Vertical integration as a source of hold-up: An experiment

Marie-Laure Allain, Claire Chambolle, Patrick Rey, Sabrina Teyssier

European Economic Review 137 (2021) 103783

Contents lists available at ScienceDirect

European Economic Review

journal homepage: www.elsevier.com/locate/eer

Vertical integration as a source of hold-up: An experiment[☆]

Marie-Laure Allain[a,*], Claire Chambolle[b,a], Patrick Rey[c], Sabrina Teyssier[d]

[a] CREST, CNRS, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France
[b] Université Paris-Saclay, INRAE, UR ALISS, 94205, Ivry-sur-Seine, France
[c] Toulouse School of Economics, University Toulouse Capitole, Toulouse, France
[d] Université Grenoble Alpes, INRAE, CNRS, Grenoble INP, GAEL, Grenoble, France

ARTICLE INFO

JEL classification:
C91
D90
L13
L41
L42

Keywords:
Vertical integration
Hold-up
Experimental economics
Bounded rationality
Social preferences

ABSTRACT

In a vertical chain in which two rivals invest before contracting with one of two competing suppliers, vertical integration can create hold-up problems for the rival. We develop an experiment to test this theoretical prediction in a setup in which suppliers can either pre-commit *ex ante* to being greedy or degrade *ex post* the input they provide to their customer. Our experimental results confirm that vertical integration creates hold-up problems. However, vertical integration also generates more departures from theory, which can be explained by bounded rationality and social preferences.

1. Introduction

The risk of expropriation of investment benefits, known as the hold-up problem, has long been recognized as an important source of under-investment (see Williamson, 1975, 1985; Klein et al., 1978). In response, the literature has emphasized the role of vertical integration as a *solution* to this problem (see Grossman and Hart, 1986). In a recent paper, however, Allain et al. (2016) – henceforth ACR – point out that vertical integration can also *create* hold-up concerns ... for rivals. This paper develops a lab experiment which provides a test of this theory.

In ACR, two downstream firms must invest before securing a key input from one of two upstream suppliers. The investment generates a return, which is reduced if the rival also invests. The upstream firms offer revenue-sharing contracts and investing is profitable for a downstream firm only if it receives a high enough share. Two market structures are considered: under vertical separation, all firms are independent; under (partial) vertical integration, two are vertically integrated and two are independent. Three variants of this model are studied. In the baseline variant, Bertrand competition leads the suppliers (integrated or not) to offer the highest revenue share; anticipating this, the downstream firms invest (no hold-up). The other two variants introduce hold-up options. In the commitment variant, suppliers have the option to commit to being greedy by demanding *ex ante* a large revenue share, that is, before downstream firms invest. In the sabotage variant, suppliers have the option to degrade *ex post* the quality

☆ We thank two anonymous referees and the associate editor, Hans Theo Normann and Emmanuel Dechenaux, as well as participants to the ANR-DFG Workshop (2015), EARIE 2016 and 2017 Bergen Competition Policy Conference for helpful comments. We thank Sri Srikandan, who developed the z-tree programs, and Pascale Bazoche for her help in running the experiments.

* Corresponding author.
E-mail addresses: marie-laure.allain@ensae.fr (M.-L. Allain), claire.chambolle@inrae.fr (C. Chambolle), patrick.rey@tse-fr.eu (P. Rey), sabrina.teyssier@inrae.fr (S. Teyssier).

https://doi.org/10.1016/j.euroecorev.2021.103783
Received 16 March 2020; Received in revised form 12 May 2021; Accepted 21 May 2021
Available online 8 June 2021

provided to the downstream firm. An integrated supplier exerts either of these options, thus creating a hold-up problem for the independent firm which discourages its investment. Without integration, there is no hold-up problem because suppliers do not exert these options then.

To test these theoretical predictions we ran a lab experiment designed to satisfy the key modeling assumptions. Three treatments, reflecting the three variants, were played first under separation and then under integration. To expedite the decision process, we simplified the setup as follows. First, we replaced the possibly integrated downstream firm by an automaton, behaving as predicted by theory; this left us with three players: a potentially integrated supplier and two independent firms (one upstream and one downstream). Second, in the Commitment and Sabotage treatments, we introduced the hold-up option only for the potentially integrated supplier.[1] Finally, we discretized the set of sharing rules.[2]

The experimental results give support to the theoretical predictions: vertical integration indeed creates hold-up in the Commitment and Sabotage treatments. Specifically, under vertical integration, downstream players invest less often and receive a lower share of revenue; this is primarily driven by U_A's actual commitment decision in the former treatment, and by the threat of sabotage in the latter. The predictions of ACR thus survive the presence of inevitable noise stemming from bounded rationality, behavioral biases, social interactions or other sources. Furthermore, the observed departures in individual decisions in the Commitment and Sabotage treatments can be rationalized by bounded rationality and social preferences. This leads us to conclude that the mechanism highlighted by the model appears sufficiently robust to be empirically relevant.

The key ingredients and mechanisms of ACR echo actual antitrust cases. *Commitment* can be achieved in practice in various ways, e.g., by designing an input in such a way that it becomes of no use for downstream competitors,[3] or by delegating the monetization of (part of) a patent portfolio to so-called "patent trolls", which aggressively enforce patent rights and litigate infringements. A case in point is provided by Microsoft's vertical integration in the downstream market for mobile devices. Right after its acquisition of Nokia's handset business in 2014, Microsoft delegated to Mosaid (now Conversant) the management of a portfolio of patents reading on such devices, prompting claims of patent trolling by rival device maker Huawei. This led the Chinese competition authority to impose behavioral remedies in order to prevent Microsoft from using its patents rights to restrict competition in the smartphone market.[4]

Sabotage can correspond in practice to degrading the quality of an input or service supplied to competitors, but also to delaying competitor's access to new features or to abusing commercially sensitive information (see, e.g., Beard et al., 2001; Mandy and Sappington, 2007). Such sabotage concerns were for example at the core of the policy debate prompted by the 2008 merger between TomTom, the leading manufacturer of portable navigation devices (or "PNDs"), and Tele Atlas, one of the two main providers of digital map databases.[5]

The experimental approach is particularly useful for testing the implications of vertical integration, which in practice is an endogenous decision prompted by various factors.[6] The controlled environment provided by lab experiments allows us instead to introduce a single exogenous change at a time. Relying on lab experiments is particularly useful also in the absence of field data. This is indeed the case here, as the key variables include specific investments, which are rarely observable, and upstream contracting terms, which constitute sensitive business secrets and are notoriously difficult to obtain.[7] Finally, we note that in the lab, subjects and professionals exhibit largely similar behaviors (see, e.g., Ball and Cech, 1996; Fréchette, 2015; Smith et al., 1988).

Two other mechanisms through which vertical integration can harm independent rivals are supplier opportunism (Hart and Tirole, 1990) and raising rivals' costs (Ordover et al., 1990; Salinger, 1988). The first one, which relies on secret contracting, has been experimentally validated by Martin et al. (2001). The second one relies in theory on a commitment to stop supplying or limit rivals' access. Yet, Normann (2011) finds in an experiment that vertical integration raises a rival's cost even without such commitment; he moreover shows that this is in line with a quantal response equilibrium, in which players do not best-respond with probability one, but choose better responses more frequently. We contribute to this literature by testing and validating a third mechanism through which vertical integration can harm independent rivals, namely, the hold-up problem highlighted by ACR.[8] We also contribute to the experimental literature on hold-up, which has focused so far on bilateral settings — one player invests, and must then share the return with the other player.[9] To test the predictions of ACR, we consider instead an extended setting in which each player faces competition.

1 In ACR, the independent supplier could also exert this option but never does so.

2 In ACR, any sharing rule could be offered. To limit the emergence of cooperative strategies, we maintained a substantial number of options.

3 See Avenel and Barlet (2000) for an example in the pulp and paper industry or Church and Gandal (2000) and Choi and Yi (2000) for examples in the software–hardware industry.

4 Distributing a portfolio of complementary patents among several patent trolls would create double marginalization problems and lead to even higher royalty rates. In a recent dispute, Cisco accuses Ericsson, with which it competes on network equipment products, of having split the management of patents reading on these products between two patent trolls, Rockstar and Spherix, so as to raise total licensing fees. See Spherix Incorporated and NNPT, LLC versus Cisco Systems, in the US District Court for the District of Delaware, C.A. No. 14-393, Cisco Systems, Inc's Answer and Amended Counterclaims.

