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COORDINATION IN OLIGOPOLY

by

Johan Stennek

INSTITUTE FOR INTERNATIONAL ECONOMIC STUDIES
Stockholm University
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Coordination in Oligopoly

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Abstract
The private and social efficiency of two “behavioral” coordination mechanisms is examined in this paper. In Cournot oligopoly, firms prefer immediate coordination on the Nash equilibrium (interpreted as a preplay communication) over the best-reply dynamics (and fictitious play) which converge to the equilibrium, but with delay (interpreted as a decentralized learning process). In Bertrand oligopoly, firms prefer the learning process. These results indicate that firms have incentives to create institutions, such as trade associations or informal meetings, to facilitate coordination of production capacities, but not prices. Moreover, quantity agreements may even increase social welfare.

I. Introduction
According to European Union competition law, agreements between firms that restrict competition are illegal. The prime examples are price and quantity-fixing agreements. Not only written contracts, but also non-binding price recommendations by trade associations and so-called concerted practices may violate the law. In Hercules Chemicals v Commission (ECR, 1991), the Court of First Instance interprets this interdict to imply that “... each economic operator must determine independently the policy which he intends to adopt in the common market” (p. 1712). The Court remarked that this requirement “... does not deprive economic operators of the right to adapt themselves intelligently to the existing and anticipated conduct of their competitors ...” (p. 1713). However, the requirement does preclude “[p]articipation in meetings concerning the fixing of price and sales volume targets during which information is

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exchanged between the competitors about the prices they intend to charge—
since the participant undertakings cannot fail to take account of the
information thus disclosed in determining their conduct on the market" (p.
1713). Hence, the Court emphasized the information-sharing rather than
the commitment nature of agreements when they are non-binding. Never-
theless, price/quantity "agreements" are considered illegal *per se*. In
particular, the contents of the agreement (for example, the intended price
level) are irrelevant, since price/quantity agreements between competitors
are believed to have no other purpose than to raise the price level, without
having any beneficial effects.¹

The purpose of this paper is to investigate whether there are non-
collusive explanations for non-binding agreements between competitors.
By "non-collusive" I mean explanations that do not rely on increases in the
price level. In particular, can agreements reduce coordination problems
when firms play non-collusive equilibria? In this study, I focus on coordina-
tion problems in the form of prediction errors made by firms when they
take their decisions without prior communication. In reality, however,
coordination problems also take the form of delays in decision-making; see
Blinder (1994).

The model is built on three assumptions. First, it is assumed that when
a firm acts unilaterally, its prediction is based on what the firm can learn
from observing its competitors' actions in the past. However, when all firms
use adaptive learning, each firm frequently fails to predict its competitors
accurately. Consequently, the firms' prices and quantities are not optimally
adjusted to each other, and profits are reduced. Here, I restrict attention
to cases where the learning process converges to a unique Nash equilibrium
in the long run. However, every change in market conditions gives rise to
prediction errors in the short run. In particular, I consider the best-reply
dynamics and fictitious play.²

All firms in the market face the same problem of strategic uncertainty
and prediction errors. This indicates that firms may create joint institutions
to facilitate coordination. For example, firms may form a trade association
which can recommend the prices they should set. Alternatively, an agree-
ment may be reached at some informal meeting between the managers of

¹Information exchange (in forms other than p/q agreements) is treated in a more subtle way.
However, according to case law, such exchange is also believed to restrict competition, unless
the data are aggregated so that individual firms and products cannot be identified, and
concern historical conditions; Holmgren (1997).

