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Working Paper

Market power of firms and exchange-rate fluctuations

Diskussionsbeiträge - Serie II, No. 278

Provided in Cooperation with:

Department of Economics, University of Konstanz

Suggested Citation: Meckl, Jürgen (1995) : Market power of firms and exchange-rate fluctuations, Diskussionsbeiträge - Serie II, No. 278, Universität Konstanz, Sonderforschungsbereich 178 - Internationalisierung der Wirtschaft, Konstanz

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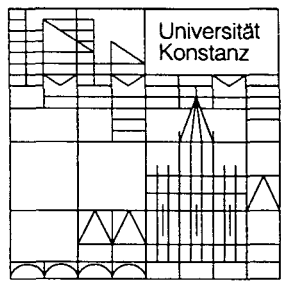
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Sonderforschungsbereich 178
„Internationalisierung der Wirtschaft“

Diskussionsbeiträge



Juristische
Fakultät

Fakultät für Wirtschafts-
wissenschaften und Statistik

Jürgen Meckl

**Market Power of Firms
and Exchange-Rate Fluctuations**

31. OKT. 1995 Weltwirtschaft

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Market Power of Firms and Exchange-Rate Fluctuations

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W 113 (278)



Serie II - Nr. 278

September 1995

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I am grateful to Max Albert, Norbert Wunner, and Günther Schulze for valuable comments on earlier versions of the paper.

Abstract

This paper explores the potential of firms to restrict industry outputs (market power) in oligopolistically organized markets where domestic firms compete with foreign ones. Within a stochastic price-setting supergame framework, market power is shown to be lower in general with flexible exchange rates for the following reasons. (i) The conditions that the fully collusive outcome—oligopolists maximizing joint profits—is sustainable in equilibrium become stronger if the exchange rate fluctuates, provided that fluctuations are sufficiently small. (ii) Even if full collusion can be sustained, industry outputs will be higher on the average with flexible than with fixed exchange rates.

1 Introduction

This paper explores the question whether market power of firms in oligopolistically organized markets where domestic firms compete with foreign ones is affected by fluctuations in the exchange rate. Market power will be interpreted as the potential of firms to restrict industry outputs and drive up market prices (thus maximizing consumer exploitation). In particular, I concentrate on the maximum of firms' market power, not on the actually realized market power; the latter may be lower if firms do not fully use their potential to restrict industry outputs. My central argument is that, at least for sufficiently small fluctuations, the necessary conditions that the fully collusive outcome—implicitly colluding oligopolists maximizing joint profits—is sustainable in equilibrium become more restrictive if the exchange rates fluctuates around some average rate than if it is stabilized at that rate. And even if full collusion can be sustained, industry outputs will be higher on the average with fluctuating exchange rates. Consequently, market power of firms is in general lower under a system of flexible exchange rates. Following Porter (1983) and assuming that implicitly colluding firms actually choose the Pareto dominating equilibrium strategy maximizing their profits, we might expect lower prices and higher industry outputs under fluctuating exchange rates than under fixed exchange rates on the average.

I will prove this assertion adopting the stochastic price-setting supergame framework of Rotemberg and Saloner (1986). They study implicit collusion in the presence of observable fluctuations in industry demand in an infinitely repeated game.¹ With serially uncorrelated random shocks in demand the gain from defection is higher in states of high demand (booms) than in states of low demand (recessions). Expected losses after defection (punishment), however, are independent of the actual state of demand. The authors' main conclusion is that the fully collusive outcome (i.e. maximization of joint profits) becomes more difficult in states of high demand. But failure of full collusion in booms does not necessarily imply competitive outcomes. For a given level of punishment there is always some level of prices strictly between the competitive and monopoly price that is sustainable in booms. The authors refer to this situation as 'some collu-

¹It is a well-known result in industrial economics that with deterministic demand implicit collusion is sustainable in an infinitely repeated game provided that punishment for defecting is sufficiently high. Cf. Tirole (1988: 245–247).

sion'. In the terminology of the present paper, their result must be interpreted such that market power of firms is lower in booms than in recessions.