5 Specifically, rival PND makers expressed concerns of sabotage through degraded map database, delayed access to new features, and leakages of commercially sensitive information (estimated sales, product roadmaps and new features). See the EC Decision of 14/05/2008 in Case No. COMP/M.4854 - TOMTOM/TELE ATLAS, at §190.

6 For a more general discussion on the experimental test of theories applied to competition policy, see Hinloopen and Normann (2009).

7 On the advantages of lab experiments for testing competition policy, see, e.g., Brandts and Potters (2018), Camerer and Weber (2013), Camerer (2015), Falk and Heckman (2009), Normann and Ricciuti (2009), Plott (1982) and Plott (1989).

8 Götte and Schmutzler (2009) present a rather large experimental literature on horizontal mergers; by contrast, the literature on vertical mergers is scarce.

9 For example, Ellingsen and Johannesson (2004) analyze the impact of communication on hold-up; Sloof et al. (2007) study instead the role of investment observability, whereas Hoppe and Schmitz (2011) focus on the effect of contract renegotiation, and Dufwenberg et al. (2013) consider the role of rights of control and vengeance.

Table 1
Costs and revenues in the baseline treatment.

D's investment	D's cost	Revenue generated by D	$\hat{D}$'s cost	Revenue generated by $\hat{D}$	Total revenue
$I = 0$	4.5	29.13	45	97.1	126.23
$I = 1$	36	74	45	74	148

Table 2
Payoff of D in the baseline treatment under VS and VI.

s	50%	55%	60%	65%	70%	75%	80%	85%	90%
$I = 0$	10	12	13	14	16	17	19	20	22
$I = 1$	1	5	8	12	16	20	23	27	31

This paper is organized as follows. Section 2 describes the experimental design and procedures. Section 3 reports the results on investment, sharing and hold-up decisions. Section 4 provides concluding remarks.

2. The experiment

We now present the three experimental treatments used to reflect the variants of ACR: Baseline, Commitment and Sabotage. We first detail the experimental design and equilibrium outcome, before presenting the experimental procedures.

2.1. Experimental design

There are three players, U_A, U_B and D.[10] The downstream firm D competes with an automaton ($\hat{D}$) and must decide whether to invest before selecting an upstream supplier, U_A or U_B. The investment decision determines the revenue generated by the partnership. In each treatment, two market structures are considered, which affect the suppliers' payoffs: vertical separation (VS) and vertical integration (VI), where U_A is integrated with $\hat{D}$.[11]

2.1.1. Baseline treatment

Timing. In the Baseline treatment, the timing is as follows:

Stage 1: D decides whether to invest; her decision, $I \in \{0, 1\}$, is publicly observed.
Stage 2: U_A and U_B simultaneously offer a revenue-sharing rule; the share s left to D is chosen in $S \equiv \{50\%; 55\%; 60\%; 65\%; 70\%; 75\%; 80\%; 85\%; 90\%\}$.[12]
Stage 3: Having observed both offers, D selects her partner.

Payoffs. The payoffs correspond to a market game in which D's investment increases her revenue but reduces $\hat{D}$'s revenue. The two suppliers, U_A and U_B, compete by offering revenue-sharing contracts. Under VS, $\hat{D}$ automatically selects the same supplier as D.[13] Under VI, $\hat{D}$ is integrated with U_A; it is thus supplied internally and its revenue goes to U_A.

Specifically, D's investment, $I \in \{0, 1\}$, generates a revenue $r(I) = (0.3 + 0.7 \times I)(97.1 - 23.1 \times I)$ for D and a revenue $\hat{r}(I) = 97.1 - 23.1 \times I$ for $\hat{D}$.[14] D bears a cost equal to $4.5 + 31.5 \times I$, whereas $\hat{D}$ bears a cost of 45.[15] Table 1 presents the resulting costs and revenues (in euros).

We now describe the (rounded) payoffs presented to the subjects. Table 2 reports D's payoff, which is the same under VS and VI: it is equal to her share s of the revenue she generates, net of her cost. For any given investment decision, D's payoff increases with the share obtained. Investing is profitable as long as the share s is large enough, namely, above $s^* \equiv 70\%$.[16]

We now turn to the payoff of the supplier selected by D, which depends on the market structure. Table 3 reports the payoff under VS, equal to a share $1 - s$ of the total revenue generated by the two downstream firms, which is larger if D invests (148 instead of 126.23, as shown in Table 1).

Under VI, the selected supplier receives a share $1 - s$ of the revenue generated by D (29.13 if D does not invest and 74 if D invests, as shown in Table 1), as reported in Table 4.

[10] For the sake of neutrality, in the experiment the players were referred to as "A" (U_A), "B" (U_B), and "C" (D). For exposition purposes, we will use "he" for U_A and U_B, and "she" for D.

[11] The automaton is assumed to behave as predicted by theory; it is not mentioned to the players and is only used to determine the payoff structure.

[12] To ensure equilibrium uniqueness, we limited the maximal share to 90%. If suppliers could offer a share of 100%, two equilibria would exist under vertical separation: one in which suppliers offer 100% and obtain zero profit, and another one in which they offer the next-best share and receive a positive expected profit. Likewise, if suppliers could offer a share of 95%, there would exist two equilibria, (90%, 90%) and (95%, 95%).

[13] In ACR, under VS, the downstream firms have the same objective and thus pick the cheaper supplier; when the suppliers offer the same terms, assuming that the downstream firms select the same one does not affect the equilibrium outcomes.

[14] The revenue functions $r(I)$ and $\hat{r}(I)$ are derived from a symmetric function presented in ACR, of the form $r(I_i, I_j) = (0.3 + 0.7 \times I_i)(120.2 - 23.1 \times (I_i + I_j))$, where I_i and I_j refer to the investments of D and $\hat{D}$, and it is a dominant strategy for $\hat{D}$ to invest; we thus assume here that $\hat{D}$ indeed invests.

[15] Even when she invests, D's cost is lower than $\hat{D}$'s (36 instead of 45). This cost difference does not alter the equilibrium outcome, but limits the payments made to U_A subjects, by reducing the additional payoffs presented in Table 5.

[16] The particular value of s^* does not matter as long as it remains strictly within the interval of feasible shares (that is, between 55% and 85%).

Table 3
Payoff of the selected supplier in the baseline treatment under VS.

s	50%	55%	60%	65%	70%	75%	80%	85%	90%
$I = 0$	63	57	50	44	38	32	25	19	13
$I = 1$	74	67	59	52	44	37	30	22	15

Table 4
Payoff of the supplier selected by D in the baseline treatment under VI.

s	50%	55%	60%	65%	70%	75%	80%	85%	90%
$I = 0$	15	13	12	10	9	7	6	4	3
$I = 1$	37	33	30	26	22	19	15	11	7

Table 5
Payoff for U_A generated by the subsidiary in the baseline treatment under VI.

$I = 0$	52
$I = 1$	29

In addition, irrespective of D's choice of supplier, the integrated U_A receives the profit generated by his downstream subsidiary $\hat{D}$, which is adversely affected by D's investment, as reflected in Table 5.[17] As a result, while U_B's payoff remains larger when D invests, U_A's total payoff (even if selected by D) is instead lower when D invests.

Finally, to avoid biases against actions that may generate negative profits (see Dufwenberg et al. 2007), suppliers obtain a fixed payment $f = 2$ in case they are not selected.[18]

Equilibrium outcomes. Under both VS and VI, for any given investment decision made in stage 1, in stage 2 the suppliers compete to be selected by D, and this competition induces them to offer the maximum share, that is, 90%. It follows that D is indifferent between the two suppliers in stage 3 and, as $90\% > s^*$, D invests in stage 1: there is no hold-up.

2.1.2. Commitment treatment

Timing. In the Commitment treatment, an *ex ante* stage 0 is added to the Baseline game, in which U_A can commit himself to being "greedy". Specifically, in this stage 0, which takes place before investment decisions, U_A can commit himself, if he wishes so, to offering the lowest share 50% to D.[19] The three stages of the Baseline game are then played, with the caveat that, in stage 2, U_A does not make any choice if he already committed himself in stage 0.

Payoffs. Using the commitment option costs 5. All payoffs are otherwise the same as in the Baseline treatment.