²As discussed in a concluding section, the most crucial assumption in these learning mechan-
isms is that firms do not attempt to influence the learning of their competitors.

\[
\begin{align*}
&\frac{1}{T} \delta T \left[ \left( \frac{1 - \delta \gamma y}{1 - \gamma} \right) \left( \frac{1 - \delta \gamma}{1 - \gamma} \right) \left( \frac{1 - \delta \gamma}{1 - \gamma} \right) \frac{1}{91 - \delta \gamma} \right. \\
&\left. - \left( \frac{1 + \delta \gamma}{1 + \gamma} \right) \left( \frac{1 + \delta \gamma}{1 + \gamma} \right) \left( \frac{1 - \delta \gamma}{1 - \gamma} \right) \frac{1}{1 + \delta \gamma} \right] \geq 1 \\
\end{align*}
\]

which is negative since \((1 + \delta \gamma)^{-1} \leq (1 - \delta \gamma)^{-1}\) and \((-1 - (\delta \gamma)^2)(1 + \delta \gamma) \leq 1 \leq (1 - (\delta \gamma)^2)/(1 - \gamma)\), and \((1 - \delta \gamma)/(1 - \gamma) \geq 1 \geq (1 + \delta \gamma)/(1 + \gamma)\).

References


firms, or through successive advertisements in the press. It is assumed that when firms make an agreement, it must be self-enforcing, i.e., constitute a Nash equilibrium (in the stage game). The rationale for this assumption is that the firms cannot sign binding contracts on prices or quantities. Moreover, for the sake of argument, it is presumed that some factor, such as the discount factor, impedes collusion. Note also that I simply presume that if firms meet and talk before they choose their prices and quantities, they will end up with a common understanding about their subsequent behavior. Nothing is said about the details of the communication and bargaining process.

These two coordination mechanisms, learning and communication, are different in two important respects. First, agreement can only be accomplished if all firms actively seek it — they must all show up at the meetings. Hence, the firms can actually choose which of the two coordination mechanisms they want to use. Second, even if learning achieves coordination after some time, there is a phase of disequilibrium behavior. In contrast, communication achieves immediate coordination. Hence, profit streams differ between the two mechanisms. In particular, from the point of view of the single firm, coordination not only produces gains, there are also potential costs: the firm's own price and quantity decisions will be revealed to its competitors. It is not a priori obvious that a firm also wants to be predictable. My third assumption is: if all firms earn higher profits through agreements than by means of learning, then the industry will use agreements, otherwise it will use learning. The maximizing choice should not be thought of as a superability to make predictions at the stage of organizational choice, but rather as the outcome of some unmodelled learning process. Note also that I only consider the two "behavioral" coordination mechanisms mentioned above; both mechanisms have been effective in laboratory experiments (see below). In particular, I do not allow firms to coordinate their decisions simply by means of reasoning, for example along the lines of rationalizability, or preplay simulation of the learning phase.

In a linear Cournot duopoly firms prefer immediate coordination to the disequilibrium learning process. But, why is it costly to be out of equilibrium? The difference in profit is decomposed into three effects, using an (exact) Taylor expansion around the equilibrium. The first effect, called the prediction effect, measures the effect on profit when the competitor produces its equilibrium quantity while the firm itself is out of equilibrium. The prediction effect is negative: a firm wants to predict its competitor accurately. The second effect, called the predictability effect, measures the effect on profit when the firm produces its equilibrium quantity, but the competitor is out of equilibrium. As it turns out, a firm also wants to be predictable at its equilibrium quantity. The reason is that when a firm's
equilibrium quantity is high, then its competitor tends to underestimate it, inducing the competitor to deviate from its equilibrium quantity in an expansive way, and put downward pressure on prices. Note that this price reduction occurs when the first firm’s quantity is high, which means that a change in the price has a large impact on profit. As a mirror image, the competitor deviates in a contractive fashion when the effect on the first firm’s profit is small. In expectation, this generates a preference to be predictable. The final co-deviation effect has ambiguous sign, but is always dominated by the negative prediction effect. This result indicates that firms have incentives to create institutions, such as trade associations or informal meetings, to facilitate coordination of production capacities (quantities). It is also shown that such quantity agreements may be welfare increasing, and could be regarded as a socially efficient coordination mechanism, rather than as a way to reduce the competitiveness of the industry. However, this is at most an argument that the competition authorities should tolerate non-binding agreements. It is not an argument that courts should enforce such agreements. With outside enforcement, more anti-competitive agreements could be constructed. In Bertrand duopoly firms prefer the learning process. Hence, firms do not have incentives to facilitate coordination of prices. If this result is robust, then price-fixing cannot be explained as a non-collusive coordination mechanism. In my view, this would strengthen the court’s view that price-fixing should be illegal per se.