The central argument of Rotemberg and Saloner does not hinge on the special source of uncertainty they consider. More generally, full collusion becomes more difficult in states of comparably high profits: punishment entails a loss of an average of high and low profits and is less harsh in states of high profit than in states of low profits. Serially uncorrelated changes in the exchange rate may bring about fluctuations in a foreign firm's profits of the kind analyzed by Rotemberg and Saloner. It will be shown that the foreign firm's gain from defection net of punishment increases with the extent of exchange-rate fluctuations if both firms have identical marginal costs. In the case of cost differentials, however, the foreign firm's net gain from defection is shown to decrease with the extent of exchange-rate fluctuations, and the home firms net gain to increase. Thus, at least for one firm the necessary condition for sustaining fully collusive outcomes becomes more severe if the exchange rate fluctuates around a certain average exchange rate than if the exchange rate were stabilized at the average level. It is in this sense that market power of firms will in general be lower with flexible exchange rates; high volatility of exchange rates has considerable impact on maximum profits sustainable in equilibrium.

The paper is organized as follows. Section 2 presents a highly simplified model of oligopolistic pricing under a system of a fixed exchange rate. This case should serve as the benchmark for the analysis of collusion with observable and serially uncorrelated exchange-rate fluctuations in section 3. Abstracting from cost differentials, exchange-rate movements can be shown to affect firms situated in different countries asymmetrically. This asymmetry has considerable impact on the foreign firm's price setting behavior. Section 4 analyzes cost advantages generated by exchange-rate fluctuations and their negative effect on market power of firms. In this setting decisions of firms in both countries are affected by exchange-rate movements. Section 5 concludes.

2 Price setting with fixed exchange rates

Consider a home and a foreign firm competing in a domestic market for a homogeneous good in an infinite-horizon setting. Demand is time invariant and a

continuously differentiable function $D(p)$ of the price p , with $D'(p) < 0$. While both firms get identical market shares if they charge identical prices, the low-price firm takes the complete market if firms charge different prices. Firms are assumed to maximize their expected present value V . Denoting the price in period t by $p(t)$ and assuming constant marginal costs c , the expected present value of the home firm is given by

$$V = E \left[\sum_{t=0}^{\infty} \alpha(t) \cdot (p(t) - c) \cdot D(p(t)) \cdot \delta^t \right], \quad (1)$$

where δ stands for the home discount factor and $\alpha(t)$ denotes the firm's market share in t . $E[x(t)]$ is equal to the mathematical expectation of a variable $x(t)$. Eqn. (1) shows that the exchange rate affects the present value of the home firm only through its effects on price-setting behavior. The present value of the foreign firm in its home currency is

$$\tilde{V} = E \left[\sum_{t=0}^{\infty} (1 - \alpha(t)) \cdot \left(\frac{p(t)}{e(t)} - \tilde{c} \right) \cdot D(p(t)) \cdot \tilde{\delta}^t \right], \quad (2)$$

where a tilde denotes foreign values. Apart from the indirect effect through price setting behavior, the exchange rate directly affects the present value of the foreign firm.

In the following, I will assume that the discount factor of the foreign country is constant over time, implying that this country is large in the sense that it dominates international financial markets. With perfect capital mobility the following must hold for discount factors:

$$\delta = \frac{E[e(t)]}{E[e(t+1)]} \cdot \tilde{\delta}. \quad (3)$$

Suppose that the exchange rate is fixed at a level \bar{e} . As (3) indicates, discount factors must then be identical for both countries. Furthermore, let $c \equiv \bar{e} \cdot \tilde{c}$; this assumption may be interpreted as reflecting a general-equilibrium property: the exchange rate is assumed to be fixed at a level equalizing production costs in both countries.²

Since the problem at hand is market power of firms, I concentrate on the conditions required for monopoly pricing to be a sustainable equilibrium. Consider

²One may think of international factor mobility ensuring that factors are equally rewarded; production costs then equalize provided both firms have access to the same technologies.

the following trigger strategies: Each firm charges the monopoly price p_M that maximizes $(p - c) \cdot D(p)$ in period 0. It furthermore charges p_M in period t if both firms have charged p_M in the preceding period and makes a profit $\pi_M/2$ per period; otherwise both firms charge competitive prices $p_C = c$ forever. Full collusion can then be sustained if the one-time extra profit $\pi_D = \pi_M/2$ by undercutting the monopoly price in $t = 0$ is less than the present value of the loss of future profits by defecting in $t = 0$ (punishment). This means that

$$\pi_D = \frac{\pi_M}{2} \leq \sum_{t=1}^{\infty} \frac{\pi_M}{2} \cdot \delta^t \quad (4)$$

must hold for the home firm, and

$$\hat{\pi}_D = \frac{\pi_M}{2 \cdot \bar{e}} \leq \sum_{t=1}^{\infty} \frac{\pi_M}{2 \cdot \bar{e}} \cdot \delta^t \quad (5)$$

must hold for the foreign firm. Obviously, eqs. (4) and (5) can both be written as $\delta/(1 - \delta) \geq 1$, which follows if

$$\delta \geq \frac{1}{2}. \quad (6)$$

With fixed exchange rates we have the well known condition for collusive pricing in the closed economy model with deterministic demand. A sufficiently high discount factor, i.e. sufficient harsh punishment, ensures that the above trigger strategies with both firms charging monopoly prices are equilibrium ones.³

