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Transaction costs and the property rights approach to the theory of the firm

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ABSTRACT

The standard property rights approach is focused on ex ante investment incentives, while there are no transaction costs that might restrain ex post negotiations. We explore the implications of such transaction costs. Prominent conclusions of the property rights theory may be overturned: A party may have stronger investment incentives when a non-investing party is the owner, and joint ownership can be the uniquely optimal ownership structure. Intuitively, an ownership structure that is unattractive in the standard model may now be desirable, because it implies large gains from trade, such that the parties are more inclined to incur the transaction costs.

1. Introduction

Why are integrated firms sometimes more successful than non-integrated firms, while in other instances the opposite holds true? Under which circumstances are joint ventures a recommendable governance structure? In the past three decades, questions along these lines have often been discussed by contract theorists in the context of the property rights approach to the theory of the firm, which has been developed in the pathbreaking contributions by Grossman and Hart (1986), Hart and Moore (1990), and Hart (1995).[1]

Consider a seller (A) and a buyer (B) of an intermediate product. Should the seller own the relevant physical assets that are needed to produce the intermediate good (non-integration) or should the buyer be the owner (integration)? Might joint ownership, such that both parties have veto power over the use of the assets, be a good idea? The property rights approach is focused on the role of non-contractible investments that a party can make in its human capital (say, at some initial date 0). After the investments are sunk, collaboration between the parties becomes contractible and negotiations may occur (we will

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[1] See Segal and Whinston (2012) for a recent literature review. A very crisp summary of the literature is provided by Hart (2011).

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refer to the negotiation phase as date 2). In the standard property rights model it is assumed that once the investments are sunk there are no relevant transaction costs, such that in line with the Coase Theorem negotiations always lead to an ex post efficient agreement. Specifically, the parties divide the attainable surplus from collaboration according to the Nash bargaining solution, where the threatpoint is determined by the ownership structure. Asset ownership improves a party's bargaining position and hence its incentives to invest. Prominent insights of the property rights theory are that (i) if only one party has a relevant investment decision, then this party should be the owner, and (ii) joint asset ownership is never optimal.

In the present paper, we extend the standard property rights model by explicitly taking into account transaction costs that may restrain the parties from reaching an efficient agreement at date 2. Following an insightful paper by Anderlini and Felli (2006), we model transaction costs in the most straightforward way that one might imagine. Specifically, at date 1 both parties simultaneously and independently have to decide whether to incur the relevant transaction costs before the negotiations can take place. The negotiation phase (date 2) is reached only if both parties pay their respective transaction costs.[2] If at least one of the parties decides not to incur its transaction costs such that the negotiations do not start or if the negotiations do not lead to an agreement, then each party gets its default payoff only. It turns out that in the presence of transaction costs, some of the main conclusions of the property rights theory may be overturned. In particular, (i) ownership by the non-investing party and (ii) joint ownership can be optimal.

In the first step, let us assume that there is no investment decision to be made. In line with the standard property rights approach, let the default payoffs depend on the ownership structure as follows. Suppose that the seller is the sole owner (A-ownership). Even if no agreement is reached, the seller can make a positive profit (say, α). Since she owns the necessary assets, she can produce the intermediate good and use it herself to produce a final good. Yet, in the absence of the buyer's human capital (i.e., the buyer's specific abilities to produce the final good), her profit will be smaller than the date-2 surplus that the parties could generate together (which we denote by V). Since the buyer has no access to the necessary assets, he makes zero profits when no agreement is reached. Next, consider sole ownership by the buyer (B-ownership). If no agreement is reached, the buyer can produce the intermediate good himself, because he has access to the assets. Yet, the buyer lacks the seller's specific knowledge, hence the buyer's profit (say, β) will be smaller than the surplus that the parties could realize by collaboration. As the seller has no access to the assets, she makes zero profits. Finally, suppose that there is joint ownership, such that each party has veto power over the use of the assets. Since no party can use the asset without the other parties' consent, in this case the default payoffs of both parties are zero.

If the negotiation stage is reached, suppose that bargaining leads to the regular Nash bargaining solution; i.e., each party gets its default payoff plus half of the gains from trade (where the gains from trade equal the collaboration surplus V minus the sum of the default payoffs). At date 1, a party is willing to incur its transaction costs only if they are smaller than half of the gains from trade. Clearly, if the transaction costs are so large that negotiations will never occur, the optimal ownership structure is the one that leads to the largest sum of the default payoffs. Without loss of generality, let us suppose that $\alpha > \beta$, such that A-ownership is the uniquely optimal ownership structure for large transaction costs. It is now interesting to note that for small transaction costs, B-ownership may be better than A-ownership, and joint ownership may be uniquely optimal. The reason is that the gains from trade are larger in the case of B-ownership (and even more so in the case of joint ownership) than they are in the case of A-ownership, so the parties are actually least inclined to pay their transaction costs in the case of A-ownership. Specifically, the optimality of B-ownership or joint ownership requires that (in the wording of Anderlini and Felli, 2006) there is a 'mismatch' between the distribution of the surplus (50:50 in the case of the regular Nash bargaining solution) and the distribution of the transaction costs (i.e., the two parties must have different transaction costs).[3] Yet, such a 'mismatch' is not a prerequisite for the optimality of B-ownership or joint ownership once we allow for investments.

In our full-fledged model, party A first can decide how much to invest in its human capital (date 0). Following the literature on the property rights approach, we assume that the investment increases the collaboration surplus more than party A's default payoff.[4] After the investment is sunk, each party decides whether to incur its respective transaction cost (date 1). Finally, if both parties have paid their transaction costs, negotiations take place (date 2). In the standard property rights model (i.e., if there were no transaction costs), A-ownership would be the uniquely optimal ownership structure, as it would maximize party A's incentives to invest. Yet, we will show that in the presence of transaction costs, party A's investment may well be larger under B-ownership and under joint ownership. Intuitively, the fact that B-ownership and in particular joint ownership are so unattractive when no agreement is reached implies that paying the transaction costs may be an equilibrium outcome under these ownership structures, even when under A-ownership the negotiation phase would not be reached. Hence, B-ownership and joint ownership may prevent ex post inefficiencies and provide stronger

[2] As discussed in detail by Anderlini and Felli (2006), the transaction costs may be interpreted as the time spent 'preparing' for the negotiations. For instance, the parties need to conceive of a suitable language to describe the states of nature, they must collect information about the legal environment, they need to spend time arranging a way to meet, etc.

[3] The reason is that when both parties have the same transaction costs, under A-ownership both parties can recoup their transaction costs whenever their sum is smaller than $V-\alpha$; i.e., whenever reaching an agreement is efficient. Thus, B-ownership or joint ownership cannot be strictly better than A-ownership, because A-ownership already yields the largest attainable total surplus, regardless of whether or not an agreement is reached.

[4] Specifically, the collaboration surplus now is $V \cdot (1+I)$, while party A's default payoff under A-ownership is $\alpha \cdot (1+I)$, where I is the investment level chosen by party A.

investment incentives for party A. As a consequence, we find that B-ownership may yield a larger total surplus than A-ownership, and joint ownership may turn out to be the uniquely optimal ownership structure.

