Vertical Mergers, Foreclosure and Raising Rivals' Costs — Experimental Evidence

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August 2007

Abstract

The hypothesis that vertically integrated firms have an incentive to foreclose the input market because foreclosure raises its downstream rivals' costs is the subject of much controversy in the theoretical industrial organization literature. A powerful argument against this hypothesis is that such foreclosure cannot occur in Nash equilibrium. The laboratory data reported in this paper provide experimental evidence in favor of the hypothesis. Markets with a vertically integrated firm are significantly less competitive than those where firms are separated. While the results violate the standard equilibrium notion, they are consistent with the quantal-response generalization of Nash equilibrium.

JEL – classification numbers: C72, C90, D43

Keywords: Experimental economics, foreclosure, quantal response equilibrium, raising rival's costs, vertical integration.

1 Introduction

The theoretical industrial organization literature has suggested that "raising rival's costs" may be a profitable strategy in oligopoly. Raising-rival's-cost arguments are based on the simple fact that it is easier to compete against less efficient firms. If a firm's input costs are raised, it will reduce output and increase price, and the other firms in the market gain from this as they can increase their market shares and prices. It follows that firms may pursue strategies from which they do not gain directly (e.g. through production efficiencies) but benefit indirectly because a competitor's costs are negatively affected. Cost-raising strategies were first proposed by Salop and Scheffman (1983, 1987) and include boycott and other exclusionary behavior, advertising, R&D efforts, and lobbying for standards and regulation.

Ordover, Saloner and Salop's (1990), henceforth OSS (1990), raising-rival's-cost paper has received particular attention because it sets out to establish a connection between vertical integration and foreclosure.[1] Here, foreclosure means that a vertically integrated firm withdraws from the input-good market, that is, it stops supplying the input to nonintegrated downstream firms. OSS (1990) argue that firms have an incentive to vertically integrate and engage in such foreclosure because they gain from a raising-rival's-costs effect. The logic is that, when a vertically integrated firm forecloses, competition in the input-good market becomes weaker. The reduction of competition implies higher input cost for the nonintegrated downstream firms. Since the downstream unit of the integrated firm benefits when downstream rivals' costs are raised, the integrated firm is better off with the fore-

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[1]Salinger (1988), Hart and Tirole (1990) and OSS (1990) are the first generation of post-Chicago foreclosure theories. See Rey and Tirole (2005) or Riordan (2005) for recent surveys.

closure strategy than when it actively competes. In other words, it pays for the integrated firm to forgo business in the input-good market and instead to gain because the downstream rivals become less competitive. Only a vertically integrated firm can profitably pursue such a strategy. It would not make sense for nonintegrated upstream firms to foreclose (they would simply lose money) nor would this strategy be feasible for nonintegrated downstream firms.

To fix ideas, consider the setup of OSS (1990) as shown in Figure 1. There are two upstream firms and two downstream firms. In the panel A, neither firm is vertically integrated and both upstream firms compete for both downstream firms. Now suppose $U1$ and $D1$ merge as in panel B of Figure 1. Since $U1$ will supply $D1$ the input internally, $U2$ can no longer compete for $D1$. If $U1$-$D1$ stops delivering $D2$ (or alternatively if it charges a very high price for the input), $U2$ will increase its price compared to before the merger and—this is the raising-rival's-cost effect—$U1$-$D1$ benefits from this price increase because $D2$'s increased input costs ultimately improve $U1$-$D1$ profits.

Researchers soon noticed a major problem with this argument. Hart and Tirole (1990) and Reiffen (1992) pointed out that, even though foreclosure would be a profitable strategy for the integrated firm, it still has an incentive to compete in the input market. The outcome OSS (1990) derive is not a Nash equilibrium. To understand this argument, note that, given the integrated firm withdraws from the input-good market and $U2$ becomes a monopolist supplier of the input for $D2$, the integrated firm has an incentive to deviate. Rather than stay out of the input market, it will re-enter and compete in order to gain the business with $D2$. $U2$ will anticipate this and then the Nash equilibrium is the same with and without vertical integration. Hart and Tirole (1990) emphasize that foreclosure can only be supported in a

Nash equilibrium when the integrated firm can credibly commit not to deliver to the downstream rival ($D2$ in Figure 1), but "commitment is unlikely to be believable" (Hart and Tirole, 1990).

Even though apparently not theoretically robust, OSS' (1990) is a seminal paper in the theoretical Industrial Organization literature, featured in various textbooks. One line of research that builds on the paper has shown that the OSS (1990) result can be rigorously derived from game-theoretic models.[2] However, this is done at the cost of making more specific modeling assumptions and, in fact, often introducing some formal commitment mechanism. Another line of research simply assumes that a raising-rival's-cost effect of vertical integration exists, and uses this as a fruitful base for further theoretical analysis (Linnemer, 2003; Buehler and Schmutzler, 2005).

The continued interest suggests that there may be more to the OSS' (1990) hypothesis than would come from a model that is plainly wrong. OSS (1992) themselves make such a claim in their reply to Reiffen (1992), and, perhaps somewhat surprisingly for mainstream theorists at the time, they use a behavioral argument when defending their position:

> *"The notion that vertically integrated firms behave differently from nonintegrated ones in supplying inputs to downstream rivals would strike a business person, if not an economist, as common sense"* (OSS, 1992).

In other words, OSS (1992) suggest that their model may have predictive

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[2]OSS (1992) show that their results hold when upstream firms bid for a nonintegrated downstream firm in a descending price auction. Choi and Yi (2000) and Church and Gandal (2000) assume that upstream firms can commit to a technology which makes the input incompatible with the technology of nonintegrated downstream firms. In either case, an outcome similar to the one proposed by OSS (1990) results.

power even though their scenario cannot be supported in a Nash equilibrium.

The quote from OSS (1992) suggests that there are actually two interpretations of the foreclosure notion. Foreclosure in a narrow sense can be said to occur when integrated firms refrain completely from supplying the input market. In OSS (1990), the integrated firms charge a price above the monopoly price $U2$ would choose—a strategy which is equivalent to the exit of the integrated firm from the input-good market. A broader interpretation of the term would be that integrated firms "behave differently" from nonintegrated firms, presumably charge higher prices, but they need not completely foreclose the input market. As a result, vertical integration has an anticompetitive effect. Broadly speaking, as long as vertical integration causes prices higher than those in markets where firms are separated, foreclosure occurs (Rey and Tirole, 2005, define foreclosure in the same broad sense).