3 Price setting with flexible exchange rates

Suppose now the exchange rate is stochastic and serially uncorrelated. At each period t the exchange rate can take on a low value (e_1) with probability 1/2, and a high value (e_2) with equal probability. With $E(e) = \bar{e}$, the interest-rate-parity

³Note that this does not imply that charging monopoly prices is the only equilibrium strategy in that case. As Friedman (1971) has shown, any price between the competitive price and the monopoly price can also be sustained as an equilibrium price as long as the discount factor fulfills condition (6). As far as market power of firms is concerned, the conditions necessary for the maximum price sustainable in equilibrium are of primary interest.

condition (3) then implies identical discount rates in both countries, just as in the case of a fixed exchange rate.⁴ Additionally, assume marginal costs to be zero.⁵

Consider first the conditions for the fully collusive outcome with both firms charging the monopoly price p_M maximizing $p \cdot D(p)$. From (4) it immediately follows that a stochastic exchange rate does not change the condition for tacit collusion for the home firm given by (6). However, it does change conditions for the foreign firm. Since punishment to undercutting depends on the expected (average) exchange rate, we may expect that the incentive to defect is higher for the foreign firm if e is low, i.e. if the currency of the importing country is overvalued. The condition for full collusion now is

$$\tilde{\pi}_D = \frac{\pi_M}{2 \cdot e_1} \leq \sum_{t=1}^{\infty} \frac{1}{4} \cdot \left(\frac{1}{e_1} + \frac{1}{e_2} \right) \cdot \pi_M \cdot \delta^t. \quad (7)$$

This condition holds if

$$\delta \geq \delta_0 \equiv \frac{2 \cdot e_2}{(3 \cdot e_2 + e_1)}. \quad (8)$$

Because $e_2 > e_1$, δ_0 lies strictly between $1/2$ and $2/3$. Obviously, δ_0 is the greater, the more the exchange rates fluctuates.⁶ Thus, the condition for full collusion is the stronger, the greater the fluctuations of the exchange rates.

However, firms may realize maximum market power *in some periods* even if the condition for full collusion (8) is not met, i.e. if $\delta \in (1/2, \delta_0)$. Following Rotemberg and Saloner (1986) we may ask whether some collusion is sustainable when full collusion is not. With respect to maximum market power, the problem is to find a pair of prices $\{p_1, p_2\}$ for $\delta \in (1/2, \delta_0)$ such that (i) both firms charge $p_s \in [p_C, p_M]$ when the exchange rate takes on the value e_s ($s = 1, 2$), (ii) $\{p_1, p_2\}$ is sustainable in equilibrium, and (iii) the expected present value of firms along

⁴I assume \bar{e} to be identical to the level of the fixed exchange rate in section 2. Thus, I actually consider the impact of fluctuations around an equilibrium exchange rate on market power of firms. The kind of exchange-rate movements considered give no reason for international factor movements since expected factor incomes are identical in both countries.

⁵This strong assumption is made to isolate the asymmetric impact of exchange-rate fluctuations on the one-time gains from defection from their effect on punishment via their asymmetric effect on costs of production. The latter will be discussed in the next section.

⁶Note that punishment becomes stronger the higher the exchange-rate fluctuations are. This effect, however, is overcompensated by the positive effect of increasing fluctuations on the one-time gain from defection.

the equilibrium path is not dominated by other equilibrium paths. In order to enforce $\{p_1, p_2\}$, firms are assumed to charge competitive prices p_C after defection.