Equilibrium outcomes. Under VS, U_A never uses the commitment option, as this would put him at a disadvantage in the competition stage and is costly. Therefore, the outcome is the same as in the Baseline treatment: the suppliers offer the maximal share 90% to D who invests.

Under VI, however, U_A benefits from D deciding not to invest, as this increases the additional payoff displayed in Table 5. Specifically, by committing himself in stage 0 to leaving 50%, U_A confers market power to U_B who, in stage 2, offers D the lowest share exceeding 50%, namely 55%; anticipating this, D does not invest in stage 1, as $55\% < s^*$. This gives U_A a profit of 52 through his subsidiary and a profit of 2 from not being selected by D; U_A's net payoff is therefore $52 + 2 - 5 = 49$. By not committing himself, U_A would instead obtain 29 from his downstream subsidiary and at most 7 from the competition for supplying D (as both suppliers offer 90%), which only amounts to 36. It is thus optimal for U_A to commit in stage 1 under VI.

Hence, in this Commitment treatment, vertical integration creates hold-up problems for D, who does not invest.

2.1.3. Sabotage treatment

Timing. The Sabotage treatment adds an *ex post* stage 4 to the Baseline game, in which, if selected by D, U_A chooses whether or not to sabotage his supply to D.[20] Specifically, in this stage 4, which takes place after the supplier selection decision, if selected, U_A can exert an option "S"; exerting this option reduces D's revenue to an extent that discourages her investment,[21] but increases the profit of U_A's downstream subsidiary under VI.

Payoffs. Using the sabotage option costs 5 and yields a payoff for D given by Table 6.[22] Under VI, it brings an additional benefit 10 to U_A's downstream subsidiary.[23]

[17] The profit generated by $\hat{D}$ amounts to $74 - 45 = 29$ if D invests, while it amounts to $97.1 - 45 = 52.1$ if D does not invest.

[18] Not granting this payment to the selected suppliers reduces the financial cost of the experiment without affecting the equilibria.

[19] Alternatively, U_A could commit to any other share strictly lower than s^*, thus discouraging D's investment.

[20] The word "sabotage" is never mentioned in the experiment, because its negative connotation could influence the subjects.

[21] That is, what matters is that D then obtains a revenue that is lower than the revenue that would otherwise be generated by a share s^*.

[22] This payoff is based on an effective share of 52.5%, which enables U_B to win the competition with a 55% share.

[23] Note that varying these cost and benefit does not affect the equilibrium outcome as long as the cost does not exceed the benefit.

Table 6
Payoff of D in the Sabotage treatment if she selects U_A who then uses option S.

$I = 0$	11
$I = 1$	3

Table 7
Theoretical predictions for all treatments and market structures.

Treatment	Market structure	Stage	Player	Action	Payoff
Baseline	VS and VI	1	D	invests	
		2	U_A ; U_B	90% ; 90%	15 ; 2[a]
		3	D	U_A or U_B	31
Commitment	VS	0	U_A	does not commit	
		1	D	invests	
		2	U_A ; U_B	90% ; 90%	15 ; 2[a]
		3	D	U_A or U_B	31
	VI	0	U_A	commits to 50%	
		1	D	does not invest	
		2	U_A ; U_B	[*no decision*] ; 55%	54 ; 13
		3	D	U_B	12
Sabotage	VS	1	D	invests	
		2	U_A ; U_B	90% ; 90%	15 ; 2[a]
		3	D	U_A or U_B	31
		4	U_A (if selected)	does not use S	
	VI	1	D	does not invest	
		2	U_A ; U_B	any $s \in \mathcal{S}$; 55%	54 ; 13
		3	D	U_B	12
		4	U_A (if selected)	uses S	

[a]The first number is the payoff of the supplier selected by D.

The payoffs of all players are otherwise the same as in the Baseline treatment.

Equilibrium outcomes. Under VS, the option S involves a cost and no benefit; hence, U_A never uses it, and the outcome remains as in the Baseline treatment: the suppliers offer the maximal share 90% to D, who invests.

By contrast, under VI, U_A has an incentive to use the option S, as this brings a net benefit $10 - 5 > 0$. As a result, regardless of the offer made by U_A and of D's investment decision, U_B wins the competition by offering the lowest share leaving D a higher payoff than that displayed in Table 6, which is 55%. Anticipating this, D does not invest in stage 1, as $55\% < s^*$. Note that, formally, there are multiple equilibria, which only differ in the offer initially made by U_A: indeed, offering any share constitutes an equilibrium strategy.

Hence, in this Sabotage treatment, vertical integration creates hold-up problems for D, who does not invest.

2.1.4. Recap

Table 7 summarizes the theoretical predictions for each treatment.

2.2. Experimental procedures

We now describe the organization of the experimental sessions. Each session is dedicated to one treatment, first played for ten periods under vertical separation (phase VS), followed by ten periods under vertical integration (phase VI). Each subject participates in only one session (but plays both phases). Thirty subjects are active in each session: 10 for U_A, 10 for U_B, and 10 for D.

At the beginning of each session, the instructions (see Online Appendix A) are given to the participants and read aloud. They include tables describing the payoffs resulting from the three players' strategies. These payoff tables are therefore common knowledge. Each subject is then randomly assigned a role (U_A, U_B or D) and keeps the same role for the whole session.

At the beginning of each period, groups of 3 subjects are constituted; these three subjects interact during that period and no communication is allowed between them. In order to limit the scope for repeated interaction, we use a perfect stranger matching protocol between U_A and U_B, ensuring that these subjects meet only once within each phase; in each period, each D subject is then randomly matched with a couple of U_A and U_B subjects.

Within a group, subjects observe all prior decisions before making their next decisions,[24] and a recap is provided to the group at the end of the period. At the end of each period, each subject learns his or her own payoff for that period. At the end of the twenty periods, one period is randomly chosen, and each subject earns the payoff obtained in that period.

[24] The only exception concerns the Sabotage treatment, in which, when selected, U_A does not observe the share offered by U_B before deciding whether to exert the option S. This, however, has no impact on the predicted behavior.

At the end of each session, subjects are asked to answer a series of questions about their age, sex and occupation; they are also asked to situate themselves on a 0 to 10 risk-aversion scale ranging from "ready to take risks" to "not ready to take risks at all" (Dohmen et al., 2005). Finally, they are asked to answer three standard questions; the number of correct answers is then used as an IQ score (from 0 to 3).[25]

We conducted nine sessions (three per treatment) at Ecole Polytechnique in Paris, from April 2015 to April 2017. In total, 270 subjects participated. The sessions lasted between 90 and 120 min, including time for instructions. On average, subjects earned 25.18 euros (including a show-up fee of 5 euros). The experiments were programmed using the software z-tree (Fischbacher, 2007). The subjects included both students (undergraduate and graduate students in engineering), and employees.[26] 32% were female (41% in the Baseline treatment, 30% in the Commitment treatment and 26% in the Sabotage treatment) and 32% were employees (40% in the Baseline treatment, 28% in the Commitment treatment and 29% in the Sabotage treatment). The average answer to the question on risk-aversion is 5.75 (5.58 in the Baseline treatment, 5.96 in the Commitment treatment, and 5.72 in the Sabotage treatment). Finally, the average IQ is 1.94 (1.65 in the Baseline treatment, 2.13 in the Commitment treatment, and 2.04 in the Sabotage treatment).

Most of the students at Ecole Polytechnique are male (in our sample, 21% of students are female, whereas 56% of employees are female); hence, gender and occupation (student or employee) are highly correlated (and occupation is itself highly correlated with age).[27] We also observe that IQ is highly correlated with these two variables (Pearson correlation tests are presented in Appendix B). In our analysis, we have chosen to control for the individuals' IQ level (which has a broader range than the binary variables). When using a Mann–Whitney ranksum test, we observe significant differences between the Baseline treatment and each of the Commitment and Sabotage treatments ($p < 0.05$), but no difference between the Commitment and Sabotage treatments ($p = 0.5691$). However, when using a Kolmogorov–Smirnov test, the IQ is not significantly different across the three treatments. Finally, no significant difference in risk-aversion is observed across the three treatments (using both a Mann–Whitney ranksum test and a Kolmogorov–Smirnov test).