This paper reports on an experimental analysis of the OSS (1990) argument. The experiments were designed to investigate whether vertical integration *per se* affects the behavior of integrated firms in the original OSS (1990) setup and without requiring any formal commitment. The experimental design allows us to study the effects (in otherwise identical markets) of vertical integration compared to non-integration.[3] Even if the static Nash

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[3]The effect of vertical integration has been analyzed in experiments before. Mason and Phillips (2000) study a bilateral Cournot duopoly when there is a (large) competitive market that also demands the input from the upstream firms. Durham (2000) and Badasyan et al. (2005) compare integrated and nonintegrated monopolies and investigate whether vertical integration mitigates the double marginalization problem. Martin, Normann and Snyder (2001) analyze whether an upstream monopoly loses its monopoly power when selling a good to multiple retailers using two-part tariffs. None of these experiments has investigated the OSS (1990) hypothesis and the design of the experiments would not be

equilibrium does not predict an effect of vertical integration, experimental data may reveal whether vertical integration results foreclosure in the broad sense or the narrow sense.

Another contribution the paper makes relates to repeated interaction. The arguments in OSS (1990, 1992), and in much of the theoretical literature, are based on the one-shot game. However, interaction in the field is often repeated. Studying a repeated setting seems particularly relevant here, since the commitment problem of the integrated firm (as highlighted in Hart and Tirole, 1990) may be resolved with repeated interaction. After all, repeated interaction (Macauley, 1963) can serve as an informal commitment device. Here, it may help the integrated firm to establish a reputation for staying out of the input market. Experiments with repeated firm interaction investigate this hypothesis. They are related to the recent theoretical literature that argues that vertical integration facilitates collusion (Nocke and White, 2006; Normann, 2005; Riordan and Salop, 1995).[4]

The design of the experiments in this paper follows the distinctions between vertical integration and separation and between the static and the repeated game. The first two treatments allow to compare markets where both firms are vertically separated to markets where one firm is vertically integrated under a random-matching scheme, such that incentives are as in a one-shot game. Treatments three and four make the same comparison with a fixed-matching scheme in order to allow for repeated-game effects. This yields a two-by-two treatment design with vertical integration and the

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suitable for doing so.

[4]It should be added that the experiments do not provide a formal test of these papers as the experimental design differs in various dimensions from the frameworks of the formal models.

matching scheme as treatment variables.

There are three main experimental results. Firstly, prices are significantly higher in markets with vertical integration compared to those in markets where the two firms are separated. Second, if there is integration, integrated firms' pricing behavior is less competitive than that of nonintegrated firms. Third, integrated firms nevertheless only rarely refrain from competing in the input market. In other words, on the one hand, there is foreclosure in the broad sense, but, on the other hand, there is almost no evidence of foreclosure in the narrow sense. All three results hold with both random and fixed matching.

As these results violate the Nash equilibrium prediction, the paper continues to by proposing an explanation for the findings. More specifically, it argues that the results are consistent with a quantal response equilibrium analysis of the game (McKelvey and Palfrey, 1995). What is going on is that vertical integration affects the magnitude of profits, even though it does not change best responses and the static Nash equilibrium. Goeree and Holt (2001) have shown for several games that changes in the payoff structure that do not affect the Nash prediction can nevertheless have drastic effects on the results in experiments.[5] More closely related to this paper, Capra et al. (2002) analyze experiments with price-setting duopolies in which the unique Nash equilibrium is the Bertrand outcome. Competition, however, is not perfect, in that the market share of the high-price firm is larger than

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[5]Goeree and Holt (2001) analyze ten simple one-shot games where the experimental data support the Nash equilibrium (the "treasure" treatments). For all ten games, they find an "intuitive contradiction" which results from a change in the payoff structure that leaves the Nash prediction unchanged but drastically alters the experimental results.

zero.[6]

The experimental results show that price levels are positively correlated with the market share of the high-price firm—a violation of the Nash prediction. The results in Capra et al. (2002), and in most of Goeree and Holt's (2001) examples, are well explained by quantal response equilibrium. For the setting of this paper, quantal response equilibrium implies that integrated firms indeed price less competitively than nonintegrated ones. Integrated firms still compete in the input market (that is, there is no foreclosure in the narrow sense), but the broad implication of the OSS model—that integration raises the price of the input—is consistent with the quantal response equilibrium generalization of Nash equilibrium.

2 Experimental Design

The experiments were designed to capture the crucial features of the OSS (1990) model but still to be as simple as possible. In all experiments, two subjects representing the two upstream firms have to make one single choice in every period, they simultaneously set a price. Basis for their decision making is the profit table reproduced in Table 1. The table is derived from a parametrized model (see Appendix A) and based on equilibrium behavior of downstream firms and final-good consumers (who were not represented by participants in the experiments). The table is fully consistent with the

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[6]Morgan, Orzen and Sefton (2006) also ran experiments with imperfect Bertrand competition. In their model, a firm not charging the lowest price still sells a positive amount due to brand-loyal consumers. Morgan, Orzen and Sefton (2006) analyze how the comparative statics predictions for changes in the degree of consumer loyalty are borne out in the data.

analysis in OSS (1990) who indeed use the same parametrized model for some
of their analysis.

Price	1	2	3	4	5	6	7	8	9
Bertrand profit (all firms)	39	54	69	81	90	99	90	72	51
Additional profit (integrated firms only)	66	74	84	96	105	132	159	180	198

Table 1: The Payoff table

There are treatments with and without vertical integration. In all treat-
ments, the set of prices subjects can choose from are the integers from one
to nine. The "Bertrand profit" row of the table is provided in all treatments
whereas the "additional profit" row is given only in the treatments with
vertical integration. In the instructions of the experiments, neutral labels
were used instead of the terms "Bertrand" and "integrated firm" (see the
instructions in Appendix B).

In the baseline treatments without vertical integration, participants play
a normal Bertrand duopoly experiment (e.g. Dufwenberg and Gneezy, 1999).
The firm who charges the lowest price will gain the profit in the according
"Bertrand profit" cell and, in the case of a tie, both firms get half the profit in
the second row. In the instructions, this was illustrated with two examples,
one of which read "If you charge a price of 7 and the other firm charges a
price of 4, you will get zero and the other firm gets 81 pence".

In the treatments with vertical integration, the two participants play
the same Bertrand game[7] but the twist is that one subject (representing the

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[7]One general implication of vertical integration is that the downstream affiliate of the
integrated firm does not buy the input from the market any more but instead obtains

integrated firm) now makes an extra profit. This is the profit the downstream affiliate of the integrated firm earns, represented in Table 1 as the "additional profit". This additional profit depends on the lower of the two prices the players charge. The instructions make it clear that "it is the lowest of the two prices that determines the ["additional"] profit, no matter whether firm 1 [the integrated firm] or firm 2 (or both) charged the lowest price". One of two illustrating examples in the instructions reads: "If firm 1 charges a price of 7 and firm 2 charges a price of 4, firm 1 only gets 96 pence" additional profit. Consistent with the theory of OSS (1990), the higher this lower of the two prices, the more "additional profit" the integrated firm earns. This is the raising rival's cost effect.