The information-sharing literature, surveyed and synthesized by Vives (1990) and Raith (1996), has shown that firms, in some cases, have incentives to share information about uncertain exogenous conditions, such as cost and demand conditions, even if they are not colluding. Moreover, information sharing may even increase social welfare. A critique of the information-sharing literature is that firms are thought of as playing Bayesian–Nash equilibria, which places high demands on the managers’ rationality. The present study may be re-interpreted as a variation of the information-sharing literature. The innovation in this context is that non-cooperating firms are thought of as following simple learning rules to adapt to changing unobservable external conditions. Moreover, according to the particular learning mechanisms considered here, a firm does not use information about its own cost to predict the competitor’s cost and hence quantity. Further, information sharing takes the form of communicating intended actions, rather than the background information itself. Such conduct is frequently observed in the economy; see, for example, Doyle and Snyder (1996). Within this information-sharing reinterpretation of my model, despite the substantial reduction in the presumed rationality of managers, I come to the same conclusions as Shapiro (1986): Cournot firms always have incentives to share information, and the exchange may

Proof of Proposition 1(c)

For the purpose of social welfare evaluations, it is convenient to express consumer utility as a function of the equilibrium quantities \( X_i \) and \( X_j \) and income \( m \). To do this compute

\[
\bar{U}(X, m) = U(X, m - p_1(X_1, X_2) \cdot X_1 - p_2(X_1, X_2) \cdot X_2)
\]

\[
= \frac{1}{2} (X_1 + \gamma X_2) X_1 + \frac{1}{2} (X_2 + \gamma X_1) X_2 + m.
\]

Define social welfare in subperiod \( t \) to be

\[
W_t = \Pi(X_{t1}, X_{t2}, c_1) + \Pi(X_{t1}, X_{t2}, c_2) + \frac{1}{T} \bar{U}(X_t, m).
\]

Since \( \bar{U} \) is linear in \( m \), this definition of social welfare in effect measures the change in social welfare consistent with the ex ante compensating variation and the compensation principle. Social welfare may be rewritten as \( W_t = W_{t1} + W_{t2} + m/T \), where \( W_{t1} = \Pi(X_{t1}, X_{t2}, c_2) + Z_0 \), and where \( Z_0 = (x - c_1)/2 - X_{t0} \). Summation over subperiods produces period variables \( W_t, W_{t1}, \) and \( Z_t \). Note that

\[
EW_{n} - EW_{t1} = (EW_{t1} - EW_{t}) + (EW_{t} - EW_{t1})
\]

and that

\[
EW_{t1} - EW_{t} = E \left( \frac{1}{T} \sum_{t=1}^{T} \delta_t \Pi(X_{t1}, X_{t2}, c_1) - \frac{1}{T} \sum_{t=1}^{T} \delta_t \Pi(X_{t1}, X_{t2}, c_1) \right)
\]

\[
= 2 + E(Z_t - Z_0).
\]

We already know that the difference in profit is negative. Note

\[
Z_1 - Z_0 = \frac{1}{2} (x - c_1)/T \sum_{t=1}^{T} \delta_t (X_{t1} - X_{t2})
\]

\[
= \frac{1}{2} [(x - \mu) - (c_1 - \mu)] [B S(\delta_t) + \mu S(-\delta_t)]
\]

Hence

\[
E(Z_1 - Z_0) = -\frac{1}{2} [S(\delta_t) E(c_1 - \mu) B_t + S(-\delta_t) E(c_1 - \mu) B_0].
\]