3. Results

We now study the impact of vertical integration on subjects' decisions. In Section 3.1, we show that, as predicted by theory, vertical integration creates hold-up problems in the Commitment and Sabotage treatments. We also observe some departures from theory, which, interestingly, are exacerbated under vertical integration in the Commitment and Sabotage treatments. In Section 3.2, we show that these departures can be explained by classic behavioral biases, namely, bounded rationality and social preferences.

3.1. Hold-up

Fig. 1 represents the evolution of the proportion of D subjects who invest. In the vertical separation phase (VS hereafter, corresponding to the first ten periods), the three treatments generate similar investments: about 82% of D subjects invest in the Baseline treatment and Commitment treatments, and 92% in the Sabotage treatment. In the vertical integration phase (VI hereafter, last ten periods), this proportion remains about the same in the Baseline treatment (90%). By contrast, this proportion drops substantially in the Sabotage treatment (to 52%) and, to a larger extent, in the Commitment treatment (to 32%).

Similar patterns arise for the evolution of the shares offered and accepted (see Figs. 2 and 3 in Appendix C). The average shares offered by the suppliers, which range from 80% to 84% under VS in the three treatments, remain in that range in the Baseline treatment under VI; by contrast, the share offered by U_B drops in the Sabotage treatment (to 68%), and the shares offered by both suppliers drop to an even larger extent in the Commitment treatment (to 58% for U_A and 62% for U_B).[28] Likewise, the average accepted share, which is about 85% under VS, remains about the same under VI in the Baseline treatment (86%); it drops instead substantially in the Sabotage treatment (to 75%), and even more so in the Commitment treatment (to 64%).

These patterns support the theoretical predictions: vertical integration has no effect in the Baseline treatment, but generates hold-up problems in the Commitment and Sabotage treatments. This is confirmed by Table 8, which reports the marginal effect of vertical integration, for each treatment, on the investment decisions as well as on the shares offered and accepted.[29] In the Baseline treatment, vertical integration does not reduce investment; it actually appears to become slightly higher, which may reflect

[25] See Appendix A for more details on the IQ questionnaire.

[26] An additional session has been conducted for each of the Commitment and Sabotage treatments. However, due to schedule constraints, these two sessions differed from the others in terms of percentage of students and IQ level. For reliability purposes, we dropped the session with an average IQ of 2.57 for the Commitment treatment and of 1.20 for the Sabotage treatment, which correspond to the two extreme values among all sessions. Including these two sessions does not affect the qualitative results.

[27] Students are aged between 18 and 27.

[28] Recall that, in the Sabotage treatment, there is no theoretical prediction about the share offered by U_A.

[29] In Tables 8–13, for binary variables, we use Probit regressions and compute average marginal effects: we first compute the marginal effect for each subject, before aggregating across subjects; see Williams (2012) for details of the method. For the shares offered and accepted, we use OLS regressions. All regressions control for session fixed effects and, as subjects make repeated decisions during a session, we evaluate standard errors using clusters at the individual level.

We provide in the Online Appendix E robustness checks controlling for IQ and risk-aversion of the decision maker and/or of all three group subjects. We also check for learning effects by discarding the first two periods of each phase. Finally, we provide an additional check using clusters at the session level. In all cases, the results are qualitatively the same.

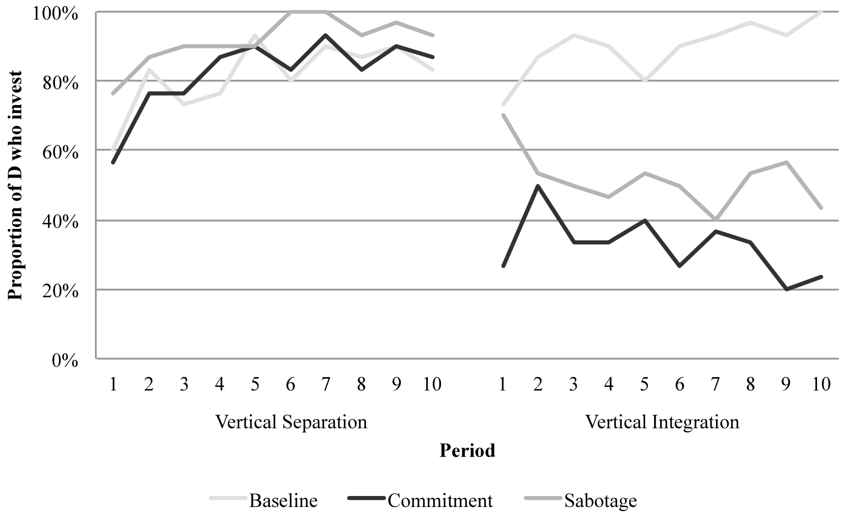

Fig. 1. Evolution of investment.

Table 8
Marginal effect of vertical integration.

	Investment	Share accepted by D	Share offered by U_A	Share offered by U_B	U_A's hold-up decision
Baseline	0.080***	0.600	0.983	−1.183	
	(0.028)	(0.553)	(0.993)	(1.056)	
Commitment	-0.428***	−20.12***	−22.583***	−18.1***	0.481***
	(0.031)	(1.282)	(2.688)	(1.416)	(0.013)
Sabotage	-0.367***	−10.45***	0.217	−13.633***	0.458***
	(0.055)	(1.181)	(1.100)	(1.826)	(0.021)

Notes: Standard errors are reported in parentheses.
***Represents significance at 1% level.

a learning effect, as the observed behavior gets closer to the prediction. By contrast, vertical integration reduces the probability of investment in the other two treatments, by 43% in the Commitment treatment and by 37% in the Sabotage treatment.

Regarding the shares offered and accepted, the results are also in line with theory. There is no significant effect in the Baseline treatment. By contrast, vertical integration significantly reduces the shares offered by both suppliers in the Commitment treatment and the share offered by U_B in the Sabotage treatment. This results in a negative marginal effect on the share obtained by D, of -20 percentage points in the Commitment treatment and -10 percentage points in the Sabotage treatment.

These findings can be summarized as:

Result 1 (*Investment and Sharing Decisions*). *In line with theoretical predictions, vertical integration does not reduce investment and has no impact on the shares offered and accepted in the Baseline treatment; by contrast, vertical integration reduces investment as well as the shares offered and accepted in the Commitment and Sabotage treatments.*

In the Commitment treatment, the impact of vertical integration is primarily driven by the proportion of U_A subjects who choose to exert the hold-up option (i.e., to commit themselves to offering a 50% share), which increases from 8% under VS to 72% under VI. This is confirmed by Table 8, which reports that vertical integration has a marginal effect of 48% on the commitment decision. Table 9 moreover confirms that U_A's commitment decision is the key driver: under both VS and VI, it has a marginal effect of −50% on D's investment and of −23% on the share offered by U_B.

In the Sabotage treatment, the impact of vertical integration is primarily driven by the threat of sabotage. Indeed, the proportion of U_A subjects who choose the sabotage option when selected increases from 10% under VS to 78% under VI. Table 8 confirms that vertical integration has a marginal effect of 46% on U_A subjects' sabotage decisions when selected.

These findings can be summarized as:

Result 2 (*Hold-Up Decisions*). *In the Commitment treatment, the impact of vertical integration is primarily driven by U_A's actual commitment decision. In the Sabotage treatment, it is instead driven by the threat of Sabotage by U_A if selected.*

Table 9
Marginal effect of U_A's commitment.

Investment	−0.500***
	(0.015)
Share offered by U_B	−22.874***
	(1.666)
Share accepted by D	−28.502***
	(2.250)

Notes: The sample includes both VS and VI. Standard errors are reported in parentheses.
***Represents significance at 1% level.

3.2. Discussion

Fig. 1 shows that, as one may expect, subjects sometimes depart from predicted behavior. Interestingly, however, these departures are more frequent under vertical integration in the Commitment and Sabotage treatments. To explore this further, we build in Appendix D a binary deviation score for each decision. We find that vertical integration increases U_A subjects' departures in hold-up decisions in the Commitment treatment: they do not exert hold-up as often as predicted. In the Sabotage treatment, it increases instead U_B and D subjects' departures: the supplier is too generous, the downstream firm invests too frequently, and the two departures are moreover correlated.

