\,\Pi^c \tag{10b}$$

$$\text{subject to:}\quad \Pi_F^C - \Pi_F^D - \frac{\delta}{1-\delta}(\Pi_F^C - \Pi_F^N) < 0$$

Since the incentive compatibility constraint of firm F holds with slack, marginal changes in the exchange rate have no impact on collusive prices. It follows that:

$$\frac{dp_F^c}{de} = \frac{dp_H^c}{de} = 0 \tag{11}$$

This result reflects the fact that at given prices a depreciation lowers the profits of the foreign firm. However, since the domestic firm is the more aggressive competitor, the foreign rival cannot recoup its profits by unilaterally varying its price, since this could induce defection and the dissolution of the tacitly collusive agreement. The foreign firm is therefore compelled to leave its price unchanged and passively absorb the depreciation in lower profit margins.

Finally, suppose that $\delta = a_F(p_H^c, p_F^c, e) > a_H(p_H^c, p_F^c, e)$. In this case firm H's incentive compatibility constraint holds with slack, while firm F's constraint is just satisfied with equality. It follows that the domestic firm now has a greater incentive to collude than its foreign rival. In the Appendix we demonstrate that:

$$\frac{dp_F^c}{de} = \frac{\Phi_e^F V_H^F}{\Gamma_F} < 0 \tag{12a}$$

$$\frac{dp_H^c}{de} = -\frac{\Phi_e^F V_F^F}{\Gamma_F} < 0 \tag{12b}$$

where: $\Gamma_F = V_F^F \Phi_H^F - V_H^F \Phi_F^F < 0$

Intuitively, this result reflects the property described in Lemma 1. A permanent depreciation lowers the collusive payoffs accruing to the more aggressive foreign firm and increases the incentive to defect. From Lemma 1 we know that this greater incentive to defect can be curtailed by lowering collusive prices. Thus, a less collusive equilibrium emerges with lower prices.

Overall these results indicate that the impact of a permanent depreciation of the exchange rate on oligopolistic prices depends critically on the rival firms' relative incentive to collude. The analysis suggests that export price variations which counteract *permanent* exchange rate movements are indicative of a more aggressive foreign firm confronting a weaker domestic rival in an infinitely repeated supergame.

4. Temporary Fluctuations in the Exchange Rate

The analysis in the previous section was based on the unrealistic assumption that exchange rate movements are permanent. Exchange rate variations are, however, typically transitory in nature. While the precise statistical properties of exchange rate fluctuations have been the subject of considerable empirical research, there is a substantial body of literature which suggests that exchange rates tend to follow a random walk (Frankel and Rose, 1995). Accordingly, in this Section we accept as a stylised fact that exchange rate fluctuations are random and explore the consequences on oligopolistic pricing behavior.

Variations in the exchange rate are incorporated into the model by assuming that the exchange rate e has domain $[\underline{e}, \bar{e}]$ with density function f(e) and cumulative distribution function F(e).[xi] We assume that these fluctuations are identically and independently distributed over time. The exchange rate process is thus not a martingale and the expected value of the exchange rate in any future period is independent of the current realisation. It is therefore impossible to predict the future level on the basis of past levels of the exchange rate.

As in the previous Section, this implies that the profit function of firm H is not directly affected by the exchange rate. However, firm F's profits are influenced by exchange rate changes so that it becomes necessary to alter the incentive compatibility constraints to take account of expected future changes in the exchange rate. Specifically, the rewards to firm F from defection in any period depend on the current realisation of e, while the punishments depend on expected future realisations of e. Thus, the incentive compatibility constraint for F is defined by:

$$\Pi_F^D(e) - \Pi_F^C(e) \leq \frac{\delta}{1-\delta} \int_{\underline{e}}^{\bar{e}} (\Pi_F^C(e) - \Pi_F^N(e)) f(e) de \qquad (13a)$$

The left hand side of (13a) describes the current rewards from defection. Since firm F’s profits depend on the prevailing exchange rate, the gains from deviation are influenced by the current level of the exchange rate.[xii] In contrast, the right hand side describes the expected future loss from the punishment which depends on expected future changes in the exchange rate. Note that by assumption the expected future change in the exchange rate is independent of its current realisation.