Empirically, our finding that joint ownership can be uniquely optimal in sustainable relationships when transaction costs are relatively high is in line with the observation that joint ventures are particularly prevalent in the context of complex R&D activities.[5] For instance, in the empirical literature Pisano (1989) reports that firms are more likely to form equity joint ventures when R&D has to be performed in the course of their collaboration (as opposed to other functions such as manufacturing or marketing). Oxley and Sampson (2004) also point out that joint ventures are often observed when alliance objectives require partners to share complex and/or tacit knowledge, especially in technologically innovative projects. Under such circumstances transaction costs are likely to be larger than in more standard situations, where the usual conclusions of the property rights theory hold.[6]

Related literature: Inspired by Coase's (1937) famous article on the nature of the firm, the property rights approach has been devised in the seminal papers by Grossman and Hart (1986) and Hart and Moore (1990), and was synthesized by Hart (1995). The by now standard property rights models have recently been criticized by Tadelis and Williamson (2012) for being too focused on ex ante investment incentives, while in practice mitigating ex post inefficiencies may also be an important role of governance structures. In our model, we explicitly take transaction costs into account and explore the implications of the different ownership structures on the ex post negotiations.[7] Hence, our contribution may help us to somewhat broaden the bridge between the property rights approach and traditional transaction costs economics.[8]

We model transaction costs following Anderlini and Felli (2006).[9] While they do not study ex ante investments, in Section 5 of their paper they also briefly consider the role of property rights. Yet, their model differs from the standard property rights approach to the theory of the firm and they focus their attention on a specific range of parameters (see our detailed discussion at the end of Section 2). Thus, in their framework they find that the ownership structure which leads to the largest sum of the default payoffs (i.e., A-ownership in our setup) is always optimal, provided that the negotiations are modeled by the Nash bargaining solution in the usual way.[10]

The property rights approach has also been criticized because the standard model cannot explain joint ownership. For instance, Holmström (1999) has emphasized that joint ventures have always been an important part of the corporate landscape, and that thus the prediction of the standard property rights model according to which joint ownership is never optimal seems to be counterfactual. Our paper adds to the literature that looks for possible explanations of joint ownership within the property rights paradigm.[11] In particular, the intuition behind our results is somewhat related to Halonen (2002).[12] She considers an infinitely repeated game and argues that joint ownership can be desirable as it may help us to sustain cooperative behavior. Specifically, the fact that joint ownership is suboptimal in a one-shot setting means that it can aggravate punishments for deviations from cooperative behavior (which trigger reversion to the stage-game equilibrium). In contrast, we stay within the usual one-shot setup of the property rights theory and in our model the fact that joint ownership leads to unattractive default payoffs is turned to an advantage because larger gains from trade increase the parties' willingness to incur the transaction costs.

Organization of the paper: The remainder of the paper is organized as follows. In Section 2, the basic model without investments is introduced. In Section 3, our main results are derived in a property rights model with non-contractible investment. Concluding remarks follow in Section 4. All formal proofs have been relegated to the Appendix.

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[5] For an empirical study that confirms the close relationship between the notion of joint ownership in the property rights theory and characteristics of joint ventures in practice, see Gattai and Natale (2013).

[6] See also Oxley (1997), who finds that equity joint ventures are more likely to be observed in the case of product or process design than in the case of production or marketing activities. Emphasizing the substantial investments in the exploration of new technologies and processes, Sampson (2004) also highlights the role of high transaction costs in the context of complex R&D activities (see also Croisier, 1998).

[7] While explicit transaction costs might be the most straightforward way to allow for ex post inefficiencies, there are of course alternatives. For example, Schmitz (2006) and Goldlücke and Schmitz (2014) assume that an agent's default payoff is better known to herself than to the other party, such that negotiations may fail due to asymmetric information. Hart and Moore (2008) and Hart (2009) introduce behavioral assumptions according to which an agent may engage in inefficient shading activities when she is aggrieved (which happens when she does not get what she feels entitled to). See also Herweg and Schmidt (2015) for a model with inefficient renegotiation based on loss aversion.

[8] On the relation between the property rights theory and traditional transaction costs economics, see also Holmström and Roberts (1998), Williamson (2002), and Whinston (2003).

[9] For more general definitions of transaction costs, see Malin and Martimort (2002).

[10] In the property rights approach to the theory of the firm, the parties' default payoffs are usually considered to constitute the threatpoint of the Nash bargaining solution (i.e., the surplus is divided according to the split-the-difference rule). De Meza and Lockwood (1998) and Chiu (1998) consider an alternative way to model the negotiations (the deal-me-out solution, where the default payoffs act as a constraint on the bargaining set). For non-cooperative foundations of the alternative bargaining outcomes, see e.g. Chiu and Yang (1999) and the textbook by Muthoo (1999).

[11] Other explanations of joint ownership include investments in physical capital (Hart, 1995, pp. 68–69), multidimensional investments (Cai, 2003, and Rosenkranz and Schmitz, 2003), and asymmetric information (Schmitz, 2008). See also Gattai and Natale (2015) for a recent literature review.

[12] See also the related work on repeated games by Baker et al. (2002) and Halonen-Akatwijuka and Pafilis (2009).

Table 1
The parties' default payoffs.

	d_A^o	d_B^o
$o=A$	α	0
$o=B$	0	β
$o=J$	0	0

2. The basic model

There are two agents, A and B, who at some future date $t=2$ can agree to collaborate in order to generate a surplus of size $V>0$. In case of negotiations not taking place or no agreement being reached, at date $t=2$ each party $i \in \{A, B\}$ obtains only its default payoff $d_i^o \geq 0$, where $o \in \{A, B, J\}$ denotes the ownership structure. The ownership structure specifies either agent i to be the owner, $o=i \in \{A, B\}$, or joint ownership, $o=J$. In line with the property rights approach to the theory of the firm, we assume that in the case of sole ownership by party A or party B, the owner's default payoff is positive but smaller than V, while the non-owner's default payoff is zero. In the case of joint ownership, each party has veto power such that both parties' default payoffs are zero.[13] The parties' default payoffs under the different ownership structures are summarized in Table 1.[14] We assume that $V>\alpha>\beta>0$.

In case of negotiations taking place and an agreement being reached, the value V is generated. The division of this value between the two agents is determined according to the generalized Nash bargaining solution, where $\lambda \in [0,1]$ and $1-\lambda$ denote agent A's and agent B's bargaining power, respectively. Specifically, suppose that agent B obtains the full value V. Then the transfer T paid from agent B to agent A solves[15]

$$\max_T \, (T-d_A^o)^{\lambda}(V-T-d_B^o)^{1-\lambda}.$$

In consequence, if negotiations lead to an agreement, agent A's payoff is

$$T=d_A^o+\lambda(V-d_A^o-d_B^o)$$

and agent B's payoff is

$$V-T=d_B^o+(1-\lambda)(V-d_A^o-d_B^o).$$

Thus, each agent receives her default payoff plus a share of the gains from trade (i.e., the available surplus over and above the sum of the default payoffs).

For negotiations to take place, however, at date $t=1$ each agent $i \in \{A, B\}$ has to pay a transaction cost $c_i>0$. The agents reach the negotiation stage only if both agents pay their respective transaction costs. We thus model transaction costs in the same way as Anderlini and Felli (2006).

To summarize, the two agents engage in the following two-stage game. At date $t=1$, the agents simultaneously and non-cooperatively decide whether to pay the transaction cost c_A and c_B. At date $t=2$, if both agents have paid their respective transaction costs, the agents can negotiate an agreement that yields a value of V. If an agreement is reached, agent B obtains value V and pays transfer T to agent A. If no agreement is reached at date $t=2$ or if at least one agent did not pay her transaction cost at date $t=1$, then at date $t=2$ agent i receives her default payoff d_i^o. The solution concept is subgame-perfect equilibrium in pure strategies.

Analysis of the model: Suppose that both parties have paid their transaction costs c_i at date $t=1$, such that negotiations take place at date $t=2$. Then an agreement will be reached and party A's payoff is $d_A^o+\lambda(V-d_A^o-d_B^o)-c_A$, while party B's payoff is $d_B^o+(1-\lambda)(V-d_A^o-d_B^o)-c_B$. If at least one party does not pay the transaction costs at date $t=1$, then the negotiations do not take place and each party gets its default payoff at date $t=2$. Hence, at date $t=1$ the two agents play the simultaneous move game shown in Fig. 1.