It is straightforward to show that \( E(c_1 - \mu) B_t = (1 - \gamma)^{-\frac{1}{2}}(1 - \rho)^{\sigma^2} \) and \( E(c_1 - \mu) B_0 = (1 + \gamma)^{-\frac{1}{2}}(1 + \rho)^{\sigma^2} \). Hence

\[
E(Z_1 - Z_0) = -\frac{1}{4} [S(\delta_t) (1 - \gamma)^{-\frac{1}{2}}(1 - \rho) + S(-\delta_t) (1 + \gamma)^{-\frac{1}{2}}(1 + \rho)]^{\sigma^2}
\]

If \( \rho = 0 \) then

\[
E(Z_1 - Z_0) = -\frac{1}{4} [S(\delta_t) (1 - \gamma)^{-\frac{1}{2}} + S(-\delta_t) (1 + \gamma)^{-\frac{1}{2}}]^{\sigma^2}
\]
spreading homogeneous equation is found by solving \( y^2 + \beta k^2 - 2 - \beta k = 0 \), that is, \( k = \pm y \). Hence, the general solution of the complete equation is \( x_t = x^*_t(c) + B_t(x) \hat{y} + \beta_k \). An initial condition is provided by the assumption of convergence in the unmodelled previous period, that is, \( x_0 = x^*_0(c') \). Moreover, \( x_n = x^*_t(c) + B_t + B_n \). Consequently

\[
\hat{B}_t + \hat{B}_n = x^*_t(c) - x^*_t(c').
\]  
(A1)

A second initial condition is \( x_1 = \frac{1}{T} (x - c) - \gamma x^*_t(c') \). Moreover, \( x_1 = x^*_t(c) + \gamma (\hat{B}_t - \hat{B}_n) \). Consequently,

\[
-\hat{B}_t + \hat{B}_n = x^*_t(c) - x^*_t(c').
\]  
(A2)

Combining (A1) and (A2) yields \( \hat{B}_t = [x^*_t(c) - x^*_t(c')] - [x^*_t(c) - x^*_t(c') + \hat{B}_n] \). The expression for the \( \hat{B}_t \)'s in the Lemma can be obtained by substituting the full expression for the equilibrium quantities. Production converges to equilibrium independently of the initial condition, i.e., the equilibrium is stable, if and only if \(-1 < \gamma < 1\), which is fulfilled by assumption.

Proof of Proposition 1(a)

First, sum subperiod effects to a period effect, for example \( pe(c, c') = \sum_{t=1}^T \hat{S}_{x_t} \delta^{t} pe_t(c', c') \). Then substitute the full expressions for \( x_t \) and \( x^*_t \) to get

\[
pe_t = -\frac{1}{2} [S(\delta y) \hat{b}_t + S(-\delta y) 2B_t + S(\delta y) B_n]
\]

\[
pbe_t = -\gamma [S(-\delta y) X_t + S(\delta y) X^*_t]
\]

\[
ce_t = -\gamma [B_t + B^*_n] S(\delta y)
\]  
(A3)

where the function \( S(\xi) = \sum_{t=1}^T \xi_t = \frac{1}{1-\xi} (1-\xi^T) \).