In contrast, firm H’s incentive compatibility constraint is given by:

$$\Pi_H^D - \Pi_H^C \leq \frac{\delta}{1-\delta} \left(\int_{\underline{e}}^{\bar{e}} (\Pi_H^C f(e) de) - \Pi_H^N \right) \qquad (13b)$$

The left hand side of equation (13b) reflects the fact that at given prices firm H’s profits are unaffected by the exchange rate. However, H’s future expected collusive profits may vary with e, if its rival’s prices fluctuate with the exchange rate. Thus, on the right hand side future expected collusive profits are allowed to vary with expected changes in the exchange rate.[xiii]

We begin by determining the impact of a change in the exchange rate on firm F’s incentive to collude. Lemma 3 reveals that a depreciation of the exchange rate lowers the foreign firm's incentive to defect and therefore makes collusion more attractive[xiv].

Lemma 3: Let $\bar{e} > \underline{e}$ then $\Psi^F(p_H^c, p_F^c, \bar{e}) - \Psi^F(p_H^c, p_F^c, \underline{e}) < 0$

where: $\Psi^F(p_H^c, p_F^c, e) = \Pi_F^D(e) - \Pi_F^c(e) - \frac{\delta}{1-\delta}\int_{\underline{e}}^{\bar{e}} (\Pi_F^c(e) - \Pi_F^N(e))\, f(e)de$

Proof:

Suppose that the exchange rate is at some level $\underline{e}$ at which F's incentive compatibility constraint binds at given collusive prices (p_H^c, p_F^c). Define F's incentive compatibility constraint at $(p_H^c, p_F^c, \underline{e})$ as:

$$\Psi^F(p_H^c, p_F^c, \underline{e}) = \Pi_F^D(\underline{e}) - \Pi_F^c(\underline{e}) - \frac{\delta}{1-\delta}\int_{\underline{e}}^{\bar{e}} (\Pi_F^c(e) - \Pi_F^N(e)) f(e)de = 0$$

Consider a depreciation of the exchange rate to some level $\bar{e} > \underline{e}$. Holding collusive prices at their given levels (p_H^c, p_F^c) the incentive compatibility constraint is then given by:

$$\Psi^F(p_H^c, p_F^c, \bar{e}) = \Pi_F^D(\bar{e}) - \Pi_F^c(\bar{e}) - \frac{\delta}{1-\delta}\int_{\underline{e}}^{\bar{e}} (\Pi_F^c(e) - \Pi_F^N(e)) f(e)de$$

Suppose that Lemma 3 is not true, this then implies that a depreciation of the exchange raises the incentive to defect so that

$$\Psi^F(p_H^c, p_F^c, \bar{e}) - \Psi^F(p_H^c, p_F^c, \underline{e}) \geq 0 \qquad \text{(I)}$$

Substituting for $\Psi^F(p_H^c, p_F^c, \bar{e}); \Psi^F(p_H^c, p_F^c, \underline{e})$ in the above equation, using (2b) and rearranging:

$$(\overline{\Pi}_F^D - \overline{\Pi}_F^C)\left(\frac{1}{\bar{e}} - \frac{1}{\underline{e}}\right) < 0$$

where: $\overline{\Pi}_F^g = p_F^g q_F(p_H^c, p_F^g)$ (g = D, C)

Since $(\overline{\Pi}_F^D - \overline{\Pi}_F^C) > 0$ by construction, it follows that (I) is satisfied iff: $\frac{1}{\bar{e}} > \frac{1}{\underline{e}}$. This yields a contradiction since we have assumed that $\bar{e} > \underline{e}$. It therefore follows that $\Psi^F(p_H^c, p_F^c, \bar{e}) - \Psi^F(p_H^c, p_F^c, \underline{e}) < 0$ so that a depreciation of the exchange rate lowers the incentive to defect. QED.