As the perfect stranger protocol used in the experiment limits the scope for cooperation based on repeated interactions, we explore in Appendix E alternative approaches based on behavioral biases. We find that bounded rationality (namely, level-k thinking) can explain why vertical integration creates departures in hold-up decisions in the Commitment treatment, where this decision comes first; U_A must therefore anticipate the other subjects' subsequent decisions, which involves higher levels of thinking.[30] That U_A subjects do not exert the hold-up option as often as predicted suggests that they may have social preferences[31] preventing them from harming others (see Table 11 in Appendix D.1).[32] We find that beliefs about such preferences can explain why vertical integration creates departures in D and U_B subjects' decisions in the Sabotage treatment where U_A's decision comes last, which exposes D and U_B to *strategic uncertainty*.[33] We develop a formal model which moreover explains the observed correlation between D and U_B subjects' departures: D invests more often if she does not expect U_A to exert his hold-up option and, as the investment decision reflects her beliefs, U_B then offers more generous shares.

These findings can be summarized as:

Result 3 (*Departures from Theory*)**.** *Level-k thinking explains the observed departures in the Commitment treatment, where the hold-up decision comes first; social preferences explain instead these departures in the Sabotage treatment, where the hold-up decision comes last.*

To conclude this discussion, we note that if bounded rationality or social preferences were less relevant for firms' managerial decisions than for lab subjects, we would expect even fewer departures from theory, thus reinforcing the prediction that vertical integration is a source of hold-up.

4. Conclusion

ACR predicts that vertical integration creates hold-up problems for independent rivals, by giving the integrated firm an incentive to either commit itself *ex ante* to being greedy ("Commitment"), or degrade *ex post* the quality provided to independent customers ("Sabotage"). To test these theoretical predictions, we designed a laboratory experiment reflecting the key modeling assumptions.

The laboratory data support the predictions: vertical integration exacerbates hold-up concerns. Specifically, in the Commitment and Sabotage treatments, vertical integration reduces investment as well as the shares offered and accepted. This is primarily driven by the integrated supplier's actual commitment decision in the first treatment, and by the threat of sabotage in the other treatment. These results show that the mechanism highlighted by ACR resists the experimental noise and thus deserves further investigations.

The data also reveal some departures from theory, which are more pronounced for hold-up decisions in case of Commitment and for investment decisions and the contract terms offered by the independent supplier in case of Sabotage; the latter departures are moreover positively correlated. We find that bounded rationality (namely, level-k theory) can explain the first pattern whereas the introduction of social preferences for the integrated supplier can instead explain the other patterns.

[30] Level-k thinking consists in introducing an iterative decision process where players vary in their levels of thinking (Stahl, 1993; Nagel, 1995; Camerer et al., 2004). The process begins with "level-0" types who are not strategic and pick an arbitrary decision. "Level-1" players then best respond to "level-0" players, and so on.

[31] Models of social preferences (see, e.g., Falk and Fischbacher, 2006) are supported by experimental tests showing the existence of such preferences among individuals (see, e.g., Charness and Rabin, 2002).

[32] VI increases substantially the average deviation scores in both treatments, but this effect is significant only in the Commitment treatment, because U_A is rarely selected in the Sabotage treatment.

[33] See, e.g., Van Huyck et al. (1990) and Heinemann et al. (2009).

As for any empirical study, the robustness of the results with respect to changes in the modeling setup (*e.g.*, the nature of the hold-up options, the competition model or the payoff structure) or in the experimental design is an important issue, which calls for additional tests using (field) experimental data or the analysis of "real-world" markets when possible. We leave this as an avenue for future research.

Funding

The authors gratefully acknowledge support from the Agence Nationale de la Recherche (ANR) and the Deutsche Forschungsgemeinschaft (DFG) for the French–German cooperation project "Competition and Bargaining in Vertical Chains", from the European Research Council under the Grant Agreement no. 340903, and from the ANR Investissements d'Avenir program under the grants ANR-11-IDEX-0003/Labex Ecodec/ANR-11-LABX-0047 and CHESS ANR-17-EURE-0010.

Appendix A. IQ questionnaire

The following three questions were asked. Each good answer yields one point, while each wrong answer brings zero. The IQ score is the sum of the three.

1. A bat and a ball cost 1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost? … cents
2. If it takes 5 machines 5 min to make 5 widgets, how long would it take 100 machines to make 100 widgets? … minutes
3. In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake? … days

Appendix B. Pearson correlation tests

Table 10
Pearson correlation coefficients.

Female and Employee	0.356***
Female and IQ	−0.436***
Employee and IQ	−0.607***

***Represents significance at 1% level.

Appendix C. Figures of the evolution of the shares offered and accepted

See Figs. 2 and 3.

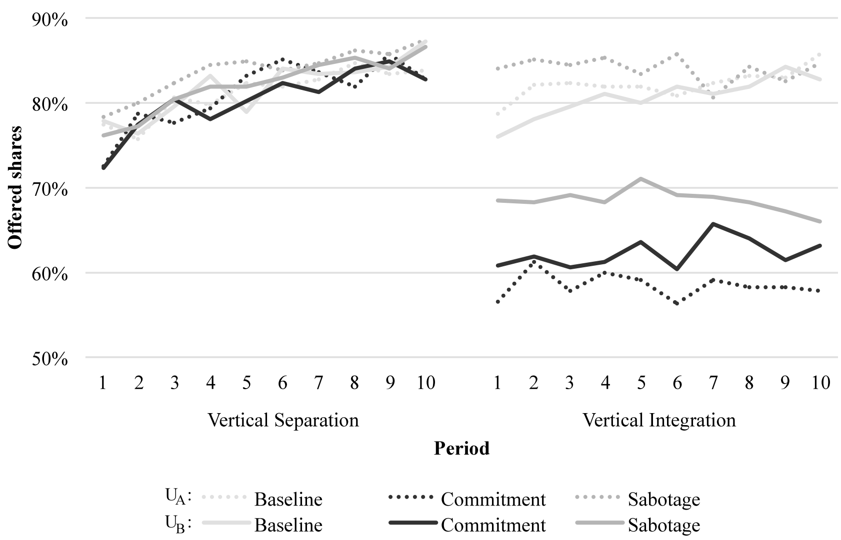

Fig. 2. Evolution of the shares offered by U_A and U_B.

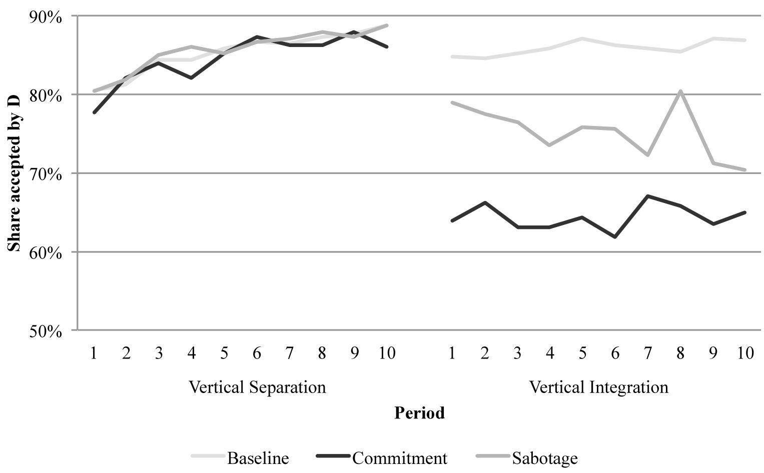

Fig. 3. Evolution of the share accepted by D.

Appendix D. Individual departures from theory

We first define binary deviation scores for all individual subjects' decisions and present the average scores for all treatments and phases (Appendix D.1).

D.1. Deviation scores

For each decision d of each player p, we build a binary deviation score, σ_p^d, as follows. For binary decisions, the score is equal to 1 whenever the observed decision differs from the prediction, and to 0 otherwise. For continuous decisions, the score allows for a margin of error of up to 10 percentage points around the equilibrium level.[34] More precisely:

U_A Subjects' hold-up decisions. σ_A^H is equal to 1 in the following instances:

- Commitment treatment: when U_A opts for the commitment option under VS, or does not do so under VI;
- Sabotage treatment, if U_A is selected:[35] when U_A opts for the sabotage option under VS, or does not do so under VI.