Moreover, \( B_t = TB_t \). Note that \( S(\xi) = \text{sign} (\xi) \). Using the expression for the \( \hat{B}_t \)'s in the Lemma, it is straightforward to show that \( EB^*_t = (1+\gamma)\frac{1}{2}(1+\rho) \sigma^2 \geq 0 \), \( E\hat{B}_t = 0 \), \( E\hat{B}^*_t = (1-\gamma)\frac{1}{2}(1-\rho) \sigma^2 \leq 0 \), \( E\hat{X}_t = (1+\gamma)\frac{1}{2}(1+\rho) \sigma^2 \leq 0 \), \( E\hat{X}^*_t = (1-\gamma)\frac{1}{2}(1-\rho) \sigma^2 \geq 0 \). The expected effects can then be written \( Epe_t = -[S(\delta y) \hat{b}_t + S(\delta y) \hat{B}_t] / 2 \), \( E\hat{b}_t = -\gamma [S(-\delta y) X_t + S(\delta y) X^*_t] \), \( E\hat{c}_t = -\gamma [B_t + B^*_n] S(\delta y) \). The expected prediction effect and the expected predictability effect are clearly negative. The expected co-deviation effect is ambiguous. However, the sum of \( Epe_t \) and \( E\hat{c}_t \) is negative.

Proof of Proposition 1(b)

Since costs are stationary, we have that \( E\hat{x}_t(c) = E\hat{x}_t(c') \) and hence that \( E\hat{B}_t(c, c') = E\hat{B}_t(c, c') = 0 \) for all \( i \), so that \( E\hat{x}_t(c, c') = E\hat{x}_t(c) \).

---

1 In general, the incentives to share information depend on many aspects of the situation. However, if firms receive perfect signals about their own cost and demand conditions, then information sharing is always an equilibrium. Bertrand oligopoly with cost uncertainty is an exception, however. In this case the incentives to share information depend on demand function parameters and the number of firms, and the information-sharing literature does not deliver any clear-cut rule; see Raith (1996).

2 Cost variability (but not uncertainty) is needed to explain why firms repeatedly find themselves outside of equilibrium. However, if the model is interpreted in terms of information sharing, then firm \( i \) should be thought of as only receiving information about \( c_i \).

does its shopping in each subperiod. Horizontal summation gives subperiod market demand \( x_t = (1/T)x_t \) and the inverse market demand per subperiod is given by \( p_t = \frac{1}{2T}x_{t-1} - \gamma x_t \).

Firm \( i \)'s profit in subperiod \( t \) is given by

\[
\Pi(x_t, c_t) = \left( x_t - \frac{1}{2}Tx_{t-1} - \gamma Tx_t - c_t \right)x_t.
\]

(1)

Firm \( i \)'s total profit during one period is \( \sum_{t=1}^{T} \Pi(x_t, c_t) \). The first-order conditions for expected profit maximization in the firm are given by

\[
x_t = \frac{1}{T} \left( x_{t-1} - \gamma x_t \right), \quad \forall i, j \text{ and } t,
\]

(2)

where \( x_t \) denotes firm \( i \)'s expectation about firm \( j \)'s quantity in subperiod \( t \).

Consider first the case of centralized coordination. Since the agreement must be a Nash equilibrium, it must solve the first-order condition and “coordinated beliefs”, that is

\[
x_t^* = x_{t-1} \quad \forall i, j \text{ and } t.
\]

(3)

Combining equations (2) and (3) and solving for quantities produces the equilibrium.

**Lemma 1.** There exists a unique Nash equilibrium, described by

\[
x_t^* = \left( \frac{1}{1 - \gamma} \right) \left( x_{t-1} - \gamma x_t \right),
\]

Also in the case of decentralized coordination, firms choose quantities according to first-order conditions (2). However, firms expect their competitors to choose the same quantity at date \( t \) as they did at date \( t - 1 \), that is

\[
x_t^* = x_{t-1} \quad \forall i, j \text{ and } t.
\]

(4)

Combining first-order conditions (2) and extrapolative beliefs according to (4) results in the simultaneous-move version of the “best-reply dynamics”, which converges to \( x^*(c) \), independent of initial conditions. Moreover, in the beginning of a period, firms produce quantities in accordance with the equilibrium that pertained in the previous period, denoted by \( x^*(c^*) \). This “initial condition” is justified by the fact that the learning process converges to the relevant equilibrium in every period.