Intuitively, this ocurs because a depreciation of the exchange rate lowers the current rewards from defection, but has no impact on the expected cost of the punishment. Thus, the expected future loss from the punishment is fixed, while the gains from deviation decline as the exchange rate depreciates. It follows that firm F has a greater incentive to collude in periods in which the exchange rate depreciates.[xv]

We begin by investigating the impact of a depreciation when the firms are initially in a symmetric equilibrium with $\delta = a_H(p_H^c, p_F^c, e) = a_F(p_H^c, p_F^c, e)$[xvi]. The equilibrium outcome is given by the solution to the maximisation problem with the incentive compatibility constraint binding on each firm. In the Appendix it is shown that the derivatives cannot be signed. This occurs because a depreciation of the exchange rate has two conflicting effects in this equilibrium. On the one hand, from Lemma 3 we know that a depreciation increases firm F's incentive to collude and therefore provides it with an incentive to establish a more collusive equilibrium with higher prices. However, since the incentive compatibility constraint binds on H, a price increase may also induce a defection and may therefore not be sustainable. Hence, the outcome is ambiguous and depends on the parameters of the model.

Consider next the case when $\delta = a_H(p_H^c, p_F^c, e) > a_F(p_H^c, p_F^c, e)$. This implies that firm F's incentive compatibility constraint holds with slack, while firm H's constraint is just satisfied with equality. Thus, relative to its foreign rival the domestic firm is the more aggressive competitor with less incentive to collude. Following the procedure outlined in the Appendix we find:

$$\frac{dp_F^c}{de} = \frac{-V_H^H \Psi_e^H}{\Delta_g} < 0 \tag{14a}$$

$$\frac{dp_H^c}{de} = \frac{V_F^H \Psi_e^H}{\Delta_g} < 0 \tag{14b}$$

where: $\Delta_g = V_H^H \Psi_F^H - \Psi_H^H V_F^H > 0$

In this equilibrium, the competitive advantage of the domestic firm is reinforced by a depreciation of the exchange rate and this leads to an equilibrium with lower prices.

Finally, suppose that $\delta = a_F(p_H^c, p_F^c, e) > a_H(p_H^c, p_F^c, e)$. In this case firm H's incentive compatibility constraint holds with slack, while that of firm F's is just satisfied with equality. Thus, F is the more aggressive competitor. In the Appendix it is demonstrated that:

$$\frac{dp_F^c}{de} = \frac{\Psi_e^F V_H^F}{\Delta_F} > 0 \qquad (15a)$$

$$\frac{dp_H^c}{de} = \frac{-\Psi_e^F V_F^F}{\Delta_F} > 0 \qquad (15b)$$

$\Delta_F = V_F^F \Psi_H^F - \Psi_F^F V_H^F < 0$

A depreciation of the exchange rate makes collusion more attractive for the foreign firm so that it raises its price. The weaker domestic firm follows its lead and also increases its price.

In contrast to the conclusions of Section 3 these results suggest that when a more aggressive foreign firm confronts a less competitive domestic rival the price set tends to amplify temporary exchange rate movements. Conversely, when the domestic firm is the more aggressive competitor, the foreign firm has an incentive to set prices which counteract temporary fluctuations in the exchange rate. These findings appear to confirm Knetter's (op cit) observation that price stabilisation of German exports in US markets reflects the fact that the "....number of competing firms faced by German exporters is greater in the US than in other destination markets." Similarly, the empirical evidence presented by Mann (1986) also suggests that US export prices tend to amplify currency movements. The results outlined here indicate that this is likely to occur either if US firms are the dominant players or compete more aggressively in overseas markets than their foreign rivals.