The profit table captures the central issue which is at the heart of the OSS (1990, 1992) papers and the debate around them. Ideally, the integrated firm would want to commit to a price of 7 or higher because the nonintegrated firm would then best respond by setting the monopoly price of 6. In that case, profits would be 132 for the integrated firm and 99 for the nonintegrated firm. However, this foreclosure strategy is not feasible without commitment as the integrated firm can obtain $90 + 105 > 132$ by deviating to a price of 5. Thus, absent commitment, vertical integration may not make any difference at all (Hart and Tirole, 1990, and Reiffen, 1992). While taking the aspects of the theoretical debate into account, the experiments are nevertheless rather simple. For example, subjects do not need to be informed about the vertical relations or other details of the market in the instructions.

it internally, at marginal cost. This implies that the input market has a bigger volume with vertical separation and thus the "Bertrand profits" in Table 2 should also be bigger without integration. However, as the experimental design needs to avoid possible wealth effects, the "Bertrand profits" are kept equal across treatments (see also Appendix A).

The experimental markets were designed such that firms still make a positive profit when they both charge 1 (the Nash equilibrium price, derived below). The reason is that subjects might be biased against an action with zero profit (Dufwenberg et al., 2007). Consistent with the underlying theoretical model, the "additional profit" is larger than the one in the "Bertrand" row. This means that the integrated firm makes a larger profit than the nonintegrated firm even if it does not get any profit in the Bertrand game.

The two treatment variables are the vertical structure and the matching scheme. The treatments with and without vertical integration are labeled *INTEG_* and *SEPAR_*, respectively. Treatments where participants were randomly rematched in every period have the label *_RAND,* and treatments where subjects repeatedly interacted in pairs of two (fixed matching) are labeled *_FIX.* All treatments lasted for 15 periods and subjects knew this from the instructions. Table 2 summarizes the 2x2 treatment design.

| | | matching | |
		random	fixed
	separation	*SEPAR_RAND*	*SEPAR_FIX*
vertical			
	integration	*INTEG_RAND*	*INTEG_FIX*

Table 2: The treatments

The subgame perfect Nash equilibrium prediction is the same for all treatments but it seems worthwhile to go through the four variants in detail separately.

- In *SEPAR_RAND,* both firms charge the lowest price of 1 in equilibrium (this is the standard Bertrand-Nash equilibrium). Equilibria where firms charge a higher price do not exist because firms have a

strict incentive to undercut at any price larger than 1. Both firms earn $39/2 = 19.5$ in equilibrium.

- Then take *INTEG_RAND.* As mentioned, the integrated firm would want to commit to a price larger than 6 but this is not a Nash equilibrium. As emphasized by Hart and Tirole (1990) and Reiffen (1992), in the unique Nash equilibrium has both firms choosing 1 also with vertical integration. In the equilibrium of this treatment, the nonintegrated firm earns 19.5 and the integrated firm earns $19.5 + 66 = 85.5$.

- In *SEPAR_FIX* there is repeated interaction and it is well known that some collusion may occur. If so, the price of 6 may would maximize joint profits. In any event, the subgame perfect Nash equilibrium is for both firms to charge the price 1 just as in the *RAND* treatments, as follows from backward induction in the finitely repeated game.

- In *INTEG_FIX,* firms may collude by charging the same price. In that case, any price between 6 and 9 is Pareto efficient (from the firms' point of view). Vertical integration may also allow for another form of collusion where firms charge different prices and collude by coordinating on foreclosure (in the narrow sense). The integrated firms could set a price larger than 6 and the nonintegrated firm could set a price of, e.g., 6. However, neither way of colluding is a subgame perfect Nash equilibrium, as follows from backward induction, and both firms choosing 1 is the subgame perfect Nash prediction once again.[8]

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[8]One could, of course, solve for the minimum discount factor required for collusion *as if* the game were infinitely repeated. Assuming simple Nash triggers, the minimum discount factor would be 0.62 in *SEPAR_FIX* (assuming a collusive price of 6), 0.59 in *INTEG_FIX* (assuming the integrated firm charges a price larger than 6 and the nonintegrated firm

3 Procedures

All treatments were run in sessions with 10 participants. Five participants acted as "firm 1" (the integrated firm in *INTEG* treatments) and the other five participants acted as "firm 2". These roles were fixed for the entire course of the experiment. In the *SEPAR* treatments, firms are symmetric but the "firm 1"–"firm 2" labels were nevertheless given in order to keep matching scheme and instructions comparable.

Ten sessions were conducted, four sessions each for treatments *SEPAR_-RAND* and *INTEG_RAND* and one session each for treatments *SEPAR_FIX* and *INTEG_FIX*. Having more sessions with random matching is motivated by the possibility of group effects within sessions under random matching.

Experiments were computerized (the programming was done in *z-Tree*, developed by Fischbacher, 2007) and were conducted at Royal Holloway College, University of London, in fall 2004 and spring 2005. In total, 100 subjects participated. Subjects were mainly undergraduate students and a large proportion of them were from faculties other than economics or business studies. The payoffs in Table 2 denote cash payments British pence. Subjects' average monetary earnings were £12.50, including a flat payment of £5.

4 Results

Table 3 and Figures 2 and 3 summarize the results. The averages in Table 3 and most formal tests are based on data from periods 6 to 15. All results reported hold qualitatively also if the analysis is based on all periods or on

charges 6), and 0.79 in *INTEG_FIX* (assuming both firms charge a price of 6).

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periods 11 to 15. The non-parametric tests use four entirely independent observations for the *RAND* treatments and five independent observations for the *FIX* treatments.

		vertical structure		
		SEPAR	*INTEG*	
matching	*RAND*	1.81 (0.43)	2.83 (0.77)	$p = 0.021$
	FIX	2.67 (1.15)	4.40 (1.02)	$p = 0.014$
		$p = 0.115$	$p = 0.033$	

Table 3: Average prices (based on session and group averages, standard deviation in parenthesis) and (one-sided) p-values of Mann-Whitney U tests for differences in means

Prices in *SEPAR_RAND* are lower than those in *INTEG_RAND*. The top panel of Figure 2 confirms this for the average prices in *SEPAR_RAND* and *INTEG_RAND* across the 15 periods and Table 3 shows that prices are about 36% higher with vertical integration. The significance of this result follows from a Mann-Whitney U test ($p = 0.021$, see also Table 3).