**Lemma 2.** The best-reply dynamics are described by

\[
x_t(c, c^*) = \left( x_{t-1} - \gamma x_t \right) (1/T) = \left[ X_t^*(c) + B_t(c, c^*) \right] (1/T)
\]

where \( B_t(c, c^*) = \left( c_t - c_{t-1} \right) (1 + \gamma) \) and \( B_t(c, c^*) = \left( c_t - c_{t-1} \right) (1 - \gamma) \).

The linear-quadratic context, only the mean is of interest. Hence, firm \( i \)'s expectations can be described by

\[
x_t^* = \left( \frac{1}{1 - \gamma} \right) \left( x_{t-1} - \gamma x_t \right),
\]

(8)

Combining first-order conditions (2) and extrapolative beliefs according to (8) defines a stochastic version of fictitious play. As it turns out, the qualitative results are unchanged: (a) firms prefer centralized coordination to decentralized learning; (b) the choice of organization does not have any anti-competitive effect; (c) if shocks are idiosyncratic (\( \rho = 0 \)), then social welfare is higher if firms coordinate centrally, than if firms use decentralized learning.

The firms may be even more sophisticated, however. Rather than treating the environmental complexity as an “error term”, they may model the underlying complexity explicitly. In particular, firm \( i \) may view its competitor as a “supply function” \( x_t(c) \), and use historical production and cost data to estimate the relation. Now firms could potentially learn to predict their competitors perfectly in the long run. However, if there are any exogenous factors that vary over time, and if some of the changes occur with a low frequency, then the learning process may continue for a very long time.

An even more sophisticated strategy would be required if firms understand that their competitors are also adaptive learners. Now firm \( i \) must consider firm \( j \) as a function \( x_t(c; x_{t-1}, x_{t-2}, \ldots) \). With this model of its competitor, a new phenomenon arises: firm \( i \) will try to influence firm \( j \)'s learning. In a Cournot setting, firm \( i \) would have an incentive to expand production in subperiod \( t \) to increase \( x_{t+1} \), and hence induce firm \( j \) to reduce \( x_{t+1} \). Now, agreements between the firms would eliminate the incentive to influence each other's learning, and hence have an anti-competitive effect. As a consequence, there would exist a trade-off between the coordinating and collusive role of agreements. Including this phenomenon is a natural next step for future analysis.

**Appendix**

**Proof of Lemma 2**

The first-order conditions (2) and extrapolative beliefs according to (4) are given by

\[
x_t = \left( x_{t-1} - \gamma x_t \right) (1/T - \gamma x_{t-1}), \quad i = 1, 2.
\]

By substitution we get a second-order linear difference equation with constant coefficients and a constant term for each firm, \( x_t = (1 - \gamma)^2 x^*_t + \gamma x_{t-1} \). A particular solution of the complete equation is given by

\[
k = (1 - \gamma)^2 x^*_t + \gamma x_{t-1},
\]

that is, \( k = x^*_t \). The general solution of the corre-
IV. Modelling Coordination in Oligopoly

One of the prime decision-making problems in oligopoly markets is that the optimal price and quantity of one firm depends on the prices and quantities of other firms. To maximize subjective expected profit in the face of this "strategic uncertainty", a firm must predict the choice of all other firms. Applied economic analysis of oligopoly markets normally abstracts from this mutual prediction (or coordination) problem by using the concept of Nash equilibrium, which presumes that all firms make correct predictions. However, there is now a great deal of evidence from laboratory experiments that coordination failures do occur; cf. Cooper et al. (1994). That is, although subjects may act rationally given their beliefs, they fail to predict the behavior of their opponents. Moreover, Blinder (1994) interviewed 200 US firms, and found evidence that strategic uncertainty and fear of coordination failure is an important factor in explaining aspects of firm pricing behavior, in particular delays (or price stickiness).7

Here, I presume that in order for the firms to reach an equilibrium, they must use some coordination mechanisms — procedures through which possibly imperfect information about intents is transmitted between the firms. In particular, I study two "behavioral" mechanisms, communication and learning, both of which have been effective in laboratory experiments.8 Unfortunately, however, there are no established methods to model learning.