5. A Numerical Example

In this section we provide a simple numerical example of the equilibria based on a linear demand function of the form:

$$q_i = 1 - p_i + 0.5p_j \quad (i = H, F; \quad i \neq j) \qquad (16)$$

where: p_i, p_j are prices denominated in country H's currency.

As in earlier sections, production costs are assumed to be zero. Solving for the one-shot Nash equilibrium prices and profits respectively:

$$p_H^N = p_F^N = 0.67 \qquad (17a)$$

$$\Pi_H^N = 0.445; \quad \Pi_F^N = 0.445 / e \qquad (17b)$$

If a firm tacitly colludes and sets a price $p_i^C > p_i^N$, then its rivals defection profits are given by:

$$\Pi_H^D = ((2 + p_F^C)/4)^2 \qquad (18a)$$

$$\Pi_F^D = \frac{1}{e}((2 + p_H^C)/4)^2 \qquad (18b)$$

Substituting (17) and (18) into the incentive compatibility constraints:

$$\Phi^H = \left|\frac{2 + p_F^C}{4}\right|^2 - \frac{1}{1-\delta}\left((1 - p_H^C + 0.5p_F^C)p_H^C - \delta(0.445)\right) \qquad (19a)$$

$$\Phi^F = \frac{1}{e}\left[\left|\frac{2 + p_H^C}{4}\right|^2 - \frac{1}{1-\delta}\left((1 - p_F^C + 0.5p_H^C)p_F^C - \delta(0.445)\right)\right] \qquad (19b)$$

In what follows we assume that the discount rate is 5%.[xvii] Observe that the incentive compatibility constraints in (19a) and (19b) are symmetric when e* = e =1. Thus, if e < e* = 1 then $a_H(p_H^c, p_F^c, e) > a_F(p_H^c, p_F^c, e)$ so that firm H is the more aggressive competitor with a greater incentive to defect and the equilibrium is defined in equation (10). Conversely, when e > e* = 1 then $a_H(p_H^c, p_F^c, e) < a_F(p_H^c, p_F^c, e)$, firm F has less incentive to collude than H and the effect of exchange rate changes is defined in equation (7).

The equilibrium outcomes are summarised in Figure 1. When e = 1, the equilibrium is symmetric and defined by equation (9) which yields collusive prices $p_H^C = p_F^C$ = 1.297 and profits $\Pi_H^C = \Pi_F^C$ = 0.46.[xviii] Conversely, when e > 1 the incentive compatibility constraint binds on firm F in equilibrium. In this equilibrium if the exchange rate depreciates beyond e = 1.4 collusion is no longer feasible as the profits that firm F earns in the one-shot noncollusive Nash equilibrium exceed those under collusion. This outcome reflects the fact that a depreciation makes defection more attractive for firm F. Thus, with a sufficiently large depreciation the incentive to collude eventually disappears. When e < 1 the equilibrium is defined by equation (10) where firm H is the more aggressive competitor with less incentive to collude. Since changes in the exchange rate have no direct impact on firm H, who is the stronger competitor, firm F is unable to vary its price in response to exchange rate changes. Thus, as equation (11) reveals collusive prices remain unchanged in this region.

Figure 1 here

Consider next random fluctuations in the exchange rate. For computational ease we focus upon a highly simplified exchange rate process which captures the main features of the model outlined in Section 4. Thus, it is assumed that the exchange rate fluctuates randomly between two discrete states e_1 and e_2. It is further supposed that state e_1 occurs with some probability $\alpha < 1$ and e_2 eventuates with probability $(1 - \alpha)$. Without loss of generality it is assumed that the exchange rate is initially in state e_1, then firm F's incentive compatibility constraint is given by:

$$\Psi^F = \frac{1}{e_1}\left[\left(\frac{2+p_H^C}{4}\right)^2 - (1-p_F^C+0.5p_H^C)p_F^C\right] - \frac{\delta}{1-\delta}\Big((1-p_F^C+0.5p_H^C)p_F^C-(0.445)\Big)\left(\frac{\alpha}{e_1}+\frac{1-\alpha}{e_2}\right) \qquad \text{(20a)}$$