Due to the fact that exchange-rate fluctuations do not affect the home firm, it will not deviate from collusive pricing for all prices $p_s \in [p_C, p_M]$ if $\delta \geq 1/2$. On the other hand, the foreign firm can be shown not to deviate from collusion if $p_1 < p_2 = p_M$ for $\delta \in (1/2, \delta_0)$. The foreign firm chooses p_1 and p_2 as to maximize its expected payoff subject to the incentive constraints:

$$\max_{p_1, p_2} \left\{ \begin{aligned} &\sum_{t=0}^{\infty} \frac{1}{4} \cdot \left(\frac{\pi_1}{e_1} + \frac{\pi_2}{e_2} \right) \cdot \delta^t : \\ &\sum_{t=1}^{\infty} \frac{1}{4} \cdot \left(\frac{\pi_1}{e_1} + \frac{\pi_2}{e_2} \right) \cdot \delta^t \geq \frac{1}{2} \cdot \frac{\pi_1}{e_1} \\ &\sum_{t=1}^{\infty} \frac{1}{4} \cdot \left(\frac{\pi_1}{e_1} + \frac{\pi_2}{e_2} \right) \cdot \delta^t \geq \frac{1}{2} \cdot \frac{\pi_2}{e_2} \end{aligned} \right\}. \quad (9)$$

As shown in the appendix the solution to this problem is given by

$$p_2 = p_M \quad (10)$$

$$\pi_1 = K \cdot \frac{e_1}{e_2} \cdot \pi_2, \quad (11)$$

where $K = \delta/(2 - 3 \cdot \delta)$. Since $K \cdot e_1/e_2 < 1$ (cf. appendix), a less strong form of collusion (some collusion) with $p_1 \in [p_C, p_M]$ is sustainable as long as the currency of the exporting country is undervalued, and full collusion $p_2 = p_M$ can be sustained as long as the currency of the exporting country is overvalued.⁷ Maximum market power may be realized only in state 2.

Put together, the conditions for sustaining monopoly prices and outputs are generally stronger with exchange rates fluctuating around some average exchange rate than with the exchange rate stabilized at that average level. For certain values of the discount factor full collusion can be sustained only if the currency of the exporting country is overvalued, and prices lie strictly between the monopoly and competitive price otherwise. It is in this sense, that fluctuations of the exchange rate increase the likelihood of lower prices and higher industry outputs compared to a system of fixed exchange rates. Exchange rate fluctuations trigger

⁷Note that (11) may be fulfilled by a price exceeding p_M ; however, we can exclude that price as a solution to the above problem because with the foreign firm setting a price above p_M the home firm gets the complete market by setting p_M .

movements in prices with the equilibrium price of the fixed exchange rate regime as the upper bound. Thus, potential market power of firms is generally higher if the exchange rate is stabilized at a fixed level.

4 Cost Asymmetries and Market Shares

Consider now the case where both firms have positive and constant marginal costs $c \equiv \bar{e} \cdot \tilde{c}$. Do conditions for full collusion necessarily change in the case of positive marginal costs and a flexible exchange rate? First, note that the analysis is qualitatively equivalent to the analysis of section 3 if both firms produce in the same country and hence have identical marginal costs when measured in the same currency. The only impact is the positive correlation between the maximum prices that can be sustained by collusion and the value of c . Thus, we can interpret the result of section 3 the following way: If two domestic firms compete in a domestic market and capital of one firm is foreign owned, fluctuations in the exchange rate will in general reduce market power of firms.

If the firms produce in different countries, however, marginal costs measured in the same currency differ as the exchange rate fluctuates. Hence movements in the exchange rate cause cost asymmetries that have a considerable effect on firms' market power.

Given our stochastic specification of exchange-rate fluctuations of section 3, marginal costs measured in the same currency always differ. With $e_1 \cdot \tilde{c} < c < e_2 \cdot \tilde{c}$, the home firm is the low-cost firm, if the exchange rate is high, and the high-cost firm otherwise. Market power of firms is maximized if they act as if they were a single monopolist. Define full collusion as maximizing joint profits. The fully collusive outcome then maximizes

$$\max_{p_{M1}, p_{M2}} \left\{ (p_{Ms} - \min\{c, e_s \cdot \tilde{c}\}) \cdot D(p_{Ms}) \right\}. \quad (12)$$

This program implies that firms take turns being monopolists.⁸ Firms charge state-dependent prices according to

$$(p_{M1} - e_1 \cdot \tilde{c}) \cdot D'(p_{M1}) + D(p_{M1}) = 0 \quad (13)$$

$$(p_{M2} - c) \cdot D'(p_{M2}) + D(p_{M2}) = 0. \quad (14)$$

⁸In the case of increasing marginal costs, it can be shown that firms take turns in realizing a greater market share.

The foreign firm holds the monopoly position in state 1, the home firm in state 2. Since $c > e_1 \cdot \tilde{c}$, p_{M2} must be greater than p_{M1} .