The best-reply dynamics are a natural point of reference, since they comprise the simplest possible learning scheme. Firm i's model of firm j is just the number $x_i$. Moreover, firm i only uses the most recent history to calibrate this model. However, even if firms start out thinking that their competitor's output is fixed, they should quickly learn that it is not. A minimalistic strategy for firm i to represent this underlying complexity is to consider $x_i$ as a stochastic variable. A reasonable estimate of the unknown distribution is to use the empirical frequency distribution of past play. In a

Proof: See Appendix.

It is assumed that the firms choose an organization before they know $x^*(c)$ and $x^*(c')$, and the exact adjustment that will be needed. Otherwise the firms' decision would depend on the direction (up- or downward) of the adjustment. In my view, this assumption is realistic since firms presumably decide whether or not to be members of a trade association less often than they adjust their prices and quantities. The firms consequently maximize expected profit.

Proposition 1(a). Consider a linear Cournot duopoly. Assume that the firms' learning is described by the best-reply dynamics. If firms cannot adjust quantities arbitrarily fast (T is finite), then firms prefer centralized coordination to decentralized learning.

Proof: See Appendix.

To simplify the comparison of the profit streams, the profit in the decentralized case can be decomposed into four terms by rewriting it as a second-order Taylor expansion around the equilibrium quantities. The sub-period profit of firm i is then

$$
\Pi(x_i, c_i) = \Pi(x^*, c^*) + \frac{1}{2} \Pi''(x^*, c^*)(x_i - x^*)^2 + \Pi'(x^*, c^*)(x_i - x^*) + \Pi(x^*, c^*)(x_i - x^*)^2
$$

The profit in equilibrium is the level of profit that the firm earns in every sub-period if coordination is immediate. The three remaining effects determine whether firms earn a higher or lower profit out of equilibrium.

The prediction effect, $p_{e}(c, c') = \frac{1}{2} (-T)(x^*_i - x^*)^2$, describes the effect on firm i's profit when firm i has not adjusted to equilibrium, given that firm j chooses its equilibrium quantity. This term is clearly negative, since it is always profitable to predict the competitors' choices accurately.

The predictability effect, $p_{e}(c, c') = [-\gamma T x^*_i](x^*_i - x^*)$, describes the effect on firm i's profit when the competitor has not adjusted to equilibrium, given that firm i is in equilibrium. The sign of the predictability effect is determined by whether the deviation $(x^*_i - x^*)$ is positive or nega-

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7 The firms were on average more worried about increasing their prices than cutting their prices, which may indicate an attempt to coordinate at a non-collusive equilibrium. In collusive equilibria, price cuts should be more risky, since they may trigger long price wars.

8 Results reported by Cooper et al. (1994) indicate that preplay communication, even if it cannot produce binding agreements, may help firms to focus on some equilibrium. In some experiments, communication reduced the disequilibrium outcomes from 59 to 4 percent of the trials. However, these results refer to experiments on the "battle of the sexes", where the existence of multiple equilibria makes coordination more difficult. Results reported by Van Huyck et al. (1990) and Crawford (1991) suggest that subjects may learn each other's behavior over time.

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tive: a positive (negative) deviation by firm $j$ is bad (good) for firm $i$'s profit. In general, deviations are positive in some periods and negative in others. As it turns out, however, the expected predictability effect is unambiguously negative, since when $x^*_i$ is high, then $x_i - x^*_i$ tends to be positive and vice versa. Intuitively, in those periods when the equilibrium quantity of firm $i$ is high, firm $j$ tends to underestimate it, inducing firm $j$ to produce a quantity that is higher than the equilibrium level (due to strategic substitutability). Hence, there is downward pressure on the price when $x^*_i$ is high, and the impact on $P$, is large. As a mirror image, firm $j$ deviates in a contractive way when the effect on $P_i$ is small. Hence, the expected impact of firm $j$ being out of equilibrium is negative.