Firm H's incentive compatibility constraint is:

$$\Psi^H = \left(\frac{2+p_F^C}{4}\right)^2 - \frac{1}{1-\delta}\Big((1-p_H^C+0.5p_F^C)p_H^C - \delta(0.445)\Big) \qquad \text{(20b)}$$

For purposes of comparison with the results in Figure 1 we begin by considering the special symmetric equilibrium when $e_1 = e_2 = 1$ and the firms have the same incentive to collude. Lemma 3 reveals that with random fluctuations in the exchange rate, a depreciation raises firm F's incentive to collude. Hence if $e_1 > 1$ then firm H is the more aggressive competitor, while $e_1 < 1$ corresponds to the case where firm F is the more aggressive competitor. The resulting equilibrium prices and profits are summarised in Figure 2.

Figure 2 here

Since depreciations of the exchange rate improve firm H's competitive position, the Figure reveals that when $e_1 > 1$ the domestic firm earns higher profits than its foreign rival in the collusive equilibrium. Moreover, firm F's one-shot Nash equilibrium profits exceed profits under tacit collusion when $e_1 < 0.4$. This result simply reflects the fact that an appreciation of the exchange rate erodes the incentive to collude.

Overall these results suggest that tacit collusion is harder to sustain when large movements of the exchange rate lower the foreign firm's incentive to collude. With permanent changes of the exchange rate, collusion is made more difficult following a large depreciation, while with temporary fluctuations tacit collusion breaks down if there is a substantial appreciation of the exchange rate. More generally, however, the numerical results reveal that the price responses depend critically upon the relative competitive strengths of the domestic and foreign firms.

6. Conclusions

The results obtained in this paper reveal that when firms interact over an indefinite period of time then the impact of a change in the exchange rate depends critically upon two factors: the expected duration of the change and the relative incentives of the firms to collude (compete). When the domestic firm is the more aggressive competitor and a depreciation is expected to be temporary , then export prices tend to be adjusted in a manner which counteract currency movements. This outcome suggests the need for future empirical research to take further account of both the relative market power of firms in tradable goods markets and the anticipated duration of a change in the exchange rate. Moreover, it should be noted that in keeping with the existing literature the analysis is based on a partial equilibrium model in which monetary phenomena (nominal exchange rate movements) have real effects. There is clearly a need to incorporate such a model into a more general macroeconomic framework.

While the results in this paper are based on a price setting supergame, the model can be easily reinterpreted in terms of quantity competition. In this case collusion is supported by reversion to the Cournot equilibrium. It can be verified that the effect of exchange rate changes on profits is qualitatively the same as that outlined in Lemmas 2 and 3 and that the main conclusions are therefore unaffected.[xix]

Appendix

Lemma 1

$$\frac{\partial \Phi^j}{\partial p_i^C} > 0 \quad (i = H, F) \text{ and } (i \neq j)$$

Proof:

Suppose that Lemma 1 is not true. Then $\partial\Phi^j/\partial p_i^c \leq 0$ which implies that an increase in p_i^c does not raise the gains from defection. Moreover, since $p_i^c < \tilde{p}_i^c$ this increases Π^C without violating the constraint. This, however, contradicts the hypothesis that p_i^c solves the maximisation problem when the constraint binds. Hence, if p_i^c is a solution to the constrained maximisation problem then: $\partial\Phi^j / \partial p_i^c > 0$. *Q.E.D.*