If an agent does not pay the transaction cost, it is the best response for the other agent also not to pay the transaction cost. Thus, neither agent paying the transaction cost always is an equilibrium of the game. In particular, if some agent i's transaction cost exceeds her share of the gains from trade, i.e., if $c_A>\lambda(V-d_A^o-d_B^o)$ or $c_B>(1-\lambda)(V-d_A^o-d_B^o)$, then the aforementioned equilibrium is the unique equilibrium of the game because not paying c_i is a strictly dominant strategy for agent i. If, on the other hand, $c_A \leq \lambda(V-d_A^o-d_B^o)$ and $c_B \leq (1-\lambda)(V-d_A^o-d_B^o)$, then the game has a second equilibrium in which both agents pay their transaction costs.

Whenever the equilibrium (*pay* c_A, *pay* c_B) exists, it Pareto-dominates the equilibrium (*don't pay* c_A, *don't pay* c_B); i.e., each agent's payoff in the former equilibrium weakly exceeds her default payoff and (except for the knife-edge case where

[13] We thus define joint ownership in the same way as it is usually done in the literature on the property rights approach (see Hart, 1995).

[14] In the Supplementary Material we illustrate that similar insights can also be gained in frameworks with ownership structures in which a party may own only a subset of the assets, so the party has to trade with alternative partners on the market (possibly requiring further transaction costs) when no agreement is reached.

[15] For a comprehensive exposition of bargaining theory, see Muthoo (1999).

	pay c_B	don't pay c_B
pay c_A	$d_A^o + \lambda(V - d_A^o - d_B^o) - c_A$ $d_B^o + (1-\lambda)(V - d_A^o - d_B^o) - c_B$	$d_A^o - c_A$ d_B^o
don't pay c_A	d_A^o $d_B^o - c_B$	d_A^o d_B^o

Fig. 1. The normal-form game played at date $t=1$. Agent A chooses a row, while agent B chooses a column. In each cell, agent A's payoff is displayed above agent B's payoff.

$c_A/\lambda = c_B/(1-\lambda) = V - d_A^o - d_B^o$) at least one of the agents is strictly better off. It is a standard assumption in contract theory that under such circumstances, agents coordinate on the Pareto-superior equilibrium. Thus, whenever it exists, we assume that the equilibrium (*pay* c_A, *pay* c_B) is played.

In particular, in line with Anderlini and Felli (2006), in the remainder of the paper we suppose that the agents coordinate on *Pareto-perfect equilibria*; i.e., we require that in every subgame an equilibrium is played which is not strictly Pareto-dominated by any other equilibrium of the same subgame.[16]

Let the *total surplus* generated under a given ownership structure be denoted by $S(o)$. Whenever the equilibrium (*pay* c_A, *pay* c_B) is played, the total surplus equals the net surplus from reaching an agreement, $V - c_A - c_B$. If, however, for a given ownership structure the equilibrium (*don't pay* c_A, *don't pay* c_B) is the unique equilibrium, then the total surplus equals the sum of the agents' default payoffs in that ownership structure.

Lemma 1. *Consider ownership structure* $o \in \{A, B, J\}$.

(i) *If* $c_A \le \lambda(V - d_A^o - d_B^o)$ *and* $c_B \le (1-\lambda)(V - d_A^o - d_B^o)$, *then* $S(o) = V - c_A - c_B$.
(ii) *If* $c_A > \lambda(V - d_A^o - d_B^o)$ *or* $c_B > (1-\lambda)(V - d_A^o - d_B^o)$, *then* $S(o) = d_A^o + d_B^o$.

An *optimal ownership structure* o^* maximizes the total surplus generated; i.e., $o^* \in \mathcal{O} := \arg\max_{o \in \{A,B,J\}} S(o)$.

With $\alpha > \beta$, the sum of the default payoffs is maximized under A-ownership and in this case equals α. Therefore, whenever $V - c_A - c_B < \alpha$, A-ownership is optimal, which results in the equilibrium (*don't pay* c_A, *don't pay* c_B) and thus payoff d_i^A for agent $i \in \{A, B\}$.

If $V - c_A - c_B \ge \alpha$, then the total surplus would be maximized if each agent pays her respective transaction cost and negotiations take place, in which case an agreement is reached. An agent is willing to incur the transaction cost, however, only if her share of the gains from trade (i.e., the value from agreement minus the sum of default payoffs) exceeds her transaction cost. Noting that the gains from trade are minimal under A-ownership and maximal under joint ownership leads to the following characterization of the optimal ownership structure.

Proposition 1.

(i) *Suppose that* $V - c_A - c_B < \alpha$. *Then* $\mathcal{O} = \{A\}$.
(ii) *Suppose that* $V - c_A - c_B > \alpha$.
(a) *If* $c_A \le \lambda(V-\alpha)$ *and* $c_B \le (1-\lambda)(V-\alpha)$, *then* $\mathcal{O} = \{A, B, J\}$.
(b) *If* $\lambda(V-\alpha) < c_A \le \lambda(V-\beta)$ *or* $(1-\lambda)(V-\alpha) < c_B \le (1-\lambda)(V-\beta)$, *then* $\mathcal{O} = \{B, J\}$.
(c) *If* $\lambda(V-\beta) < c_A \le \lambda V$ *or* $(1-\lambda)(V-\beta) < c_B \le (1-\lambda)V$, *then* $\mathcal{O} = \{J\}$.
(d) *If* $\lambda V < c_A$ *or* $(1-\lambda)V < c_B$, *then* $\mathcal{O} = \{A\}$.

Proof. See the Appendix.

Let us take a closer look at part (ii) of Proposition 1. Note that any ownership structure that leads to both agents paying the transaction costs and thus the maximum surplus $V - c_A - c_B$ to be generated is optimal. If the gains from trade are too small even under joint ownership for one of the agents to recoup her transaction cost, case (d), then this agent will never be willing to pay her transaction cost irrespective of the ownership structure. With negotiations not taking place under any ownership structure, the optimal ownership structure maximizes the sum of the agents' default payoffs. Hence, A-ownership is optimal.

If, on the other hand, both agents can recoup their respective transaction costs even under A-ownership where gains from trade are minimal, case (a), then both agents can recoup the transaction cost also under any other ownership structure. Hence, negotiations will take place and the maximum surplus will be achieved irrespective of the ownership structure, such that all ownership structures are equally efficient.

Regarding cases (b) and (c), from $V - c_A - c_B > \alpha$ it follows that if agent i cannot recoup her transaction cost c_i under some specific ownership structure $\tilde{o}$, then agent $j \ne i$ can recoup her transaction cost c_j under ownership structure $\tilde{o}$ and any

[16] For a detailed discussion of Pareto perfection, see Bernheim et al. (1987) and Benoît and Krishna (1993). Alternatively, as has also been pointed out by Anderlini and Felli (2006), we could modify the timing such that the parties have to pay their transaction costs sequentially (in this case there would be no multiplicity of equilibria and the same results would be obtained as under Pareto perfection).

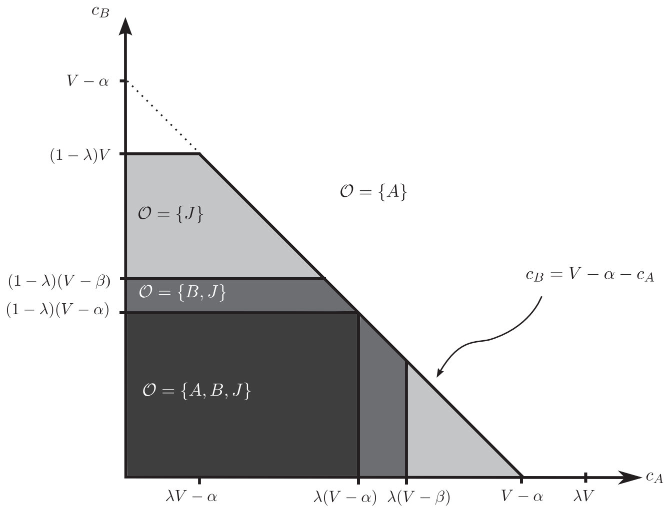

Fig. 2. Optimal ownership structures.

ownership structure that leads to higher gains from trade than $\tilde{o}$. Hence, if some agent cannot cover her transaction cost under A-ownership but under B-ownership (and thus also under joint ownership), case (b), then both B-ownership and joint ownership achieve the maximum surplus and thus are optimal. Likewise, if some agent cannot cover her transaction cost under B-ownership (and thus also not under A-ownership) but under joint ownership, case (c), then only joint ownership achieves the maximum surplus and thus is the uniquely optimal ownership structure.