The co-deviation effect, $ce_j(c, e^r) = \{-\gamma l\}(x_i - x^*_i)(x_j - x^*_j)$, describes the synergy resulting from both firms being out of equilibrium simultaneously. If costs are perfectly correlated between firms, that is $\rho = 1$, then the expected co-deviation effect is negative. On the other hand, if the correlation between firms' costs is weak, that is $\rho = 0$, then the expected co-deviation effect is positive. However, independent of the sign of the expected co-deviation effect, the expected prediction effect dominates the expected co-deviation effect.

Using the indirect utility function $V(p, m) = U(X(p, m), Y(p, m))$, consumer welfare is given by

$$V(p, m) = \Gamma^+(\alpha \beta)^2 \Gamma^{-}(p_i - \beta)(p_j - \beta) + m,$$

(6)

where $\Gamma^+ = (1/2 + \gamma)^{-1}$ and $\Gamma^- = (1/2 - \gamma)^{-1}$. Assume that $V$ satisfies the von Neumann–Morgenstern property, and compute the expected consumer welfare as

$$EV(p, m) = \Gamma^+(\alpha - E \beta)^2 + [\Gamma^+ + \Gamma^-] \cdot \mathbb{E} \{\beta\} - \Gamma^- \cdot \text{cov} \{p_i, p_j\} + m.$$

(7)

In effect this assumption means that the consumer is risk neutral towards fluctuations in income. One possible reason for the centralized organization to be preferred by firms is that it may raise expected average price $E \beta$ or, equivalently, contract expected average quantity $E \beta$, an anti-competitive effect. However,

**Proposition 1(b). The choice of organization does not have any anti-competitive effect.**

**Proof:** See Appendix.

Hence, organizational choice affects consumer welfare only through its impact on price variability. It is possible to show that consumers are better off in the decentralized mode than in the centralized mode, at least if cost shocks are common ($\rho = 1$). However, rather than discussing the details of consumer welfare, I turn directly to social welfare.

To assess the effect of centralized coordination on social welfare, consumer welfare is measured in monetary terms, with a willingness-to-pay interpretation, by the ex ante compensating variation, an extension of the ordinary compensating variation to the case of price variability; see Helms (1985). Moreover, I use the compensation principle, implying that the social value of one currency unit is independent of to whom it belongs.

**Proposition 1(c). If shocks are idiosyncratic ($\rho = 0$), then social welfare is higher if firms coordinate centrally than if firms use decentralized learning.**

**Proof:** See Appendix.

Even if it is also possible to find cases where society as a whole gains from using the disequilibrium process, the interesting aspect is that there exist cases where society as a whole gains if firms coordinate production decisions centrally.

III. Bertrand Competition

The model of price competition is identical to the model of quantity competition, apart from the fact that firms commit to prices rather than quantities.

**Proposition 2. Consider a linear Bertrand duopoly. Assume that the firms’ learning is described by the best-reply dynamics. If firms cannot adjust prices arbitrarily fast ($T$ is finite), then firms prefer decentralized learning to centralized coordination.**

The proof follows the same lines as in the Cournot case, and is therefore omitted. Why is it beneficial to be out of equilibrium? Although a firm wants to predict its competitors accurately, it does not want to be predictable by its competitors. To see this consider the following. When the equilibrium price of firm $i$ is high, then its price-to-cost margin $p^*_i - c$, tends to be high. In such cases the effect of firm $j$’s deviation has a large effect on firm $i$’s profit. Since $p^*_i$ is high, firm $j$ tends to underestimate it and sets the price lower than its equilibrium level. So, beneficial deviations in firm $j$ occur when deviations have a large effect on firm $i$’s profit. Further, the co-deviation effect is positive, and the positive predictability and co-deviation effects dominate the negative prediction effect.