This result already gives some insight. If the fully collusive outcome can be sustained, exchange rate movements generate cost asymmetries with the consequence of fluctuating monopoly prices. Compared to the fixed exchange-rate system, marginal costs are less if the exchange rate is below \bar{e} , and identical otherwise. Thus, even with fully collusive pricing industry outputs are higher on the average and market power of firms is thus lower on the average if the exchange rate fluctuates than it is with the exchange rate stabilized at the average. However, the problem to be solved now is whether the conditions required for full collusion to be a sustainable outcome become less restrictive or more restrictive with flexible exchange rates. I will show that the latter is the case concentrating on the case of linear demand functions $D(p) = a - b \cdot p$.

In order to enforce full collusion assume that firms switch to Bertrand competition after deviation. With asymmetric marginal costs, the low cost firm takes the complete market and sets a price either marginal under the high-cost firm's marginal costs or equal to its monopoly price, if the latter is lower than the former. Thus the home firm gets the market if the exchange rate is high and sets a price

$$p_{B2} = \min\{e_2 \cdot \tilde{c}, p_{M2}\}, \quad (15)$$

and the foreign firm gets the market if the exchange rate is low and sets a price

$$p_{B1} = \min\{c, p_{M1}\}. \quad (16)$$

Consider the conditions for full collusion to be sustainable in equilibrium for the home firm first. Deviation from the fully collusive solution when the exchange rate is low ($s = 1$) generates a one-time gain

$$\pi_D(e_2) = (p_{M1} - c) \cdot D(p_{M1}), \quad \pi'_D \leq 0$$

in period 0, and a Bertrand profit of

$$\pi_B(e_2) = (p_{B2} - c) \cdot D(p_{B2}), \quad \pi'_B \geq 0$$

in the following periods whenever the exchange rate is high ($s = 2$). The home firm's condition for fully collusive behavior then is

$$\pi_D(e_2) \leq \sum_{t=1}^{\infty} \frac{1}{2} \cdot [\pi_M - \pi_B(e_2)] \cdot \delta^t, \quad (17)$$

where $\pi_M = (p_{M2} - c) \cdot D(p_{M2})$ denotes the profits by not deviating from full collusion. A necessary condition for deviation is that $\pi_D(e_2) > 0$. Since $\pi'_D(e_2) \leq 0$, π_D is positive for $e_2 \in (\bar{e}, \bar{e}_2)$, where the value of \bar{e}_2 depends on demand parameters and the value of marginal costs.⁹ Within that range, (17) follows if

$$\delta \geq g(e_2) \equiv \frac{2 \cdot \pi_D(e_2)}{2 \cdot \pi_D(e_2) + \pi_M - \pi_B(e_2)} \quad (18)$$

holds. As shown in the appendix, $g(e_2)$ must lie in the interval $(2/3, 1]$. This implies that the condition for the home firm not to deviate from full collusion is stronger than in the case of a fixed exchange rate. Only for sufficiently high exchange-rate fluctuations ($e_2 > \bar{e}_2$), the home firm will never defect from collusion since gains from defection are negative. In this situations, however, Bertrand competition yields the same outcome as fully collusive behavior.

Look at the foreign firm now. Deviation when the exchange rate is high yields a one-time gain

$$\tilde{\pi}_D(e_2) = \left(\frac{p_{M2}}{e_2} - \tilde{c} \right) \cdot D(p_{M2}), \quad \tilde{\pi}'_D \leq 0$$

in period 0 and a Bertrand profit of

$$\tilde{\pi}_B(e_2) = \left(\frac{p_{B1}}{e_1} - \tilde{c} \right) \cdot D(p_{B1}), \quad \tilde{\pi}'_B \geq 0$$

in the following periods whenever the exchange rate is low. The condition for fully collusive behavior then is

$$\tilde{\pi}_D(e_2) \leq \sum_{t=1}^{\infty} \frac{1}{2} \cdot [\tilde{\pi}_M(e_2) - \tilde{\pi}_B(e_2)] \cdot \delta^t, \quad (19)$$

which follows if

$$\delta \geq \tilde{g}(e_2) \equiv \frac{2 \cdot \tilde{\pi}_D(e_2)}{2 \cdot \tilde{\pi}_D(e_2) + \tilde{\pi}_M(e_2) - \tilde{\pi}_B(e_2)}. \quad (20)$$

It is shown in the appendix that $\tilde{g}(e_2)$ approaches $2/3$ as e_2 goes to \bar{e} , and that $\tilde{g}(\hat{e}_2) = 0$, where $\hat{e}_2 > \bar{e}_2$ is implicitly defined by $\tilde{\pi}_D(e_2) = 0$ (or equivalently by

⁹Since e_1 must be positive, e_2 must lie in the interval $(\bar{e}, 2 \cdot \bar{e})$. Hence, for certain values of marginal cost and demand parameters, $2 \cdot \bar{e} < \bar{e}_2$, and π_D is positive for all possible values of e_2 .