Proposition 1 is illustrated in Fig. 2.[17] Consider the case in which it would be efficient for the parties to reach an agreement, such that c_B lies below the curve $V-\alpha-c_A$. Anderlini and Felli (2006) have pointed out that if the distribution of the transaction costs is sufficiently 'mis-matched' with the distribution of the surplus (in Fig. 2, this is the case when $c_B>(1-\lambda)V$ and thus $c_A<\lambda V-\alpha$), then negotiations do not take place and the optimal ownership structure maximizes the sum of the default payoffs (in our case, this means that A-ownership is optimal).[18] Yet, what is important to observe is the fact that the ownership structure also matters if c_B is smaller than $(1-\lambda)V$, which has not been studied by Anderlini and Felli (2006). In particular, it is interesting to note that then there are parameter regions where A-ownership is strictly worse than $o=B$ and $o=J$. Intuitively, the gains from trade are larger under $o=B$ than under $o=A$. Hence, the parties are more inclined to incur the transaction costs under B-ownership than under A-ownership. Analogously, the parties are even more willing to incur the transaction costs under joint ownership. For this reason, $o=J$ may be the uniquely optimal ownership structure.

Note that in order for A-ownership to be strictly dominated by $o=B$ or $o=J$, we need a 'mismatch' between the distribution of the transaction costs (c_A, c_B) and the distribution of the surplus which is determined by the parties' bargaining powers (λ, $1-\lambda$). In the symmetric case where $c_A=c_B{=:}c$ and $\lambda=1/2$, Proposition 1(i) implies that A-ownership is optimal for $V-2c<\alpha$, while Proposition 1(ii)(a) implies that all ownership structures are optimal for $V-2c>\alpha$.[19] Thus, in the symmetric case, A-ownership is always optimal.

Corollary 1. *Suppose that $\lambda=1/2$ and $c_A=c_B$. Then $A\in\mathcal{O}$.*

In contrast, in the following section we will demonstrate that even in the symmetric case the presence of transaction costs can have interesting implications for the (sub-)optimality of A-ownership when we take incentives to make non-contractible investments into account.

3. Transaction costs and investment incentives

We now consider a full-fledged property rights model with an ex ante investment stage and explore the implications that the introduction of transaction costs has for the optimal ownership structure. Specifically, let us consider the following extension of our basic model.

Suppose that at date $t=0$ agent A can make a non-contractible investment $I\geq 0$ at cost $K(I)$, where $K(0)=K'(0)=0$, $K'>0$ for $I>0$, $K''>0$, $K'''\geq 0$, and $\lim_{I\to\infty}K'(I)=\infty$. In line with the property rights approach (cf. Hart, 1995), agent A can invest in

[17] In the figure, we depict the case where $\max\{(V-\alpha)/V,\alpha/V\}<\lambda<(V-\alpha)/(V-\beta)$.

[18] Anderlini and Felli (2006) assume that the default payoffs can be freely chosen, provided that they add up to zero. This is somewhat unusual in the property rights approach, where typically an exogenous set of ownership structures is considered. Note that if default payoffs could indeed be negative and freely chosen without the restriction of adding up to zero, the parties could always ensure that negotiations take place and an agreement is reached.

[19] It is straightforward to see that $\mathcal{O}=\{A,B,J\}$ must also hold in the knife-edge case $V-2c=\alpha$.

Table 2
The parties' default payoffs with ex ante investment.

	$d_A^o(I)$	d_B^o
$o=A$	$\alpha(1+I)$	0
$o=B$	0	β
$o=J$	0	0

her human capital. Thus, the effect of the investment is twofold. First, the investment affects the value generated in case of both agents paying the transaction costs and reaching an agreement; i.e., the date-2 surplus in case of collaboration is now given by $V\cdot(1+I)$. Second, the investment also affects agent A's default payoff in case of A-ownership. Formally, $d_A^A(I)=\alpha\cdot(1+I)$ and $d_A^B=d_A^J=0$, where we still assume that $0<\alpha<V$. Thus, in case agent A does not invest at all, i.e., for $I=0$, the value from cooperation and agent A's default payoff equal V and α, respectively, just as in the baseline model without ex ante investment. Agent B's default payoff is unaffected by agent A's investment in her human capital; i.e., $d_B^A=d_B^J=0<\beta=d_B^B$. The default payoffs are summarized in Table 2.

As before, we assume that $\beta<\alpha$, which ensures that if no agreement is reached, $o=A$ maximizes the date-2 total surplus, regardless of the investment level. Moreover, in order to simplify the exposition we also assume that $V>2\alpha$, which means that agent A making the investment leads to a sufficiently large increase in the value of reaching an agreement relative to the increase in agent A's default payoff. As will become clear below, we thus restrict our attention to the most interesting cases with regard to the optimal ownership structure.

In accordance with the property rights approach, the investment decision of agent A becomes observable for agent B between dates $t=0$ and $t=1$.[20] Thereafter, events unfold as in the baseline model. Thus, at date $t=1$ both agents simultaneously and non-cooperatively decide whether to pay their respective transaction costs; if both agents have paid their transactions costs, then at date $t=2$ negotiations take place.

In the absence of transaction costs ($c_A=c_B=0$), we have a standard property rights model in the tradition of Grossman and Hart (1986), in which $o=A$ is the uniquely optimal ownership structure (since agreement is always reached and investment incentives are maximized when agent A's default payoff in the negotiations is as large as possible).[21]

In the remainder of the paper, following most of the literature on the property rights approach,[22] we assume that the negotiations lead to the regular Nash bargaining solution; i.e., both parties have the same bargaining power, $\lambda=1/2$. Moreover, we also assume that both parties have the same transaction costs, $c_A=c_B=:c$. Hence, in the wording of Anderlini and Felli (2006), the distribution of the transaction costs is not 'mis-matched' with the distribution of the surplus. Recall that in the baseline model without investment ($I\equiv 0$), A-ownership is always optimal in this symmetric case (see Corollary 1).[23]

Hence, we have stacked the deck in favor of A-ownership. If either the transaction costs are zero or there is no investment decision to be made, then A-ownership is optimal. As a consequence, when we will find that $o=B$ or $o=J$ is strictly better than $o=A$, then this result must follow from the interplay of the transaction costs with the investment decision.

3.1. Investment incentives

Consider ownership structure $o\in\{A,B,J\}$. Suppose that agent A has invested amount $I\geq 0$ at date $t=0$. In analogy to the baseline model, it is straightforward to see that at date $t=1$ both agents paying the transaction cost c is an equilibrium if and only if $c\leq\frac{1}{2}\left[V(1+I)-d_A^o(I)-d_B^o\right]$ or, equivalently, if and only if agent A's investment is sufficiently high,

$$I\geq\tilde{I}^o:=\frac{2c+d_B^o}{V-\mathbb{I}^o\alpha}-1,$$

where $\mathbb{I}^o$ is an indicator function with

$$\mathbb{I}^o=\begin{cases}1 & \text{if } o=A,\\ 0 & \text{if } o\in\{B,J\}.\end{cases}\tag{1}$$

Thus, if agent A invests below $\tilde{I}^o$, then neither agent will pay the transaction costs and agent A's utility equals her default payoff minus the investment cost,

$$\underline{u}_A^o(I):=\mathbb{I}^o(1+I)\alpha-K(I).$$

If, on the other hand, agent A's investment exceeds $\tilde{I}^o$, then both agents will pay the transaction costs and agent A's utility

[20] In the Supplementary Material we illustrate that our main insights can also be obtained in a model where party B can observe party A's investment only after party B has incurred its transaction costs c_B.