The top panel of Figure 3 indicates that there are some differences between the prices of integrated and nonintegrated firms in *INTEG_RAND*. Averaging across periods 6 to 15, integrated firms' prices are about 8% higher with random matching. These differences are significant (one-sided matched-pairs Wilcoxon, $p = 0.034$) although quantitatively perhaps not particularly big.

Essentially the same results also hold in the *FIX* treatments. Comparing *SEPAR_FIX* and *INTEG_FIX*, Figure 2 and Table 3 indicate differences due to integration which are quantitatively bigger than with random matching.

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The relative increase is roughly the same, however, as prices are about 39% higher with integration in *FIX*. These differences are significant ($p = 0.014$). As with random matching, integrated firms in *INTEG_FIX* charge 8% higher prices than nonintegrated firms (significant according to a matched-pairs Wilcoxon, $p = 0.039$).[9]

Result 1: There is evidence of foreclosure broadly defined. Markets with a vertically integrated firm have significantly higher prices than markets where the two firms are separated. In markets with integration, the vertically integrated firms charge significantly higher prices than the nonintegrated firms.

How about foreclosure in the narrow sense then? Strong evidence in favor of that would be if the integrated firms charged a price higher than 6 as it would imply a complete withdrawal from the input market.

It is already clear from Figures 2 and 3 and the averages in Table 3 that there is only little evidence of such behavior, and a concrete search for these foreclosure outcomes confirms that they are rare. In *INTEG_RAND*, only one of 20 subjects representing an integrated firm charged prices which deviated from the general pattern visible in Figure 2. This subject charged prices of 7 and 8 from period 2 to 13 and clearly did not compete in the "Bertrand" market except for the last two periods. This can be interpreted as foreclosure behavior, narrowly defined. In total, however, only 29 of 300 observations

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[9]Both Figure 2 and Figure 3 seems to indicate a negative time trend in the data. In *INTEG_FIX,* however, prices are stable except for an end-game effect in the last three periods. Moreover, in both *INTEG_RAND* and *INTEG_FIX,* the integrated firms raise their prices again in the last period. Hence, there is no indication that an experiment with a longer time horizon would reduce the price differences between either *INTEG* and *SEPAR* treatments or integrated and nonintegrated firms in *INTEG*.

(data from all periods) include prices of 7 or higher, and 12 of these cases are accounted for by the subject just mentioned. For comparison, nonintegrated firms in *INTEG_RAND* charged a price of 7 or higher in 4 (of 300) cases, and in *SEPAR_RAND* there were 11 (of 600) such observations. Hence, whereas these shares are somewhat lower than those of the integrated firms in *INTEG_RAND,* too few observations in *INTEG_RAND* are consistent with (narrow) foreclosure to suggest it is important in the data.

In treatment *INTEG_FIX*, integrated firms charged prices of 7 or higher in 5 of 75 cases. Compared to this, nonintegrated firms did so in 2 of 75 cases, and in *SEPAR_FIX* there are 5 (of 150) such cases (data from all periods). Hence, *INTEG_FIX* contains not more evidence of foreclosure in the narrow sense than in *INTEG_RAND*.

A look at the five individual duopoly pairs in *INTEG_FIX* yields further insights. Duopoly #1 had both firms charging a collusive price of 6 in all periods except for the first two and the last three. Duopoly #2 priced competitively in the first and last third of the experiment and only in two outcomes in the middle of the experiment did the integrated firm charge high prices. Duopoly #3 colluded non-systematically. Sometimes, there was symmetric collusion, sometimes there were apparently competitive outcomes with either firm being the low-price firm. In duopoly #4, the integrated firm never charged a price lower than the rival, possibly suggesting a foreclosure strategy—but then, why did this firm not go all the way and set a price above 6? Finally, duopoly #5 started competitively and then colluded symmetrically at a price of 6. To summarize, there is not more evidence of foreclosure with fixed matching either. If firms collude successfully at all, they both tend to choose a price of 6 rather than have the integrated firm foreclosing the input market.

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Low price firm	Treatment	
	INTEG_RAND	*INTEG_FIX*
integrated	32%	22%
nonintegrated	39%	40%
ties	29%	38%
# observations	200	50

Table 4: Number of observations when the integrated firm or the nonintegrated firm charged the lowest price, and number of ties.

Even if integrated firms do not charge prices higher than 6, it could still be that they do not compete and that they only rarely charge a lower price than nonintegrated firms as a result. Table 4 shows data on which type of firm turned out to be the low-price firm in the *INTEG* treatments (in periods 6–15). The table also lists the number of ties. Integrated firms charge the lowest price less frequently than nonintegrated firms both in *INTEG_RAND* and *INTEG_FIX*. These differences are significant according to binomial tests in *INTEG_RAND* ($p = 0.069$, one sided) and *INTEG_FIX* ($p = 0.037$, one sided) but, while consistent with Result 1, they are quantitatively too minor to support the narrow foreclosure hypothesis.

Result 2: There is little evidence of foreclosure narrowly defined. Even though integrated firms are the low-price firm significantly less often, they still compete actively in the input-good market.

5   Quantal Response Equilibrium Analysis

The results suggest that vertical integration has an impact. We saw that integrated firms charge significantly higher prices. This effect was sufficient to render less competitive the markets where vertical integration is present.

While this confirms the OSS (1990) hypothesis in a broad sense, the lack of evidence for foreclosure rejects the narrow OSS prediction. How can one account for these results?

In this section, it will be argued that the above findings are consistent with the quantal-response equilibrium analysis (McKelvey and Palfrey, 1995) of the game. QRE is a generalization of Nash equilibrium that takes decision errors into account. Players do not always choose the best response with probability one but they do choose better choices more frequently. Because of this, changes in the payoff structure that do not affect the standard Nash prediction can still have an impact on the QRE outcome(s). In the model of this paper, vertical integration (compared to nonintegration) has exactly this impact. Therefore, QRE is a good candidate for explaining the results.