$\pi_M(e_2) = \pi_B(e_2)$). This implies that the condition for the foreign firm not to deviate from full collusion is stronger than with a fixed exchange rate provided exchange-rate fluctuations are sufficiently small, but it becomes less strong if the amplitude of exchange-rate movements increases.

Our analysis emphasizes the asymmetric influence of exchange-rate fluctuations on the home and the foreign firm. The condition for the home firm not to defect from the fully collusive outcome must become the stronger the more exchange rate fluctuates as long as there is a positive one-time gain from defection. The opposite holds for the foreign firm. The economic intuition behind these results is straightforward. Fluctuations in the exchange rate reduce one-time profits from undercutting, because firms can only defect from collusion when their home currency is overvalued (they hold a monopoly position in states of undervaluation). But exchange-rate fluctuations also cause cost differentials that allow for positive profits under Bertrand competition and thus reduce punishment. For the home firm, punishment reduction is relatively strong so that (reduced) punishment must receive higher weight to prevent the home firm from defection; the restriction for the discount factor becomes stronger. For the foreign firm, punishment reduction is relatively weak. An increase in the amplitude of exchange-rate movements increases monopoly profits *and* Bertrand profits for the foreign firm; the first effect partly offsets the punishment reduction by the second effect. Hence, punishment can receive less weight for the foreign firm not to undercut; the restriction for the discount factor becomes less strong. However, if exchange-rate fluctuations are sufficiently strong, the home firm behaves identically under collusion and under Bertrand competition, and the foreign firm has no incentive to defect from collusion then. Hence, sufficiently high fluctuations yield collusive outcomes again with prices that are lower on the average than with a fixed exchange rate.

It is now straightforward to show that some collusion is possible if the condition for fully collusive behavior is not met. As we would expect from the analysis in section 3, there exists a pair of prices $\{p_1 < p_{M1}, p_2 = p_{M2}\}$ that is sustainable in equilibrium if the condition for full collusion is fulfilled for the foreign firm but not for the home firm. On the other hand, there will exist a pair of prices $\{p_1 < p_{M1}, p_2 < p_{M2}\}$ that is sustainable in equilibrium if the condition for full

collusion is not fulfilled for both firms.¹⁰ In general, market power of firms is reduced by sufficiently small fluctuations in the exchange rates.

5 Conclusions

This paper has shown that exchange-rate fluctuations restrict market power of firms in oligopolistically organized markets provided that fluctuations are sufficiently small. Movements in the exchange rate reinforce the conditions for full collusion to be a sustainable outcome of an infinitely repeated Bertrand game. Thus, the potential of firms to restrict industry outputs is higher with fixed exchange rates. Assuming that firms choose Pareto-dominating outcomes, we may expect outputs to be higher with flexible exchange rates on the average.

The analysis emphasizes the real effects of exchange-rate movements. Contrary to conventional argumentation, these real effects are favorable for consumers. Thus, advocates of a flexible-exchange-rate system can make a stronger argument than that in a world economy of imperfect competition there is a “kind of delinking of exchange rates and the real economy ... (ensuring that) ... *exchange rates can move so much precisely because they seem to matter so little.*” (Krugman 1989: 40) Fluctuations in the exchange rate may have considerable effects on the price setting behavior in imperfectly competitive markets, strengthening limitations to market power of firms.

¹⁰An alternative collusive outcome with a pair of prices $\{p_1 < p_{M1}, p_2 < p_{M2}\}$ is possible if firms allow for efficient market-sharing arrangements (cf. Tirole 1988: 250). However, all kinds of market-sharing arrangements under cost asymmetries reduce maximum market power of firms if they imply positive market shares for both firms in all states $s = 1, 2$.