[21] The formal proof of this result is a special case of our analysis below.

[22] See e.g. the seminal work by Grossman and Hart (1986), Hart (1995), and Hart et al. (1997).

[23] It is straightforward to extend our analysis to the case of asymmetric bargaining powers. In the Supplementary Material we show that then joint ownership can yield a larger total surplus than A-ownership even when the transaction costs are small.

equals her default payoff plus half the gains from trade minus the transaction cost minus the investment cost,

$$\overline{u}_A^o(I) := \frac{1}{2}\left[(1+I)(V+\mathbb{I}^o\alpha) - d_B^o\right] - c - K(I).$$

Define

$$\overline{I}^o := \arg\max_{I\geq 0} \overline{u}_A^o(I) = \phi\left(\frac{V+\mathbb{I}^o\alpha}{2}\right) \quad \text{and} \quad \underline{I}^o := \arg\max_{I\geq 0} \underline{u}_A^o(I) = \phi(\mathbb{I}^o\alpha),$$

where $\phi(\cdot) \equiv K'^{-1}(\cdot)$ denotes the inverse of the marginal investment cost function $K'(\cdot)$. One can show that agent A's maximum utility when both agents pay the transaction costs exceeds her maximum utility when neither agent pays the transaction costs if and only if the transaction costs are sufficiently small; i.e., there exists $\tilde{c}^o$ such that $\overline{u}_A^o(\overline{I}^o) \gtreqless \underline{u}_A^o(\underline{I}^o)$ if and only if $c \lesseqgtr \tilde{c}^o$. Furthermore, it can be shown that $c < \tilde{c}^o$ implies $\overline{I}^o > \tilde{I}^o$ and that $c > \tilde{c}^o$ implies $\underline{I}^o < \tilde{I}^o$. Thus, agent A's investment behavior under ownership structure $o \in \{A, B, J\}$ can be characterized as follows.

Lemma 2. *For $o \in \{A, B, J\}$, there exists a threshold $\tilde{c}^o$ such that agent A's optimal level of investment is given by*

$$I^o = \begin{cases} \phi\left(\frac{V+\mathbb{I}^o\alpha}{2}\right) & \text{if } c \leq \tilde{c}^o, \\ \phi(\mathbb{I}^o\alpha) & \text{if } c > \tilde{c}^o. \end{cases}$$

Proof. See the Appendix.

Note that $\phi(0) = 0$, such that $I^B = I^J = 0$; i.e., under ownership structures $o = B$ and $o = J$, if agent A prefers to invest such that transaction costs will not be paid, then he will not invest at all because his default payoff is zero under these ownership structures.

Furthermore, note that $\tilde{c}^B < \tilde{c}^J$ must hold because, intuitively, while agent A's optimal investment is the same for $o = B$ and $o = J$ in case that both agents are willing to pay the transaction costs, the gains from trade generated by this investment are strictly lower under B-ownership (because of agent B's strictly positive default payoff). In consequence, the maximum level of transaction costs being compatible with both agents actually paying these transaction costs is higher under joint ownership than under B-ownership.

3.2. The optimal ownership structure

Under ownership structure $o \in \{A, B, J\}$, if $c \leq \tilde{c}^o$, then the gains from trade given agent A's optimal investment are sufficiently high for both agents to recoup their transaction costs such that the negotiations take place. If $c > \tilde{c}^o$, on the other hand, then the gains from trade under agent A's optimal investment are too low for both agents to recoup their respective transaction costs such that the agents are not willing to pay these transaction costs in the first place.

From Lemma 2 it follows that when our assumptions hold then agent A's investment under an ownership structure under which negotiations take place is always larger than under an ownership structure under which the transaction costs are not paid, $\max_{o \in \{A,B,J\}} \underline{I}^o < \min_{o \in \{A,B,J\}} \overline{I}^o$. Hence, Lemma 2 implies the following result.

Proposition 2.

(i) *If $\max\{\tilde{c}^A, \tilde{c}^B\} < c \leq \tilde{c}^J$, then $I^B < I^A < I^J$.*
(ii) *If $\tilde{c}^A < c \leq \tilde{c}^B$, then $I^A < I^B = I^J$.*
(iii) *Otherwise, $I^B \leq I^J < I^A$.*

To impose somewhat more structure on the analysis of investment incentives under the alternative ownership arrangements, we make the following assumption.

Assumption 1. Let $K(I) = \psi k(I)$ with $\psi > 0$, $k(0) = k'(0) = 0$, $k' > 0$ for $I > 0$, $k'' > 0$, $k''' \geq 0$, and $\lim_{I\to\infty} k'(I) = \infty$.

The following lemma summarizes important characteristics of the thresholds $\tilde{c}^o$, which, given that Assumption 1 holds, are continuous functions of the investment cost parameter ψ; i.e., $\tilde{c}^o = \tilde{c}^o(\psi)$.

Lemma 3. *Suppose Assumption 1 holds.*

(i) *The threshold $\tilde{c}^o(\psi)$ is strictly decreasing in ψ, with $\lim_{\psi\to\infty} \tilde{c}^o(\psi) = (V - d_A^o(0) - d_B^o)/2$, for each $o \in \{A, B, J\}$.*
(ii) *There exist critical values $\tilde{\psi}^{AJ}$ and $\tilde{\psi}^{AB} \geq \tilde{\psi}^{AJ}$ such that $\psi > \tilde{\psi}^{AJ} \Rightarrow \tilde{c}^A(\psi) < \tilde{c}^J(\psi)$ and $\psi > \tilde{\psi}^{AB} \Rightarrow \tilde{c}^A(\psi) < \tilde{c}^B(\psi)$.*

Proof. See the Appendix.

Part (i) of Lemma 3 says that the critical level of transaction costs above which negotiations do not take place decreases in the investment cost parameter ψ. Intuitively, as each unit of the investment becomes more costly, agent A's optimal investment in case that both agents subsequently pay the transaction costs decreases. Since this decrease in investment

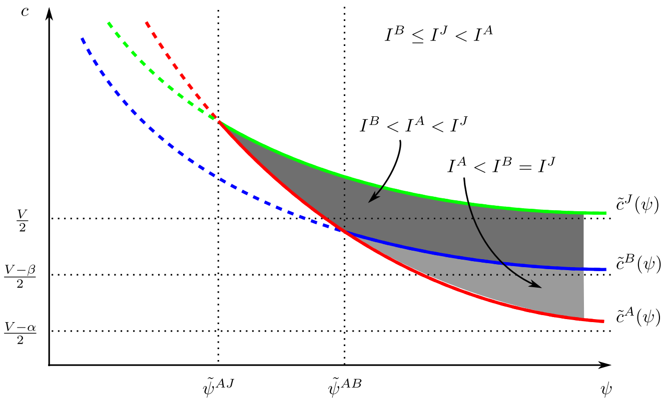

Fig. 3. Optimal investment levels for $K(I) = \psi I^2/2$.

decreases the gains from trade, the maximum level of transaction cost for which both agents are willing to actually pay the transaction costs also decreases.

With regard to part (ii) of Lemma 3, for high values of the investment cost parameter the maximum level of transaction costs for which negotiations take place is lowest under A-ownership. Intuitively, in this case, where investments are very small under any ownership structure, the fact that for a given investment level the gains from trade are larger under B-ownership and maximal under joint ownership overcompensates the stronger incentives to invest under A-ownership.