Consider the logit equilibrium variant of QRE. Firm i, $i = 1, 2$, believes that the other firm will choose price p_k, $k \in \{1, 2, ..., 9\}$, with probability ρ_i^k. Accordingly, firm i's expected profit from choosing price j is

$$\Pi_i^j = \sum_{k=1}^{9} \rho_i^k \pi_i(p_j, p_k), \;\; j = 1, ..., 9.$$

where $\pi_i(p_j, p_k)$ are the profits as in the Bertrand game of Table 1 (note that profit functions are not symmetric in the *INTEG* treatments). As mentioned, firms choose better choices more frequently. In particular, choice probabilities, σ_i^j, are specified to be ratios of exponential functions

$$\sigma_i^j = \frac{e^{\lambda \Pi_i^j}}{\sum_{k=1}^{9} e^{\lambda \Pi_i^k}}, \;\; j = 1, ..., 9.$$

λ is the error parameter. If $\lambda = 0$, behavior is completely noisy and all prices are equally likely regardless of their expected profit. As $\lambda \to \infty$, firms choose the best response with probability one. In the logit equilibrium, beliefs and choice probabilities have to be correct, that is, $\rho_1^j = \sigma_2^j$ and $\rho_2^j = \sigma_1^j$, $j = 1, ..., 9$.

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It is difficult to solve explicitly for the logit equilibrium here, in particular, in the asymmetric setup with vertical integration. Therefore, the *Gambit* computer software (McKelvey et al., 2005) is used. *Gambit* finds a unique equilibrium (given λ), illustrated in Figure 4. It shows the relative frequency of the price of 1 in QRE conditional on the error parameter λ. The impact of λ is intuitive. If $\lambda = 0$, the price of 1 (like any other price) is chosen with probability 1/9 and, as $\lambda \to \infty$, it is chosen with probability one, as in the standard Nash equilibrium. Vertical integration does not have any impact when $\lambda = 0$ and $\lambda \to \infty$. For any $\lambda \in (0, \infty)$, however, vertical integration implies (among other things) that the frequency of the price 1 is lower than in markets with separation. The figure also shows that the integrated firms in *INTEG* set the price of 1 less often than nonintegrated firms.

The last point can be generalized. It turns out that, regardless of the realization of λ, the distribution of the prices of the nonintegrated firm first-order stochastically dominates that of integrated firms in the *INTEG* setup. This supports the claim that integrated firms are less competitive than their nonintegrated counterparts. However, it does not generally follow that prices will be lower in *SEPAR* compared to *INTEG* (in the sense of first-order stochastic dominance).

To summarize up to this point, whereas neither the static Nash equilibrium nor the foreclosure outcome organize the data in the *RANDOM* treatments well, QRE does. The qualitative predictions of QRE are confirmed. In particular, the QRE analysis is consistent with the finding that, although integrated firms charge somewhat higher prices, they do not completely refrain from competing in the input market. The intuition is that an integrated firm still has an incentive to compete (which confirms Hart and Tirole, 1990, and Reiffen, 1992) but that this incentive is weaker than for a nonintegrated firm (which confirms OSS' broad foreclosure interpretation). An integrated

firm simply loses less profit when the rival undercuts its price. QRE captures this, in that integrated firms charge prices larger than one are played with higher probability, rendering the *INTEG* treatments less competitive.

The next step would be to estimate λ. Using data from *INTEG_RAND* and *SEPAR_RAND* and periods 6-15, and taking differences between currencies into account, Maximum Likelihood estimates of the error term yield $\lambda = 0.134$ with a standard error of 0.006. Capra et al. (2002) find $\lambda = 0.15$ in a duopoly experiment with imperfect Bertrand competition. Anderson, Goeree and Holt (2002) suggest that $\lambda = 0.125$ is consistent with the Bertrand oligopoly data in Dufwenberg and Gneezy (1999). The value found for the present data set is of a similar magnitude.

The estimate can be used to quantify the expected differences between treatments. For $\lambda = 0.134$, the expected average price under separation is 2.13, and it is 2.89 and 2.23 in *INTEG_RAND* for the integrated and nonintegrated firm, respectively. Actually averages are 1.81 in *SEPAR_RAND,* and 2.96 and 2.71 for the integrated and nonintegrated firm in *INTEG_RAND.* The expected lowest price (that is the expected minimum of the two prices) is 1.30 in treatment *SEPAR_RAND* and 1.57 in *INTEG_RAND.* The actual average is 1.30 in *SEPAR_RAND* and 2.17 in *INTEG_RAND.* Further, the expected frequency of the lowest price is 50.3% in *SEPAR_RAND* and we observe 55%. In *INTEG_RAND,* the expected and observed frequencies are 43.0% and 23.2%, respectively, for the nonintegrated firms, and 34.4% and 20.0%, respectively, for the integrated firms. Whereas the broad magnitude of expected values corresponds to the actual values, it appears that the QRE prediction (given $\lambda = 0.134$) somewhat overestimates the differences between integrated and nonintegrated firms and underestimates the differences between the treatments' averages.

The result that *INTEG_FIX* has higher average prices than *SEPAR_FIX*

is not well captured by standard game theory either. On the one hand, the unique subgame perfect Nash equilibrium of the finitely repeated game predicts a price of 1, which we do not observe. On the other hand, arguments based on the infinitely repeated game, if anything, suggest that the likelihood of collusion would be either roughly the same, or even lower in *INTEG_FIX* (see footnote 6) and this, too, is not the case. Quantal response equilibrium arguments generally have less bite in repeated-game settings because there is less uncertainty about the action of the other player. However, even in duopolies with stable collusion, an element of uncertainty always remains when subjects make their choices (even if stable collusion occurs, it is only observed ex post). Moreover, as mentioned, some duopoly pairs behaved competitively in the treatments with fixed matching. Therefore, quantal response equilibrium may have predictive power as with random matching, and this could explain why prices are significantly higher in *INTEG_FIX*.

6   Conclusion

This paper contributes to the literature on vertical integration and raising rivals' cost with the use of a laboratory experiment. The experiments were designed to analyze the raising-rivals'-costs argument of Ordover, Saloner and Salop (1990). In simple duopoly treatments (with random and fixed matching), the data show how the presence of an integrated firm affects market outcomes.

The experimental results support the hypothesis of Ordover, Saloner and Salop (1990) in that overall competition is reduced when one firm vertically integrates and, in markets where an integrated firm is present, it charges significantly higher prices compared to nonintegrated firms. On the other hand,

there is very little evidence of foreclosure in the sense that virtually no integrated firm completely refrains from competing in the input market. Whereas these results are inconsistent with the standard notion of Nash equilibrium, these results are consistent with the quantal response equilibrium (McKelvey and Palfrey, 1995) generalization of Nash equilibrium. The results are also consistent with Ordover, Saloner and Salop's (1992) broad notion of foreclosure which says that vertical integration generally causes an anticompetitive effect even if no refusal to supply the input market is observed.