Appendix

Some collusion with zero marginal costs

The following derives the solution of the maximization problem (9) in the text. This problem is equivalent to

$$\max_{p_1, p_2} \left\{ \begin{array}{l} \frac{p_1}{e_1} \cdot D(p_1) + \frac{p_2}{e_2} \cdot D(p_2) : \\ \frac{p_1}{e_1} \cdot D(p_1) \leq K \cdot \frac{p_2}{e_2} \cdot D(p_2) \\ \frac{p_2}{e_2} \cdot D(p_2) \leq K \cdot \frac{p_1}{e_1} \cdot D(p_1) \end{array} \right\}, \quad (21)$$

where $K \equiv \delta/(2 - 3 \cdot \delta) > 1 \forall \delta \in (1/2, 2/3)$. Denoting the multipliers for the constraints by λ_s , the first-order conditions for this problem can be written as:

$$\left[\frac{D(p_1)}{e_1} + \frac{p_1}{e_1} \cdot D'(p_1) \right] \cdot (1 - \lambda_1 + K \cdot \lambda_2) = 0 \quad (22)$$

$$\left[\frac{D(p_2)}{e_2} + \frac{p_2}{e_2} \cdot D'(p_2) \right] \cdot (1 + K \cdot \lambda_1 - \lambda_2) = 0 \quad (23)$$

$$\frac{p_1}{e_1} \cdot D(p_1) - K \cdot \frac{p_2}{e_2} \cdot D(p_2) \leq 0, \quad \lambda_1 \geq 0 \quad \text{w.c.s.} \quad (24)$$

$$\frac{p_2}{e_2} \cdot D(p_2) - K \cdot \frac{p_1}{e_1} \cdot D(p_1) \leq 0, \quad \lambda_2 \geq 0 \quad \text{w.c.s.}, \quad (25)$$

where w.c.s. stands for ‘with complementary slackness’. The only solution to this problem is $\lambda_2 = 0$, i.e. the first constraint must be binding.¹¹ Since $\lambda_1 \geq 0$, p_2 must then equal p_M for (23) to hold. Eq. (24) will then be fulfilled only if $p_1 < p_M$,¹² since $K \cdot e_1/e_2 < 1$: for $\delta \in (1/2, \delta_0)$ we have $K < K_0$, where $K_0 \equiv \delta_0/(2 - 3 \cdot \delta_0)$. The condition $K_0 \cdot e_1/e_2 < 1$ then is sufficient for $K \cdot e_1/e_2 < 1$. Using (8) we have

$$\begin{aligned} K_0 \cdot \frac{e_1}{e_2} &= \frac{\frac{2 \cdot e_2}{2 \cdot e_2 + \bar{e}}}{2 - \frac{6 \cdot e_2}{2 \cdot e_2 + \bar{e}}} \cdot \frac{e_1}{e_2} \\ &= \frac{e_2}{2 \cdot \bar{e} - e_2} \cdot \frac{e_1}{e_2} = 1. \end{aligned} \quad (26)$$

¹¹Intuitively, it is clear that the first constraint should be binding since the temptation to undercut is greater if $e = e_1$.

¹²Note that we can exclude $p_1 > p_M$ as a solution since otherwise the home firm will get the complete market.

Finally, eq. (22) gives $\lambda_1 = 1$. Inserting the solution of (24) into (25) gives $1 \leq K^2$, which implies that the nonbinding constraint holds due to the fact that K must exceed unity.

Full collusion with cost asymmetries

In the following I want to prove that the condition for full collusion for the home firm is the stronger, the greater the fluctuations of the exchange rate for a linear demand curve

$$D(p) = a - b \cdot p. \quad (27)$$

The condition for the foreign firm, however, is less restrictive for greater fluctuations of the exchange rate.

With linear demand, prices are given by

$$p_{Ms} = \frac{a + b \cdot c \cdot \min \{1, e_s/\bar{e}\}}{2 \cdot b} \quad (28)$$

$$p_{B1} = \min \left\{ c, \frac{a + b \cdot c \cdot (2 - e_2/\bar{e})}{2 \cdot b} \right\} \quad (29)$$

$$p_{B2} = \min \left\{ \frac{e_2}{\bar{e}} \cdot c, \frac{a + b \cdot c}{2 \cdot b} \right\}. \quad (30)$$

In order to ensure a positive supply in each state, a/b must be greater than c .¹³

The home firm's profits under Bertrand competition are equal to monopoly profits under full collusion if $p_{B2} = p_{M2}$, which follows if

$$e_2 \geq \hat{e}_2 \equiv \frac{a + b \cdot c}{2 \cdot b} \cdot \frac{\bar{e}}{c}. \quad (31)$$

The one-time gain from defection becomes nonpositive if $p_{M1} \leq c$, which follows if

$$e_2 \geq \bar{e}_2 \equiv \frac{a}{b} \cdot \frac{\bar{e}}{c}. \quad (32)$$

Since we assumed c to be less than a/b , \bar{e}_2 must exceed \hat{e}_2 , thus ensuring $\pi_D(\hat{e}_2) > 0$.