U_B Subjects' offered shares. σ_B^O is equal to 1 in the following instances:

- Baseline treatment: when U_B chooses a share in $[50\%, 75\%]$;
- Commitment treatment: when U_B chooses a share in $[70\%, 90\%]$ if U_A opted for the commitment option, or in $[50\%, 75\%]$ if U_A did not do so;
- Sabotage treatment: when U_B chooses a share in $[50\%, 75\%]$ under VS, or in $[70\%, 90\%]$ under VI.

D Subjects' investment decisions. σ_D^I is equal to 1 in the following instances:

- Baseline treatment: when D does not invest;
- Commitment treatment: when D invests if U_A chose to commit himself, or fails to invest if U_A chose instead not to commit himself;
- Sabotage treatment: when D does not invest under VS, or invests under VI.

D Subjects' choice of supplier. σ_D^U is equal to 1 in the following instances:

- Sabotage treatment under VI: when D chooses U_A even though U_B offered at least 55%;
- otherwise: when D chooses the supplier who offered the lower share.

Table 11 reports the average deviation score for each treatment and phase. All periods are taken into consideration. Accounting for potential learning effects (by ignoring the first two periods of each treatment/phase) does not qualitatively change the findings (see Table 16 in online Appendix B).

[34] This applies to the offered shares. However, the deviation score for the share offered by U_A cannot be defined under VI in the Sabotage treatment (as any share can then be offered in equilibrium) or for subjects exerting the commitment option in the Commitment treatment. We therefore omit it here; we note however in Online Appendix B.2 that this score is not significantly affected by vertical integration.

[35] U_A is selected by 40% of D subjects under VS and by 26% under VI.

Table 11
Average deviation scores.

Treatment	Phase	σ_A^H	σ_B^O	σ_D^I	σ_D^U
Baseline	VS		0.24	0.18	0.06
	VI		0.28	0.10	0.04
Commitment	VS	0.08	0.21	0.15	0.02
	VI	0.28	0.21	0.18	0.06
Sabotage	VS	0.10[a]	0.19	0.08	0.10
	VI	0.22[a]	0.51	0.52	0.24

[a]For selected U_A.

Table 12
Marginal effect of vertical integration on deviation scores.

	σ_A^H	σ_B^O	σ_D^I	σ_D^U
Commitment	0.198***	0.002	0.028	0.043*
	(0.074)	(0.041)	(0.036)	(0.022)
Sabotage	0.115	0.301***	0.389***	0.143***
	(0.078)	(0.058)	(0.044)	(0.039)

Notes: Standard errors are reported in parentheses.
***Represents significance at 1% level.
*Represents significance at 10% level.

Table 13
Marginal effect of σ_D^I on σ_B^O under VI.

	Commitment	Sabotage
σ_D^I on σ_B^O	−0.014	0.175***
	(0.026)	(0.059)

Notes: Standard errors are reported in parentheses.
***Represents significance at 1% level.

Under VS, we observe in Table 11 an average difference of 8% to 18% across treatments between the predicted investment behavior and the observed one. Under VI, this difference remains about the same (10%) in the Baseline treatment, but increases substantially in the other two treatments (32% for Commitment and 52% for Sabotage).[36]

D.2. Effect of vertical integration on deviation scores

Table 12 reports the marginal effect of vertical integration on the deviation scores in the Commitment and Sabotage treatments.

Table 13 reports the marginal effect of D subjects' departures from theory in their investment decisions on U_B subjects' departures in the shares they offer, under VI in the two hold-up treatments. There is a positive impact in the Sabotage treatment (marginal effect of 17%), where D investing is positively correlated with U_B subsequently offering too high shares in the same period. We did not find any other relevant interplay, in either phase, between deviations over sequential decisions (see Tables 19 and 20 in Online Appendix B.3).

Appendix E. Behavioral approaches

E.1. Level-k thinking

In what follows we present the main findings from applying level-k thinking to the Sabotage and Commitment games.[37] For simplicity we assume that, for $k \geq 1$, each level-k player believes that all the other players are of level-$(k-1)$. We also assume that when indifferent between several actions, players randomly choose each of these actions with equal probability. A more detailed analysis is provided in Online Appendix C.

[36] See Online Appendix E.3 for a detailed analysis of the Baseline treatment. If anything, we observe slightly fewer departures in the VI phase, which may reflect a learning effect.

[37] Another classic bounded rationality approach relies on the concept of quantal response equilibrium (see McKelvey and Palfrey, 1995 and Normann, 2011), which assumes that players do not choose the best response with probability one. Unfortunately, this approach is difficult to apply to multi-stage games such as the one studied here.

Table 14
Level 1, probability distribution of the expected best offer.

Best offer	51.25%	53.75%	55%	56.25%	58.75%	60%	61.25%	63.75%	65%
Probability	1/81	1/81	2/81	2/81	2/81	4/81	3/81	3/81	6/81
Best offer	66.25%	68.75%	70%	71.25%	75%	80%	85%	90%	
Probability	4/81	4/81	8/81	5/81	9/81	9/81	9/81	9/81	

Table 15
Level 1, probability distribution of the best offer.

Best offer	50%	55%	60%	65%	70%	75%	80%	85%	90%
Probability	1/81	3/81	5/81	7/81	9/81	11/81	13/81	15/81	17/81

E.1.1. Sabotage

Level-0 players play randomly. Hence, on level 0 of the Sabotage game, under both VS and VI: in stage 1, D invests with probability $1/2$; in stage 2, both suppliers select each possible sharing-rule with probability $1/9$; in stage 3, D selects either supplier with probability $1/2$, regardless of the shares offered; and whenever selected, in stage 4 U_A uses the sabotage option with probability $1/2$.

From level 1 on, U_A never uses the sabotage option under VS, and uses it whenever selected under VI.

On level 1, anticipating a random selection by a level-0 D, both suppliers offer the lowest share (50%). In stage 3, D selects the offer providing the higher expected payoff, given that she expects U_A to engage in sabotage with probability $1/2$.[38] In stage 1, D anticipates random offers by level-0 suppliers, and a random use of the sabotage option by U_A. Table 14 displays the probability distribution of the resulting best expected offer received by D.

As a result, D expects a share of 72.55 and thus invests.

From level 2 on, U_A is expected to use the sabotage option whenever selected under VI, and not to use it under VS. Hence, under VI, U_B always offers 55% and D never invests. By contrast, under VS, each supplier seeks to outbid his level-(*k-1*) rival; hence, suppliers' best offer increases gradually with k, reaches 70% (the share that leaves D indifferent between investing or not) when $k = 5$, and is maximal (90%) from level 9 on.

E.1.2. Commitment

On level 0 of the commitment game, under both VS and VI: U_A commits himself with probability $1/2$ in stage 0; D invests with probability $1/2$ in stage 1; in stage 2, U_A (if not committed) and U_B select each of possible sharing-rule with probability $1/9$; in stage 3, D selects either supplier with probability $1/2$, regardless of the shares offered.

On level 1, anticipating a random selection by D, U_B offers the lowest share (50%) whereas U_A makes the commitment decision randomly and, if not committed, offers 50% as well. If U_A does not commit himself in stage 0, then D anticipates random offers from U_A and U_B. The probability distribution of the resulting best offer is presented in Table 15 and induces D to invest (her expected payoff is then 21.4, higher than 18 when she does not invest). By contrast, if U_A commits himself in stage 0, then D anticipates that the best offer will be determined by U_B's random selection. Her expected payoff is then $143/9$ whether she invests or not; D thus invests randomly and, in stage 3, selects the higher offer.

On level 2, under both VS and VI, and regardless of U_A's commitment decision, D expects 50% shares from level-1 suppliers, and does not invest. Similarly, U_B expects a level-1 U_A to offer 50% and thus offers the next best share (55%) — offering 50% is less profitable, as it reduces by half the selection probability. Likewise, U_A chooses to not commit himself, and offers a 55% share — committing himself would furthermore reduce the probability of investment by a level-1 D.