The lack of evidence for foreclosure (narrowly defined) suggests that the commitment problem of the integrated firm pointed out by Hart and Tirole (1990) and Reiffen (1992) is significant. In experiments, participants do generally not manage to resolve commitment problems by mere intentions. This has been found in Huck and Müller (2000), Reynolds (2000), Cason and Sharma (2001) and Martin, Normann and Snyder (2001).[10] In these experiments, subjects failed to achieve desirable outcomes when there was no formal commitment mechanism, and the same appears to be going in this study.

Further investigating the commitment issue also seems promising for future research. For example, will firms commit if they are given the opportunity to do so? Likewise, will firms learn to commit if they are forced to do so over a transitory period?

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[10]Huck and Müller's (2000) experiments show that a Stackelberg leader has serious difficulties exploiting the first-mover advantage when second movers obtain a noisy signal of its action. Reynolds (2000) and Cason and Sharma (2001) show that monopolies producing durable goods often fail to achieve full monopoly profits. Similarly, in the experiments of Martin, Normann and Snyder (2001), a firm loses its monopoly power when selling its product through multiple retailers.

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Appendix A: The model

This appendix presents the model underlying the payoff table of the experiment. The model has two upstream firms ($U1$ and $U2$) which are Bertrand competitors and two downstream firms ($D1$ and $D2$) which transform the input into differentiated final goods.

We begin at the downstream level. Downstream firm Di's demand is

$$q_i(p_i, p_j) = a - bp_i + dp_j; \ i, j = 1, 2; \ i \neq j, \tag{1}$$

where p_i and p_j are the prices the downstream firms i and j set ($i, j = 1, 2$; $i \neq j$). Suppose downstream firm i purchases the input good at a linear price of c_i per unit. As the D firms incur no other costs, they operate at constant marginal costs of c_1 and c_2, respectively. Thus, at the downstream level, this is a standard Bertrand duopoly model with product differentiation and asymmetric cost. It is straightforward to solve for downstream Nash equilibrium prices

$$p_i^* = \frac{(2b + d)a + 2b^2 c_i + bd c_j}{4b^2 - d^2}, \tag{2}$$

outputs

$$q_i^* = b \frac{(2b + d)a - (2b^2 - d^2)c_i + bd c_j}{4b^2 - d^2}, \tag{3}$$

and profits $\pi_{Di}^* = (q_i^*)^2/b$.

Upstream firms have constant marginal cost which are assumed to be zero for simplicity. The upstream firms compete for each of the two downstream markets in a Bertrand fashion. Specifically, upstream firm k sets two prices, c_1^{Uk} and c_2^{Uk}, for downstream firms 1 and 2, respectively. The Bertrand logic implies that the downstream firm i buys from the upstream firm with the lowest price, formally $c_i = \min\{c_i^{U1}, c_i^{U2}\}, i = 1, 2$. Put it another way, an upstream firm will sell a positive amount to Di only if it charges the lowest price. Formally, when upstream firm k bids c_i^{Uk} to downstream firm i, it will make the following profit with Di

$$\pi_i^{Uk}(c_i^{Uk}, c_i^{Ul}) = \begin{cases} c_i^{Uk} q_i^* & \text{if} \quad c_i^{Uk} < c_i^{Ul} \\ c_i^{Uk} q_i^*/2 & \text{if} \quad c_i^{Uk} = c_i^{Ul} \\ 0 & \text{if} \quad c_i^{Uk} > c_i^{Ul} \end{cases} \tag{4}$$

where $k, l = 1, 2$; $k \neq l$; $i = 1, 2$.

When neither firms is integrated, in the general model, $U1$ and $U2$ set prices (c_1^{U1}, c_2^{U1}) and (c_1^{U2}, c_2^{U2}), respectively. For the derivation of the payoff

table, c_1 is set equal to zero. The reason is that $c_1 = 0$ with vertical integration. Thus, in order to keep treatments comparable and avoid wealth effects, one also needs $c_1 = 0$ without integration. Essentially, this is implies that firms only compete for $D2$ also absent integration. This is without loss of generality of the qualitative features of Bertrand competition are unaffected by this. $D2$ buys at the lower of the two prices such that $c_2 = \min\{c_2^{U1}, c_2^{U2}\}$. Next, given $c_1 = 0$ and c_2, $D1$ and $D2$ set the final good prices. In equilibrium, $D1$ and $D2$ charge p_i^*, $i = 1, 2$. Downstream profits are $\pi_{D1}^* = (q_1^*)^2/b$ and $\pi_{D2}^* = (q_2^*)^2/b$, and upstream profits are π_2^{U1}, π_2^{U2} and $\pi_1^{Uk} = 0$.

A vertical merger of $U1$ and $D1$ implies that the integrated firm's true input price is $U1$'s marginal cost (Bonanno and Vickers, 1988). Thus, $D1$ will be delivered efficiently at $c_1 = 0$ and $U2$ cannot compete for the $D1$ business any more. For both upstream firms, only the $D2$ market remains a source for potential business. Profits are as follows. $D2$ earns $\pi_{D2}^* = (q_2^*)^2/b$, $U2$ earns π_2^{U2}, and the integrated firm $U1$-$D1$ makes a profit of $\pi_2^{U1} + \pi_{D1}^* = \pi_2^{U1} + (q_1^*)^2/b$.

Table 2 can be derived from these closed-form solutions for the parameters $a = 35/2$, $b = 4$, $d = 2$. The actual price parameters used to derive the profits in the table differ from the prices labels "1" to "9". In particular, profits around the joint-profit maximizing prices are quite flat. Hence, prices were increased in steps larger than one to avoid the "flat-maximum" critique (Harrison, 1989). The actual price parameters underlying the values in the table are $\{1.1, 1.6, 2.2, 2.9, 3.5, 5.0, 6.5, 7.6, 8.5\}$. Additionally, profits were multiplied by three and rounded to yield the payoff in real currency subjects received.

Appendix B: Instructions (not intended for publication)

This is an experiment on market decision-making. Funds for this experiment have been provided by an external research foundation. Take the time to read carefully the instructions. A good understanding of the instructions and well thought out decisions during the experiment can earn you a considerable amount of money. All earnings from the experiment will be paid to you in cash at the end of the experiment.

YOUR ROLE AND TASK IN THE EXPERIMENT

There are a total of 10 participants in this experiment (you and 9 others). Each participant will represent a firm. There are two types of firms, firm 1 and firm 2. The computer randomly assigns five participants the role of firm 1 and the other five participants the role of firm 2. Your role as firm 1 or firm 2 will remain fixed throughout the experiment, and you will learn whether you are firm 1 or firm 2 before we begin the experiment.