The proof of our assertion that $g(e_2) \in (2/3, 1]$ for $e_2 \in (\bar{e}, \hat{e}_2]$ proceeds in three steps.

¹³Note that otherwise there will be no supply in the case of a fixed exchange rate.

- (i) For e_2 approaching \bar{e} , the one-time gain π_D goes to π_M , and π_B goes to zero; hence

$$\lim_{e_2 \rightarrow \bar{e}} g(e_2) = 2/3. \quad (33)$$

- (ii) For $e_2 = \hat{e}_2$, the price set by the home firm under Bertrand competition equals p_{M2} ; hence

$$g(\hat{e}_2) = 1. \quad (34)$$

- (iii) $g'(e_2) > 0$ for all values of $e_2 \in (\bar{e}, \hat{e}_2]$. Differentiation of (18) gives

$$g'(e_2) = \frac{g(e_2)}{2 \cdot \pi_D(e_2)} \cdot [2 \cdot \pi'_D(e_2) \cdot (1 - g(e_2)) + g(e_2) \cdot \pi'_B(e_2)]. \quad (35)$$

Given that, $g'(e_2) \geq 0$ holds if

$$g(e_2) \geq \frac{2 \cdot \pi'_D(e_2)}{2 \cdot \pi'_D(e_2) - \pi'_B(e_2)}. \quad (36)$$

We proof (36) by contradiction. Assume $g'(e_2) < 0$ for some $e_2 \in (e'_2, e''_2)$. Since the maximal value of $g(e_2)$ cannot exceed unity, and $g(e_2)$ is a continuous function of e_2 , e'_2 and e''_2 must solve

$$g(e_2) = \frac{2 \cdot \pi'_D(e_2)}{2 \cdot \pi'_D(e_2) - \pi'_B(e_2)} \equiv h(e_2). \quad (37)$$

In the case of linear demand we have

$$\pi_D(e_2) = \frac{1}{4 \cdot b} \cdot \left(a - b \cdot c \cdot \frac{e_2}{\bar{e}} \right) \cdot \left[a - b \cdot c \cdot \left(2 - \frac{e_2}{\bar{e}} \right) \right]$$

$$\pi_B(e_2) = \left(a - b \cdot c \cdot \frac{e_2}{\bar{e}} \right) \cdot \left(\frac{e_2}{\bar{e}} - 1 \right) \cdot c.$$

Hence, $h(e_2)$ is an increasing function of e_2 with $h(e_2) \in (0, 1]$:

$$h'(e_2) = \frac{2 \cdot \pi''_D(e_2)}{2 \cdot \pi'_D(e_2) - \pi'_B(e_2)} - \frac{2 \cdot \pi'_D(e_2)}{(2 \cdot \pi'_D(e_2) - \pi'_B(e_2))^2} \cdot (2 \cdot \pi''_D(e_2) - \pi''_B(e_2)),$$

where

$$\begin{aligned} \pi''_D(e_2) &= -\frac{b \cdot c^2}{2 \cdot \bar{e}^2} < 0 \\ \pi''_B(e_2) &= -\frac{2 \cdot b \cdot c^2}{\bar{e}^2} < 0 \end{aligned}$$

ensures that $h'(e_2) > 0$. This guarantees that there exists exactly one solution to (37), namely $e_2 = \hat{e}_2$. The latter, however, contradicts our assumption that $g'(e_2) < 0$ is possible.

For the foreign firm we have the following results.

- (i) For e_2 approaching \bar{e} , the one-time gain $\hat{\pi}_D$ goes to $\hat{\pi}_M$, and $\hat{\pi}_B$ goes to zero; hence

$$\lim_{e_2 \rightarrow \bar{e}} \tilde{g}(e_2) = 2/3. \quad (38)$$

- (ii) For $e_2 = \hat{e}_2$, the price set by the home firm under collusion equals the foreign firm's marginal costs. Consequently, the one time gain by defection is zero, and it will be negative for $e_2 > \hat{e}_2$. Collusive behavior of the foreign firm is then ensured irrespective of the value of δ :

$$\tilde{g}(e_2) = 0 \quad \forall e_2 \in [\hat{e}_2, 2 \cdot \bar{e}). \quad (39)$$

- (iii) Since $\tilde{g}(e_2)$ is continuous, there must exist an \check{e}_2 such that $\tilde{g}(e_2) < 1/2$ for all $e_2 \in (\check{e}_2, \hat{e}_2)$. Thus, the condition for fully collusive behavior of the foreign firm becomes less strong than in the case of a fixed exchange rate provided exchange-rate fluctuations are sufficiently high.

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