The critical thresholds $\tilde{c}^o(\psi)$ are illustrated in Fig. 3 as a function of the investment cost parameter ψ for the case of a quadratic investment cost function.[24]

Recall that in the standard property rights model without transaction costs ($c=0$), agent A's investment incentives can never be larger under $o=B$ or $o=J$ than under A-ownership. In contrast, as illustrated in Fig. 3 and in accordance with Proposition 2(ii), when there are positive transaction costs, then B-ownership can induce agent A to choose a larger investment level than she would do under $o=A$. The reason is that for a given investment level the gains from trade are larger under $o=B$ than under $o=A$, such that it may happen that both agents paying the transaction costs is an equilibrium under $o=B$ but not under $o=A$. Similarly, in accordance with Proposition 2(i), it may even be the case that joint ownership leads to a larger investment level than both $o=A$ and $o=B$, because not reaching an agreement is most unattractive under $o=J$, such that the agents may be most willing to incur the transaction costs under joint ownership.

As before, let the total surplus under ownership structure $o \in \{A, B, J\}$ be denoted by $S(o)$. If the transaction costs are sufficiently small such that in equilibrium they are incurred by both agents, then the total surplus equals the value generated by negotiation minus twice the transaction costs minus agent A's investment costs. On the other hand, if the agents do not pay the transaction costs, then the total surplus equals the sum of the agents' default payoffs minus agent A's investment costs. Formally,

$$S(o) = \begin{cases} V(1+I^o) - 2c - K(I^o) & \text{if } c \leq \tilde{c}^o, \\ d_A^o(I^o) + d_B^o - K(I^o) & \text{if } c > \tilde{c}^o. \end{cases}$$

If the transaction costs are rather low and thus paid by both agents irrespective of the ownership structure, i.e. if $c \leq \min\{\tilde{c}^A, \tilde{c}^B\}$, then agent A's optimal investment level is strictly higher under A-ownership than under B-ownership or joint ownership, $I^A > I^J = I^B$. Since the total surplus is a concave function of the investment level and there is always underinvestment with regard to the first-best benchmark,[25] the ownership structure that leads to the largest investment level is optimal. In consequence, A-ownership is the uniquely optimal ownership structure in this case.

Likewise, if transaction costs are relatively high, i.e. if $c > \max\{\tilde{c}^A, \tilde{c}^J\}$, then neither agent pays the transaction costs. While not investing at all under B-ownership or joint ownership, agent A makes a strictly positive investment under A-ownership because of the investment's favorable effect on her default payoff. Thus, A-ownership again provides maximum investment incentives and therefore is the uniquely optimal ownership structure.

As we have seen, however, there may be cases in which the agents are willing to pay the transaction costs under joint ownership (and possibly also under B-ownership) but not under A-ownership, such that agent A no longer makes the largest investment under A-ownership. It thus stands to reason that the optimal ownership structure not necessarily gives ownership to the investing agent A, because joint ownership or B-ownership may avoid ex post inefficiencies and provide stronger investment incentives. Specifically, in these cases $o=A$ is suboptimal if the transaction costs (which are incurred under $o=B$ and $o=J$ only) are not too large, as stated formally in the following result.

[24] Thus, $k(I) = \frac{1}{2}I^2$. In this case, $\tilde{\psi}^{AJ} = \frac{1}{2}(V - \frac{3}{2}\alpha)$ and $\tilde{\psi}^{AB} = \alpha\tilde{\psi}^{AJ}/(\alpha - \beta)$. Furthermore, $\tilde{c}^A(\psi) \gtreqless \tilde{c}^J(\psi)$ if and only if $\psi \lesseqgtr \tilde{\psi}^{AJ}$ and $\tilde{c}^A(\psi) \gtreqless \tilde{c}^B(\psi)$ if and only if $\psi \lesseqgtr \tilde{\psi}^{AB}$. All calculations for the case of a quadratic cost function are provided in the proof of Corollary 2.

[25] The first-best investment level conditional on transaction costs being paid is given by $I^{FB} = \arg\max_{I \geq 0} V(1+I) - 2c - K(I) = \phi(V)$.

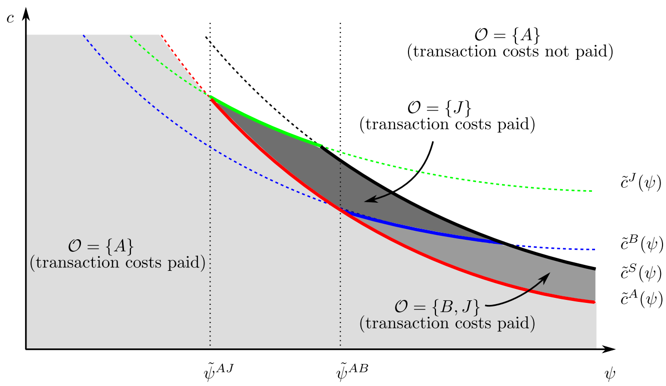

Fig. 4. Optimal ownership with ex ante investment for $K(I) = \psi I^2/2$.

Lemma 4. *Suppose Assumption 1 holds.*

(i) *There exists a threshold $\tilde{c}^S(\psi)$ such that for $\tilde{c}^A(\psi) < c \le \tilde{c}^o(\psi)$ with $o \in \{B, J\}$, we have $S(o) \gtreqless S(A) \iff c \lesseqgtr \tilde{c}^S(\psi)$. The threshold $\tilde{c}^S(\psi)$ is strictly decreasing, with $\lim_{\psi \to \infty} \tilde{c}^S(\psi) = (V - \alpha)/2$.*
(ii) *There exists a critical value $\tilde{\alpha} > 0$ such that for $\alpha < \tilde{\alpha}$ we have $\tilde{c}^A(\psi) < \tilde{c}^S(\psi)$.*

Proof. See the Appendix.

Lemmas 3 and 4 together imply that as long as α is sufficiently small and marginal investment costs are sufficiently high, there always exists an intermediate range of transaction costs for which A-ownership is strictly inferior to B-ownership and joint ownership.

Proposition 3. *Suppose Assumption 1 holds and that $\alpha < \tilde{\alpha}$. For $o \in \{B, J\}$, if $\psi > \tilde{\psi}^{Ao}$, we have $\tilde{c}^A(\psi) < \min\{\tilde{c}^S(\psi), \tilde{c}^o(\psi)\}$ and, thus, $S(o) > S(A)$ for $c \in (\tilde{c}^A(\psi), \min\{\tilde{c}^S(\psi), \tilde{c}^o(\psi)\})$.*

Proof. See the Appendix.

For the case of a quadratic investment cost function, the optimal allocation of ownership in our model with ex ante investment can be fully characterized as follows.

Corollary 2. *Suppose Assumption 1 holds with $k(I) = \frac{1}{2}I^2$. Furthermore, suppose $V > \alpha(2 + \sqrt{2})$.*

(i) *If $\max\{\tilde{c}^A(\psi), \tilde{c}^B(\psi)\} < c < \min\{\tilde{c}^J(\psi), \tilde{c}^S(\psi)\}$ or $\tilde{c}^A < c = \tilde{c}^J < \tilde{c}^S$, then $\mathcal{O} = \{J\}$.*
(ii) *If $\tilde{c}^A(\psi) < c < \min\{\tilde{c}^B(\psi), \tilde{c}^S(\psi)\}$ or $\tilde{c}^A < c = \tilde{c}^B < \tilde{c}^S$, then $\mathcal{O} = \{B, J\}$.*
(iii) *Otherwise, $A \in \mathcal{O}$.*

Proof. See the Appendix.

Corollary 2 is illustrated in Fig. 4. In the standard property rights model without transaction costs ($c = 0$), A-ownership must be optimal, because agreement is always reached and agent A's incentives to invest are larger under $o = A$ than under $o = B$ or $o = J$. Yet, when there are positive transaction costs, then ownership by the non-investing party B may be better than A-ownership. Moreover, joint ownership may be the uniquely optimal ownership structure.

Specifically, if the transaction costs are sufficiently low such that they will be paid under A-ownership, $c \le \tilde{c}^A(\psi)$, then A-ownership also provides maximum investment incentives, $\overline{I}^A > \max\{\overline{I}^J, \overline{I}^B, \underline{I}^J, \underline{I}^B\}$, and is the uniquely optimal ownership structure. Moreover, if the transaction costs are so high such that they will not be paid irrespective of the ownership structure, $c > \max\{\tilde{c}^A(\psi), \tilde{c}^J(\psi)\}$, then A-ownership again provides the highest investment incentives, $\underline{I}^A > \underline{I}^J = \underline{I}^B$, and is thus the uniquely optimal ownership structure.