The experiment takes place over 15 rounds. In each round, a firm 1 and a firm 2 will meet in a market for a fictitious commodity, called market A. Firm 1 operates also in market B but firm 2 does not. The computer will randomly match the firm 1-firm 2 pairs in every round. The matching is completely random, meaning that there is no relation between the participant you have been matched with last round (or any other previous round) and the participant to whom you will be assigned this round.

Your task is the same in every round, no matter whether you are firm 1 or firm 2. You have to decide on a price, and this single price is valid in both markets A and B. The price can be any (whole) number from 1 to 9. The profit you can make by charging the price is as follows.

PROFIT CALCULATION

In market A, the firm that charges the lowest price will receive the profit corresponding to this price in the following table. The firm with the higher price gets zero profit in that round, and, if both firms set the same price, they share the profit equally.

Price	profit in market A in pence	profit in market B in pence (firm 1 only)
1	39	66
2	54	74
3	69	84
4	81	96
5	90	105
6	99	132
7	90	159
8	72	180
9	51	198

Consider two examples for market A. If you charge a price of 7 and the other firm charges a price of 4, you will get zero and the other firm gets 81

pence in market A. Or, if both firms charge a price of 3, both will get 69 / 2 = 34.5 pence in market A.

In market B, firm 1 only receives a profit - the profit of the "market B" column in the table. As in market A, it is the lowest of the two prices that determines the profit, no matter whether firm 1 or firm 2 (or both) charged the lowest price.

Consider an example for market B. If firm 1 charges a price of 7 and firm 2 charges a price of 4, firm 1 only gets 96 pence in market B.

Taking both markets into account, firm 1 receives the profit it made in market A plus the profit it made in market B. Firm 2 does not get any profit in market B, only in market A.

EACH ROUND

A round ends when all firms have chosen their price. At the end of the round, each firm sees its own price, the price of the other firm and the own profit from the round.

At the completion of 15 rounds, you will be paid your earnings in pounds you have accumulated during the experiment. In addition to these earnings, each participant will receive a payment of 5£. While the earnings are being counted for distribution, you will be asked to complete a questionnaire related to the experiment.

QUESTIONS?

If you have any questions about the instructions, please raise your hand and an experimenter will come to assist you. Thank you for your participation.
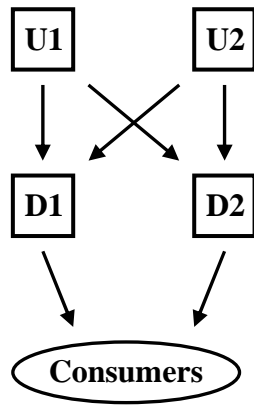
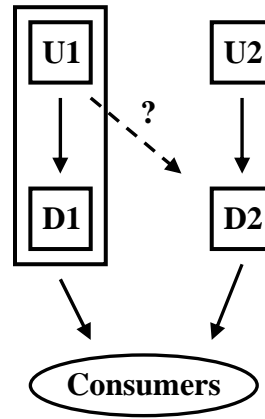**A. Nonintegration**   **B. Integration**
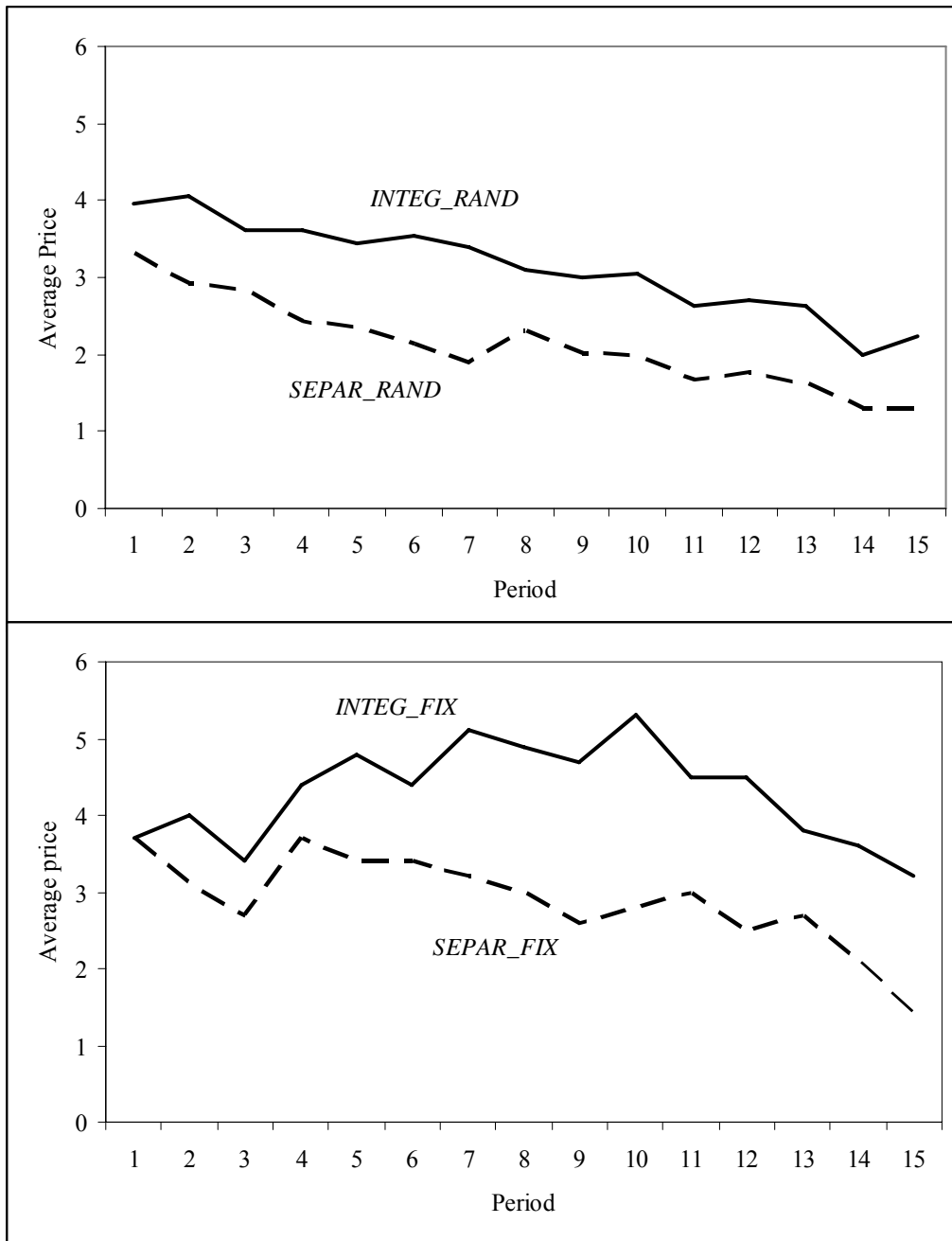