Equation 9

Totally differentiating the incentive compatibility constraints of the firms yields the system of equations:

$$\begin{vmatrix} \Phi_F^F & \Phi_H^F \\ \Phi_F^H & \Phi_H^H \end{vmatrix} \begin{vmatrix} dp_F^c \\ dp_H^c \end{vmatrix} = - \begin{vmatrix} \Phi_e^F de \\ 0 \end{vmatrix} \tag{A1}$$

where: subscripts on Φ^i are used to denote partial derivatives and

$\Phi_i^i = \partial\Phi^i / \partial p_i^c = -(\delta_i / (1-\delta_i))(\partial\Pi_i^C / \partial p_i^C) > 0 \quad (i = H, F)$ (Since $p_i^D \in \operatorname{Arg\,max} \Pi_i^C(p_i^D, p_j^C)$ and $p_i^c > p_i^D$ then $\partial\Pi_i^C / \partial p_i^C < 0$).

$\Phi_j^i = \partial\Phi^i / \partial p_j^c > 0$ (i = H, F) by Lemma 1

$\Phi_e^i = \partial\Phi^i / \partial e > 0$ (i = F) by Lemma 2

The determinant is: $D = \Phi_F^F\Phi_H^H - \Phi_F^H\Phi_H^F > 0$ (since it is easily verified that by (1b) own price effects on profits exceed the cross price effects so that: $|\Phi_F^F| > |\Phi_H^F|; |\Phi_H^H| > |\Phi_F^H|$).

Solving (A1) yields equations (9a) and (9b) in the text.

Equation 12

Following an analogous procedure to that outlined above yields:

$$V^F = q_F + p_F^c \frac{\partial q_F}{\partial p_F^c} + p_H^c \frac{\partial q_H}{\partial p_F^c} = 0 \tag{A2}$$

Note that $\partial V^F / \partial e = 0$. Since the constraint binds firm H's most collusive sustainable price is determined by the solution to:

$$\Phi^F \equiv \Pi_F^D - \frac{1}{1-\delta}(\Pi_F^C - \delta\Pi_F^N) \tag{A3}$$

By Lemma 2 $\partial\Phi^F / \partial e > 0$. Totally differentiating and rearranging:

$$\begin{vmatrix} V_F^F & V_H^F \\ \Phi_F^F & \Phi_H^F \end{vmatrix} \begin{bmatrix} dp_F^c \\ dp_H^c \end{bmatrix} = - \begin{vmatrix} 0 \\ \Phi_e^F de \end{vmatrix} \tag{A4}$$

where: $V_F^F < 0$ from the second order conditions, and by (3b) $V_H^F > 0$. The determinant is $\Gamma_F = V_F^F\Phi_H^F - \Phi_F^F V_H^F < 0$. Solving (A4) yields (12a) and (12b).

Define $\Psi^H = \Pi_H^D - \Pi_H^C - \frac{\delta}{1-\delta}\left(\int_{\underline{e}}^{\bar{e}} \Pi_H^C f(e)de - \Pi_H^N\right)$ (A5)

By Lemma 1: $\Psi_F^H \equiv \frac{\partial \Psi^H}{\partial p_F^c} > 0$. Moreover, $\Psi_H^H \equiv \frac{\partial \Psi^H}{\partial p_H^c} > 0$. Finally,

$$\Psi_e^H \equiv \left.\frac{\partial \Psi^H}{\partial e}\right|_{dp_H^C = dp_F^C = 0} < 0$$

<u>Proof that with temporary changes when e= e* then $dp_i/de \lesseqgtr 0$ (i = H,F):</u>

Following the procedure outlined above, differentiation of the incentive compatibility constraints gives the system of equations:

$$\begin{vmatrix} \Psi_F^F & \Psi_H^F \\ \Psi_F^H & \Psi_H^H \end{vmatrix} \begin{bmatrix} dp_F^c \\ dp_H^c \end{bmatrix} = - \begin{vmatrix} \Psi_e^F de \\ \Psi_e^H de \end{vmatrix} \quad \text{(A6)}$$