From level 3 on, under both VS and VI, commitment by U_A discourages investment by D: U_B's best response to level-$(k-1)$ players' strategies is then to offer a 55% share, and D's is not to invest. However, an independent U_A never commits himself: this would yield the lowest possible payoff (2), whereas not committing and matching U_B 's offer, for example, would yield a higher payoff with positive probability. Furthermore, absent commitment, each supplier seeks to outbid his level-(*k-1*) rival; hence both suppliers' offers increase gradually with k, reach 70% (the share that leaves D indifferent between investing or not) when $k = 5$, and is maximal (90%) from level 10 on.[39]

It follows that U_A never commits before $k = 7$ (expecting no influence on investment, this would only limit his ability to compete) and D never invests before $k = 6$, where it does so with probability $1/2$. Differences between VS and VI appear from level 7 on. Under VS, U_A never commits himself, the suppliers compete and, anticipating high enough offers from level-$(k-1)$ suppliers, D invests. Under VI, by contrast, U_A commits himself to prevent D from investing, as this strategy becomes more profitable than competing to supply D.[40]

[38] Recall that D's payoff in case of sabotage is based on an effective share $\tilde{s} \equiv 52.5$ (see footnote 22); thus, if U_A offers a share s_A, then selecting that offer gives D an expected share $(s_A + \tilde{s})/2$.

[39] There is a slight difference in the progression of suppliers' shares in the two treatments, due to the role of D's expectations about the hold-up decision. In the sabotage treatment, on level 2 the suppliers expect a level-1 D to anticipate sabotage with probability $1/2$ from a level-0 U_A; by contrast, in the commitment treatment, uncertainty about the hold-up decision is resolved upfront, and even a level-1 D thus observes that U_A does not exert hold-up.

[40] For example, by committing himself on level-7 under VI, U_A prevents D from investing and obtains a payoff of 54; he expects that not committing himself (and offering a 80% share) would instead induce the level-6 D to invest with probability $1/2$, giving him an expected payoff of 51.

E.1.3. Insights

Level-k thinking predicts that vertical integration triggers substantial departures from theory in U_A subjects' hold-up decisions in the Commitment treatment. This is because the hold-up decision comes first, and thus depends on U_A's anticipations regarding all subsequent decisions. On level 1, suppliers anticipate a random selection by a level-0 D and thus offer the lowest share. It follows that, in the absence of commitment by U_A, the shares offered increase gradually, from 50% on level 1 to 90% from level 9 onward. Hence, D does not invest until level 6, where she invests with probability 1/2. As a result, it is only from level 7 onward that U_A commits himself to offering a low share, as predicted by theory.

By contrast, in the Sabotage treatment, the hold-up decision comes last, once all other decisions have been made and observed; it follows that, from level 1 onward, predictions coincide with theory: whenever selected by D, U_A always uses the S option under VI, and never uses it under VS.

Level-k thinking cannot explain either the observed impact of vertical integration on D and U_B subjects' departures from theory. D's investment decisions are the same in the two treatments: under VS, D invests from level 7 onward; under VI, D never invests from level 2 onward in the Sabotage treatment and in case of commitment in the other treatment. Concerning U_B's behavior, level-k thinking actually predicts more departures from theory in the Commitment treatment than in the Sabotage treatment, which goes in the opposite direction, compared with the observed behavior. The reason hinges again on the role of anticipations. From level 2 onward, sabotage is not a concern under VS but is expected under VI. Thus, under VI, U_B's offer is primarily driven by D's fear of sabotage, and coincides with theory from then on.[41] Under VS, the offer of a level-k supplier is instead driven by his expectations about a level-$(k-1)$ rival's offer. As noted above, level-1 suppliers expect a random selection and thus offer the lowest share; these offers are then enhanced only gradually, and do not coincide with theory before level 9. Vertical integration thus *reduces* U_B's departures from theory rather than exacerbating them.

E.2. Social preferences

Social preferences can explain why a fraction of U_A subjects are reluctant – in both treatments – to exert the hold-up option under VI (see Table 11). Beliefs about such preferences may, in turn, affect the behavior of D and U_B subjects in the Sabotage treatment, where U_A's hold-up decision comes last. By contrast, these beliefs cannot play any role in the Commitment treatment, where any uncertainty about U_A's hold-up behavior is resolved upfront.

We now show that beliefs about U_A's social preferences can actually explain not only D and U_B subjects' observed departures in the Sabotage treatment, but also their correlation. The intuition is that what matters for U_B is D's beliefs about U_A's social preferences, rather than U_A's actual preferences or U_B's own beliefs about them. It follows that D investing signals that she is optimistic about U_A's behavior, which in turn induces U_B to be more generous in order to be selected.

E.2.1. Formal analysis

To see this, we introduce the possibility of social preferences in a stylized version of the Sabotage treatment under vertical integration, where: (i) U_A is replaced by an automatized robot, which may either provide a good option reflecting social preferences, or an unattractive one; (ii) U_B can choose among two offers; and (iii) D is either optimistic or pessimistic about U_A's behavior.

• *Players.* There are two players: U_B and D. In addition, D has access to an outside option (standing for U_A), the quality of which is "good" ($q = G$) with probability x and "bad" ($q = B$) otherwise; a good outside option enables D to obtain a share $\hat{s} \in (0,1)$ of the revenue that she generates, whereas a bad outside option leaves her no revenue.

• *Information*. At the beginning of the game, U_B and D believe that the outside option is good with probability $\hat{x}$. D then observes a binary signal $\sigma \in \{g, b\}$, distributed in such a way that:[42]

- with probability $\lambda \in (0,1)$, D observes $\sigma = g$; she then becomes "optimistic "and believes that the outside option is good with probability $x_H \in (0,1)$;
- with probability $1-\lambda$, D observes $\sigma = b$; she then becomes "pessimistic" and believes that the outside option is good with lower probability $x_L \in (0, x_H)$.

• *Decisions*. D chooses whether or not to invest (at cost $I > 0$); she generates a revenue $R > 0$ if she does not invest and $R+\Delta > R$ if she invests. U_B chooses whether to offer D a share $s_H \in (0,1)$ or a lower share $s_L \in (0, s_H)$.

• *Payoffs*. Let $\delta \in \{0,1\}$ denote D's investment decision (where $\delta = 1$ if D invests, and $\delta = 0$ otherwise), and $s \in \{s_L, s_H\}$ denote the share offered by U_B. The payoffs are as follows:

- If D opts for the outside option, then D obtains $\hat{s}(R+\delta\Delta) - \delta I$ if the outside option is of good quality and $-\delta I$ otherwise; U_B obtains 0.
- If instead D accepts U_B's offered share s, then D obtains $s(R+\delta\Delta) - \delta I$ and U_B obtains $(1-s)(R+\delta\Delta)$.

• *Timing*. There are three stages:

[41] Specifically, on level-2 U_B believes that a level-1 D expects a level-0 U_A to sabotage with probability 1/2; from level-3 on, U_B believes that a level-$(k-1)$ D expects a level-$(k-2)$ U_A to sabotage with probability 1. In both instances, U_B believes that offering 55% suffices to win.

[42] That is, the joint distribution of q and σ is given by $\Pr(G,g) = \lambda x_H$, $\Pr(B,g) = \lambda(1-x_H)$, $\Pr(G,b) = (1-\lambda)x_L$ and $\Pr(B,b) = (1-\lambda)(1-x_L)$.

- Stage 0: Nature randomly draws the quality $q \in \{G, B\}$ of the outside option and the signal $\sigma \in \{g, b\}$; the former is not observed, whereas the latter is privately observed by D.
- Stage 1: D chooses whether or not to invest; this decision is observed by U_B.
- Stage 2: U_B chooses whether to offer s_L or s_H; having observed the offer, D chooses whether to accept it, or to select the outside option.

We assume that the ratio I/Δ and the shares satisfy:

$$s_H > x_H \hat{s} > I/\Delta > s_L > x_L \hat{s}. \tag{1}$$

That is, investing is profitable for D only if she obtains s_H from U_B, or if she is optimistic and picks the outside option; in addition, U_B can win D's business with s_L when she is pessimistic, otherwise he needs instead to offer her the higher share s_H.

We moreover assume that D is likely to be pessimistic:

$$\lambda < \bar{\lambda} \equiv \frac{s_H - s_L}{1 - s_L}. \tag{2}$$

This rules out a trivial outcome in which U_B always offers s_H and D always invests.

Under these assumptions, D's investment decision indeed signals her belief, which in turn affects U_B's decision:

Proposition 1. *Under Assumptions (1) and (2), there exists a unique equilibrium, in which:*

- *D invests with probability 1 when optimistic, and with probability*

$$y^* \equiv \frac{\lambda\left(1 - s_H\right)}{(1-\lambda)\left(s_H - s_L\right)} \in (0,1) \tag{3}$$

otherwise.