Figure 1. Market structure

Figure 2. Average prices in *SEPAR* (dashed lines) and *INTEG*
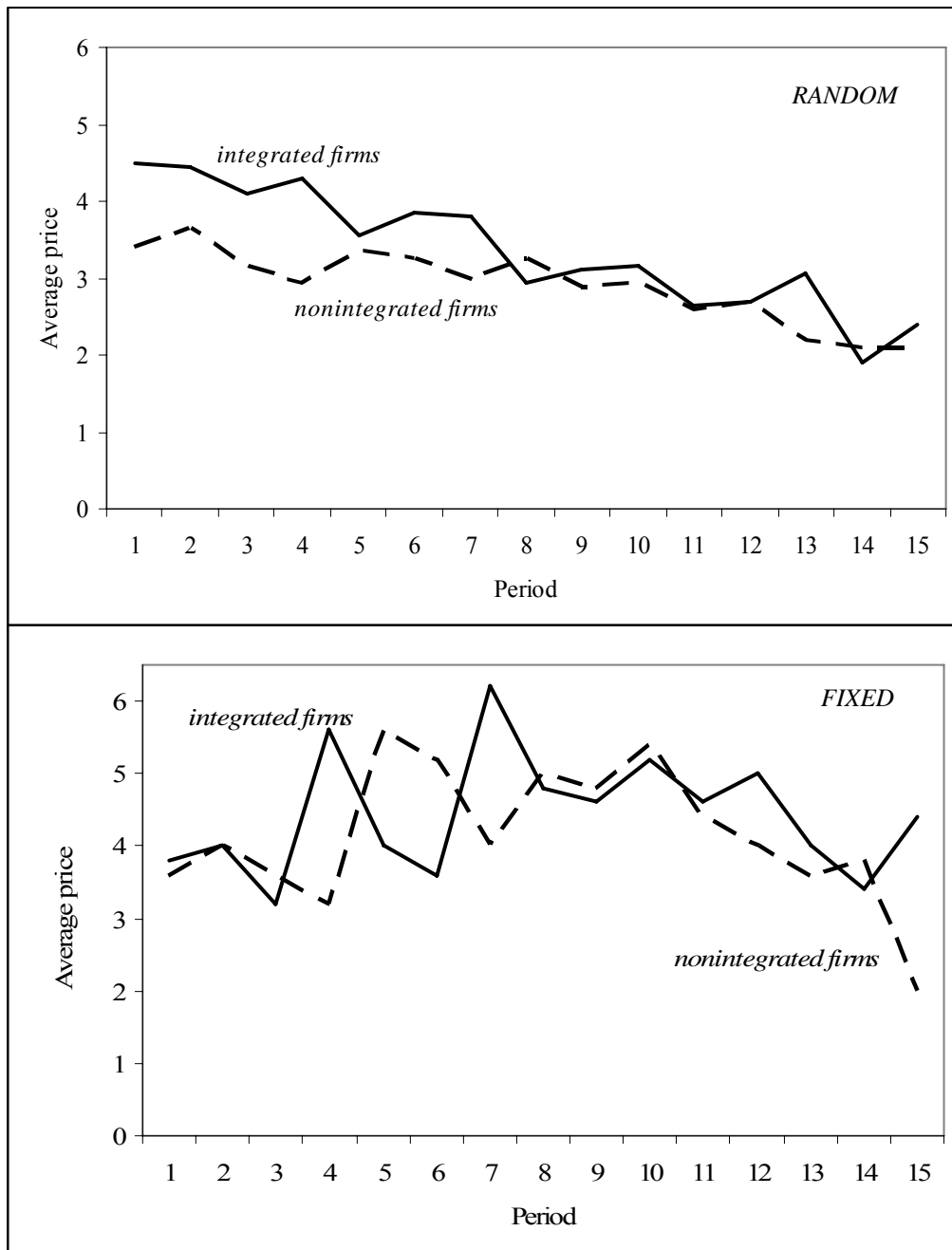(solid lines) for random matching (top panel) and fixed
matching (bottom panel)

Figure 3. Average prices of integrated firms (solid lines) and nonintegrated firms (dashed lines) in the *INTEG* treatments, random matching (top panel) and fixed matching (bottom panel)
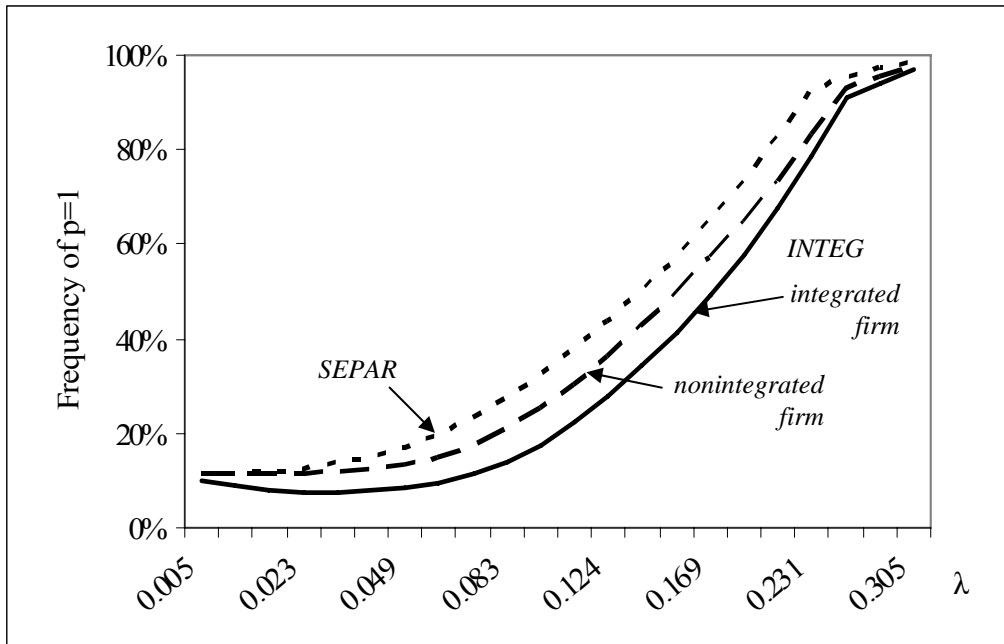
Figure 4. Quantal Response Equilibrium simulations for the frequency of
the price of 1.