However, as can be seen in Fig. 4, there are parameter constellations where the transaction costs are paid (i.e., the relationship is sustained) only under joint ownership, $\max\{\tilde{c}^A(\psi), \tilde{c}^B(\psi)\} < c \le \tilde{c}^J(\psi)$. Furthermore, there are parameter constellations where the transaction costs are paid under joint ownership and under B-ownership, but not under A-ownership, $\tilde{c}^A(\psi) < c \le \tilde{c}^B(\psi)$. In the former case, joint ownership provides maximum investment incentives, while in the latter case both joint ownership and B-ownership provide maximum investment incentives, since $\overline{I}^J = \overline{I}^B > \underline{I}^A > \underline{I}^B$. These higher investments translate into higher surplus levels only if the transaction costs are not too high, i.e., for $c < \tilde{c}^S(\psi)$. Hence, the optimal ownership structures are as displayed in Fig. 4.

Intuitively, what makes joint ownership so unattractive in standard property rights models is the fact that when no agreement is reached, each party has veto power so that no surplus is realized. It is precisely this property of joint ownership that can make it attractive in the case of positive transaction costs, because the parties will be more inclined to pay the transaction costs when failing to do so leads to a very undesirable outcome. Since an ex post agreement may thus be reached under joint ownership but not under A-ownership, joint ownership may provide stronger investment incentives and turn out to be the optimal ownership structure.

4. Conclusion

In the past three decades, the property rights approach to the theory of the firm, pioneered by Grossman and Hart (1986), Hart and Moore (1990), and Hart (1995), has become a leading paradigm in institutional and organizational economics. While the property rights approach is sometimes regarded as a formalization of transaction costs economics, its main focus has been on ex ante non-contractible investments, while ex post negotiations are assumed to be without frictions. In the present paper, we have introduced explicit transaction costs in the negotiation stage. It has turned out that the straightforward formalization of transaction costs as proposed by Anderlini and Felli (2006) is very useful to enrich the standard property rights model. Even when we keep the standard assumption of equal bargaining powers and assume that both parties have the same transaction costs (such that in the absence of investment decisions, the ownership structure that maximizes the sum of the parties' default payoffs is always optimal), prominent conclusions of the property rights theory may be overturned. In particular, depending on the magnitude of the transaction costs, ownership by a non-investing party and joint ownership can be optimal. The reason that ownership structures which are suboptimal in standard property rights models can turn out to be optimal in our setup is the fact that under these ownership structures the ex post gains from trade are particularly large, which increases the willingness of the parties to incur the transaction costs in the first place.

While Anderlini and Felli's (2006) concise way of modeling transaction costs fits in nicely with the usual property rights framework that makes use of the Nash bargaining solution, in future research it might also be interesting to explore the role of ownership and transaction costs when the negotiations are modelled by a non-cooperative bargaining game. Specifically, Anderlini and Felli (2001) have introduced transaction costs in an alternating offers bargaining model, and it could be worthwhile to study the implications of different property rights allocations in their setup. Moreover, in the present paper we followed the standard property rights approach by assuming that the parties are symmetrically informed. In future research, we plan to study the role that private information about transaction costs might play.

Finally, while we have shown that the presence of transaction costs can overturn some of the most prominent conclusions of the property rights approach, we would like to emphasize that our findings are in support of what one might consider to be the main insight of the theory developed by Oliver Hart and his coauthors: Ownership matters. Given that in practice model parameters such as the magnitude of transaction costs may be constantly changing, the property rights theory is indeed well in line with the observation that firms "are continually merging and demerging, outsourcing and insourcing" as has been pointed out by Hart (2011, p. 104).

Acknowledgments

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Appendix A

Proof of Proposition 1. (i) Suppose that $V-c_A-c_B<\alpha$ holds. In this case, it cannot be that both conditions $c_A \le \lambda(V-d_A^A-d_B^A)$ and $c_B \le (1-\lambda)(V-d_A^A-d_B^A)$ are satisfied, because this would imply $c_A+c_B \le V-d_A^A-d_B^A = V-\alpha$. Thus, at least one of the parties does not pay the transaction costs and $S(A)=\alpha$ (see Lemma 1). Since $\alpha > \max\{\beta, V-c_A-c_B\}$, ownership by agent A leads to a surplus that is strictly larger than the surplus levels that may be attained under any other ownership structure. Hence, $\mathcal{O}=\{A\}$.

(ii) Suppose that $V-c_A-c_B>\alpha$ holds.

(a) If $c_A \le \lambda(V-\alpha)$ and $c_B \le (1-\lambda)(V-\alpha)$, then both conditions $c_A \le \lambda(V-d_A^o-d_B^o)$ and $c_B \le (1-\lambda)(V-d_A^o-d_B^o)$ are satisfied for all $o \in \{A,B,J\}$. Thus, both parties pay the transaction costs and the total surplus is $V-c_A-c_B$ under each ownership structure (see Lemma 1). Hence, $\mathcal{O}=\{A,B,J\}$.

(b) Suppose $\lambda(V-\alpha)<c_A \le \lambda(V-\beta)$. In this case, $c_B < V-\alpha-c_A<(1-\lambda)(V-\alpha)$ must be true. Party A does not pay the transaction costs under A-ownership since $c_A > \lambda(V-d_A^A-d_B^A)$, hence $S(A)=\alpha$. However, $c_A \le \lambda(V-d_A^o-d_B^o)$ and $c_B<(1-\lambda)(V-d_A^o-d_B^o)$ hold for $o\in\{B,J\}$, so both parties pay the transaction costs under B-ownership and joint ownership. Therefore, $S(B)=S(J)=V-c_A-c_B$ and $\mathcal{O}=\{B,J\}$. Analogous arguments can be made in the case $(1-\lambda)(V-\alpha)<c_B\le(1-\lambda)(V-\beta)$.

(c) Suppose $\lambda(V-\beta)<c_A\le\lambda V$. In this case, $c_B<V-\alpha-c_A<(1-\lambda)V$ must hold. Observe that $c_A>\lambda(V-d_A^o-d_B^o)$ for $o\in\{A,B\}$, hence party A does not pay the transaction costs under these ownership structures. Thus, $S(A)=\alpha$ and $S(B)=\beta$. Yet, both parties pay their transaction costs under joint ownership, because $c_A \leq \lambda(V-d_A^J-d_B^J)$ and $c_B \leq (1-\lambda)(V-d_A^J-d_B^J)$. As a consequence, $S(J)=V-c_A-c_B$ and hence $\mathcal{O}=\{J\}$. Analogous arguments can be made in the case $(1-\lambda)(V-\beta)<c_B \leq (1-\lambda)V$.