- *U_B offers s_L with probability 1 when D does not invest, and offers s_H with probability*

$$z^* \equiv \frac{I - s_L \Delta}{\left(s_H - s_L\right)(R + \Delta)} \in (0,1) \tag{4}$$

otherwise.

Proof. See Online Appendix D. ■

E.2.2. Insights

The above analysis confirms that introducing the possibility of U_A being reluctant to exert hold-up induces D and U_B to depart from the initially predicted behavior, in such a way that D's investment decision moreover influences U_B's behavior: in equilibrium, D invests with positive probability, in which case U_B responds by offering the higher share s_H with positive probability. This is because D is more likely to invest when she is optimistic about U_A's behavior; hence, when she does invest, U_B expects D to be more likely to be optimistic, which induces him to be more generous. By contrast, when D does not invest, she reveals that she is pessimistic and U_B therefore expects her to accept the lower share.

It can moreover be noted that introducing uncertain social preferences for U_A has no impact under vertical separation, as U_A never engages in sabotage anyway. Likewise, in the Commitment treatment, introducing such a possibility would have no impact under both vertical separation and vertical integration, as the associated uncertainty would be resolved before the other players have to make decisions.

Appendix F. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.euroecorev.2021.103783. The supplementary material includes the Online Appendix, the data and the replication files.

References

Allain, M.-L., Chambolle, C., Rey, P., 2016. Vertical integration as a source of hold-up. Rev. Econom. Stud. 83 (1), 1–25.
Avenel, E., Barlet, C., 2000. Vertical foreclosure, technological choice, and entry on the intermediate market. J. Econ. Manage. Strategy 9 (3), 211–230.
Ball, S.B., Cech, P.-A., 1996. Subject pool choice and treatment effects in economic laboratory research. In: Isaac, M.R. (Ed.), Research in Experimental Economics. JAI Press, Greenwich, C.T., pp. 239–292, (Ch. 6).
Beard, T.R., Kaserman, D.L., Mayo, J.W., 2001. Regulation, vertical integration and sabotage. J. Ind. Econ. 49 (3), 319–333.
Brandts, J., Potters, J., 2018. Experimental industrial organization. In: Corchón, L.C., Marini, M.A. (Eds.), Handbook of Game Theory and Industrial Organization. Edward Elgar Publishing Ltd., pp. 453–474, (Ch. 17).
Camerer, C.F., 2015. The promise and success of lab-field generalizability in experimental economics: A critical reply to levitt and list. In: Fréchette, G.R., Schotter, A. (Eds.), Handbook of Experimental Economic Methodology. Oxford University Press, pp. 249–296, (Ch. 14).
Camerer, C., Ho, T., Chong, J., 2004. A cognitive hierarchy model of games. Q. J. Econ. 119 (3), 861–898.
Camerer, C.F., Weber, R.A., 2013. Experimental organizational economics. In: Gibbons, R., Roberts, J. (Eds.), Handbook of Organizational Economics. Princeton University Press, pp. 213–262, (Ch. 6).

Charness, G., Rabin, M., 2002. Understanding social preferences with simple tests. Q. J. Econ. 117 (3), 817–869.
Choi, J.P., Yi, S.-S., 2000. Vertical foreclosure with the choice of input specifications. Rand J. Econ. 31 (4), 717–743.
Church, J., Gandal, N., 2000. Systems competition, vertical merger, and foreclosure. J. Econ. Manage. Strategy 9 (1), 25–51.
Dohmen, T., Falk, A., Huffman, D., Sunde, U., Schupp, J., Wagner, G., 2005. Individual risk attitudes: New evidence from a large, representative, experimentally-validated survey, DIW Berlin Discussion Paper, 511.
Dufwenberg, M., Smith, A., Van Essen, M., 2013. Hold-up: with a vengeance. Econ. Inq. 51 (1), 896–908.
Ellingsen, T., Johannesson, M., 2004. Is there a hold-up problem? Scand. J. Econ. 106 (3), 475–494.
Falk, A., Fischbacher, U., 2006. A theory of reciprocity. Games Econom. Behav. 54, 293–315.
Falk, A., Heckman, J.J., 2009. Lab experiments are a major source of knowledge in the social sciences. Science 326 (5952), 535–538.
Fischbacher, U., 2007. z-Tree: Zurich toolbox for ready-made economic experiments. Exp. Econ. 10 (2), 171–178.
Fréchette, G.R., 2015. Laboratory experiments: Professionals versus students. In: Fréchette, G.R., Schotter, A. (Eds.), Handbook of Experimental Economic Methodology. Oxford University Press, pp. 360–390, (Ch. 17).
Götte, L., Schmutzler, A., 2009. Merger Policy: what can we learn from experiments? In: Hinloopen, J., Normann, H.-T. (Eds.), Experiments and Competition Policy. Cambridge University Press, pp. 185–216, (Ch. 8).
Grossman, S.J., Hart, O.D., 1986. The costs and benefits of ownership: A theory of vertical and lateral integration. J. Polit. Economy 94 (1), 691–719.
Hart, O., Tirole, J., 1990. Vertical integration and market foreclosure. Brook. Pap. Econ. Act. Microecon. 205–285.
Heinemann, F., Nagel, R., Ockenfels, P., 2009. Measuring strategic uncertaintly in coordination games. Rev. Econom. Stud. 76 (1), 181–221.
Hinloopen, J., Normann, H.-T., 2009. Experiments and Competition Policy. Cambridge University Press.
Hoppe, E.I., Schmitz, P.W., 2011. Can contracts solve the hold-up problem? Experimental evidence. Games Econom. Behav. 73, 186–199.
Klein, B., Crawford, G., Alchian, A., 1978. Vertical integration, appropriable rents, and the competitive contracting process. J. Law Econ. 21 (2), 297–326.
Mandy, D.M., Sappington, D.E.M., 2007. Incentives for sabotage in vertically related industries. J. Regul. Econ. 31 (3), 235–260.
Martin, S., Normann, H., Snyder, C., 2001. Vertical foreclosure in experimental markets. Rand J. Econ. 32 (3), 466–496.
McKelvey, R.D., Palfrey, T.R., 1995. Quantal response equilibria for normal form games. Games Econom. Behav. 10 (1), 6–38.
Nagel, R., 1995. Unraveling in guessing games: An experimental study. Amer. Econ. Rev. 85 (5), 1313–1326.
Normann, H., 2011. Vertical mergers, foreclosure and raising rival's cost-experimental evidence. J. Ind. Econ. 59 (3), 506–527.
Normann, H.-T., Ricciuti, R., 2009. Laboratory experiments for economic policy making. J. Econ. Surv. 23 (3), 407–432.
Ordover, J., Saloner, G., Salop, S., 1990. Equilibrium vertical foreclosure. Amer. Econ. Rev. 80 (1), 127–142.
Plott, C.R., 1982. Industrial organization theory and experimental economics. J. Econ. Lit. 20 (4), 1485–1527.
Plott, C.R., 1989. An updated review of industrial organization: Applications of experimental methods. In: Schmalensee, R., Willig, R. (Eds.), Handbook of Industrial Organization. North-Holland, Amsterdam, pp. 1109–1176, (Ch. 19).
Salinger, M., 1988. Vertical mergers and market foreclosures. Q. J. Econ. 103 (2), 345–356.
Sloof, R., Oosterbeek, H., Sonnemans, J., 2007. Does making specific investments unobservable boost investment incentives? J. Econ. Manage. Strategy 16 (4), 911–942.
Smith, V.L., Suchanek, G.L., Williams, A.W., 1988. Bubbles, crashes, and endogenous expectations in experimental spot asset markets. Econometrica 56 (5), 1119–1151.
Stahl, D.O., 1993. Evolution of smart players. Games Econom. Behav. 5 (4), 604–617.
Van Huyck, J.B., Battalio, R.C., Beil, R.O., 1990. Tacit coordination games, strategic uncertainty, and coordination failure. Amer. Econ. Rev. 80 (1), 234–248.
Williams, R., 2012. Using the margins command to estimate and interpret adjusted predictions and marginal effects. Stata J. 12 (2), 308–331.
Williamson, O., 1975. Markets and Hierarchies: Some Elementary Considerations. Free Press, New York.
Williamson, O., 1985. The Economic Institutions of Capitalism. Free Press, New York.