The determinant is $\Delta_r = \Psi_H^F \Psi_F^H - \Psi_F^F \Psi_H^H > 0$ (since $|\Psi_F^F| > |\Psi_H^F|; |\Psi_H^H| > |\Psi_F^H|$) . Solving:

$$\frac{dp_F^c}{de} = \frac{\Psi_H^H \Psi_e^F - \Psi_H^F \Psi_e^H}{\Delta_r} \lesseqgtr 0 \quad \text{(A7)}$$

$$\frac{dp_H^c}{de} = \frac{\Psi_F^F \Psi_e^H - \Psi_F^H \Psi_e^F}{\Delta_r} \lesseqgtr 0 \quad \text{(A8)}$$

<u>Equation (14)</u>

Differentiating the system yields:

$$\begin{bmatrix} \Psi_F^H & \Psi_H^H \\ V_F^H & V_H^H \end{bmatrix} \begin{bmatrix} dp_F^c \\ dp_H^c \end{bmatrix} = - \begin{bmatrix} \Psi_e^H de \\ 0 \end{bmatrix} \quad \text{(A9)}$$

with determinant $\Delta_H = -V_F^H \Psi_H^H + \Psi_F^H V_H^H < 0$. Solving yields (14 a and b) in the text.

<u>Equation (15)</u>

Differentiating the system:

$$\begin{bmatrix} V_F^F & V_H^F \\ \Psi_F^F & \Psi_H^F \end{bmatrix} \begin{bmatrix} dp_F^c \\ dp_H^c \end{bmatrix} = - \begin{vmatrix} 0 \\ \Psi_e^F de \end{vmatrix} \quad \text{(A10)}$$

$\Delta_F = V_F^F \Psi_H^F - \Psi_F^F V_H^F < 0$. Solving gives (16a and b) in the text.

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ii A similar result is also reported in Mann (1986) who studied the effect of dollar appreciations and depreciations on US export margins.

ii See Knetter (*op cit*), Fisher (1989b)

iii In this model assumptions about the profit function ensure that there is a unique one shot Nash equilibrium.

iv There are other equilibria of the supergame. Attention is restricted to constrained collusive equilibria since this allows us to identify the manner in which marginal changes in the exchange rate influence prices.

v The joint profit maximising prices are defined as those that would be set by a monopolist producing the differentiated products. Hence prices are set to maximise the combined profits of the two firms.

vi The precise relationship between a_i and e depends upon the impact of e on the incentive compatibility constraints. This in turn depends on expected changes in e. These matters are discussed in further detail in the following sections.

vii This approach to modeling constrained collusive equilibria has been widely adopted in the literature. Examples include Davidson and Martin (1985), Damania (1994) amongst others. The rationale underlying this approach follows from Lemma 1 and is explained later in this Section.

viii In the parlance of Friedman (1989) this is termed a "balanced temptation equilibrium".

ix Note that we use the fact that since $\Pi_F = p_F q_F/e$; then $\partial\Pi_F/\partial e = - p_F q_F/e^2 = -\Pi_F/e$.

x Firm F's market share increases because the domestic firm raises its price while the foreign firm's price declines.

xi It is, of course, implicitly assumed here that the support of e is a positive subset of real numbers.

xii This follows from the fact that $\Pi^g{}_F = (p^g_F\ q_F)/e$, (g = C, D).

xiii In contrast, from equation (4) we know that in the one-shot Nash equilibrium, prices are independent of the exchange rate and hence Π^N_H is unaffected by exchange rate fluctuations.

xv This result is analogous to that of Rotemberg and Saloner (1986) where the incentive to defect is greatest in periods of high demand.

xvi As in the previous section $a_i(.)$ is the relative incentive to defect, and is derived by rearranging the incentive compatibility constraints.

xvii This corresponds to a discount factor of 0.952.

xviii As is well known the incentive compatibility constraint in a constrained symmetric equilibrium reduces to a quadratic, with one solution at the one-shot Nash equilibrium price and the other solution at the higher collusive price.

xix All results for the case of quantity competition are available from the author upon request.