(d) If $\lambda V < c_A$, then party A will not pay the transaction costs regardless of the ownership structure, because $c_A > \lambda(V-d_A^o-d_B^o)$ for all $o \in \{A,B,J\}$. Similarly, if $(1-\lambda)V<c_B$, then party B will not pay the transaction costs. Hence, $S(A)=\alpha$, $S(B)=\beta$, and $S(J)=0$. As a result, $\mathcal{O}=\{A\}$.□

Proof of Lemma 2. *A-ownership*. With $\mathbb{I}^A=1$, we have $\overline{u}_A^A(I)=\frac{1}{2}(1+I)(V+\alpha)-c-K(I)$ and $\underline{u}_A^A(I)=(1+I)\alpha-K(I)$. Both $\overline{u}_A^A(I)$ and $\underline{u}_A^A(I)$ are strictly concave functions of agent A's investment I; i.e., $\partial^2\overline{u}_A^A(I)/\partial I^2=\partial^2\underline{u}_A^A(I)/\partial I^2=-K''(I)<0$. Furthermore, the slope of $\overline{u}_A^A(I)$ is strictly larger than the slope of $\underline{u}_A^A(I)$ for each investment level; i.e., $\partial\overline{u}_A^A(I)/\partial I=\frac{V+\alpha}{2}-K'(I)>\alpha-K'(I)=\partial\underline{u}_A^A(I)/\partial I$. With $\partial\underline{u}_A^A(I)/\partial I|_{I=0}>0$, the level of investment $\underline{I}^A$ that globally maximizes $\underline{u}_A^A(I)$ is determined by the first-order condition $\partial\underline{u}_A^A(\underline{I}^A)/\partial I=0$ and is given by

$$K'(\underline{I}^A)=\alpha \iff \underline{I}^A=\phi(\alpha). \tag{2}$$

Likewise, the level of investment $\overline{I}^A$ that globally maximizes $\overline{u}_A^A(I)$ is determined by the first-order condition $\partial\overline{u}_A^A(\overline{I}^A)/\partial I=0$ and is given by

$$K'\left(\overline{I}^A\right)=\frac{V+\alpha}{2} \iff \overline{I}^A=\phi\left(\frac{V+\alpha}{2}\right). \tag{3}$$

Note that $\overline{I}^A>\underline{I}^A$ as $\phi'>0$.

First, suppose that $c\leq\frac{V-\alpha}{2}$. In this case, $\tilde{I}^A:=\frac{2c}{V-\alpha}-1\leq 0$ such that—as outlined in the text—both agents are willing to pay the transaction costs irrespective of agent A's investment. Hence, agent A chooses his investment to maximize $\overline{u}_A^A(I)$; i.e., for $c\leq\frac{V-\alpha}{2}$, agent A's optimal investment is $I^A=\overline{I}^A$.

Next, suppose that $c>\frac{V-\alpha}{2}$, such that $\tilde{I}^A>0$. As outlined in the text, both agents pay the transaction cost c if $I\geq\tilde{I}^A$. If $I<\tilde{I}^A$, on the other hand, neither agent pays the transaction cost c. Observe that

$$\overline{u}_A^A\left(\overline{I}^A\right)\gtreqless\underline{u}_A^A\left(\underline{I}^A\right) \iff c\lesseqgtr\tilde{c}^A:=\frac{V-\alpha}{2}+\Gamma\left(\frac{V+\alpha}{2}\right)-\Gamma(\alpha), \tag{4}$$

where $\Gamma(x)\equiv\phi(x)x-K(\phi(x))$ with $\Gamma'(x)=\phi(x)>0$. Furthermore,

$$\tilde{I}^A>\underline{I}^A \iff c>\underline{c}^A:=\frac{V-\alpha}{2}+\frac{V-\alpha}{2}\phi(\alpha) \tag{5}$$

and

$$\tilde{I}^A<\overline{I}^A \iff c<\overline{c}^A:=\frac{V-\alpha}{2}+\frac{V-\alpha}{2}\phi\left(\frac{V+\alpha}{2}\right). \tag{6}$$

Comparison of $\underline{c}^A$ and $\tilde{c}^A$ reveals that

$$\underline{c}^A<\tilde{c}^A \iff \frac{V+\alpha}{2}>\frac{K(\overline{I}^A)-K(\underline{I}^A)}{\overline{I}^A-\underline{I}^A}, \tag{7}$$

where the latter inequality holds by strict convexity of $K(\cdot)$ together with $K'\left(\overline{I}^A\right)=\frac{V+\alpha}{2}$. Likewise, comparison of $\overline{c}^A$ and $\tilde{c}^A$ shows that

$$\overline{c}^A>\tilde{c}^A \iff \alpha<\frac{K(\overline{I}^A)-K(\underline{I}^A)}{\overline{I}^A-\underline{I}^A}, \tag{8}$$

where the latter inequality holds by strict convexity of $K(\cdot)$ together with $K'(\underline{I}^A)=\alpha$. Thus, $\underline{c}^A<\tilde{c}^A<\overline{c}^A$. Hence, if $c\leq\tilde{c}^A$ and agent A invests $\overline{I}^A$, then $\overline{I}^A>\tilde{I}^A$ such that both agents pay the transaction cost and agent A obtains his largest possible utility $\overline{u}_A^A(\overline{I}^A)$. If $c>\tilde{c}^A$ and agent A invests $\underline{I}^A$, then $\underline{I}^A<\tilde{I}^A$ such that neither agent pays the transaction cost and agent A obtains his largest possible utility $\underline{u}_A^A(\underline{I}^A)$. Overall, agent A's optimal investment is $I^A=\overline{I}^A$ if $\frac{V-\alpha}{2}<c\leq\tilde{c}^A$ and $I^A=\underline{I}^A$ if $c>\tilde{c}^A$.

B-ownership: With $\mathbb{I}^A=0$, we have $\overline{u}_A^B(I)=\frac{1}{2}[(1+I)V-\beta]-c-K(I)$ and $\underline{u}_A^B(I)=-K(I)$. Both $\overline{u}_A^B(I)$ and $\underline{u}_A^B(I)$ are strictly concave functions of agent A's investment I. Furthermore, the slope of $\overline{u}_A^B(I)$ is larger for each investment level than the slope of $\underline{u}_A^B(I)$. With $\partial\underline{u}_A^B(I)/\partial I|_{I=0}=0$, the level of investment $\underline{I}^B$ that globally maximizes $\underline{u}_A^B(I)$ is equal to zero, $\underline{I}^B=0$. The level of investment $\overline{I}^B$ that globally maximizes $\overline{u}_A^B(I)$, on the other hand, is strictly positive and determined by the first-order condition $\partial \overline{u}_A^B(\overline{I}^B)/\partial I = 0$. Hence,

$$K'\left(\overline{I}^B\right) = \frac{V}{2} \iff \overline{I}^B = \phi\left(\frac{V}{2}\right). \tag{9}$$

First, suppose that $c \le \frac{V-\beta}{2}$. In this case, $\tilde{I}^B := \frac{2c+\beta}{V} - 1 \le 0$ such that both agents are willing to pay the transaction cost irrespective of agent A's investment. Hence, agent A maximizes $\overline{u}_A^B(I)$; i.e., for $c \le \frac{V-\beta}{2}$, agent A's optimal investment is $I^B = \overline{I}^B$.

Next, suppose that $c > \frac{V-\beta}{2}$, such that $\tilde{I}^B > 0$. As outlined in the text, both agents pay the transaction cost c if $I \ge \tilde{I}^B$. If $I < \tilde{I}^B$, on the other hand, neither agent pays the transaction cost c. Observe that

$$\overline{u}_A^B\left(\overline{I}^B\right) \gtreqless \underline{u}_A^B\left(\underline{I}^B\right) \iff c \lesseqgtr \tilde{c}^B := \frac{V-\beta}{2} + \Gamma\left(\frac{V}{2}\right). \tag{10}$$

Furthermore,

$$\tilde{I}^B > \underline{I}^B \iff c > \underline{c}^B := \frac{V-\beta}{2} \tag{11}$$

and

$$\tilde{I}^B < \overline{I}^B \iff c < \overline{c}^B := \frac{V-\beta}{2} + \frac{V}{2}\phi\left(\frac{V}{2}\right). \tag{12}$$

Comparison of $\overline{c}^B$ and $\tilde{c}^B$ reveals that

$$\overline{c}^B > \tilde{c}^B \iff -K(\overline{I}^B) < 0. \tag{13}$$

Likewise, comparison of $\underline{c}^B$ and $\tilde{c}^B$ shows that

$$\underline{c}^B < \tilde{c}^B \iff \Gamma\left(\frac{V}{2}\right) = \frac{V}{2}\overline{I}^B - K\left(\overline{I}^B\right) > 0, \tag{14}$$

where the last inequality holds because $\overline{I}^B = \arg\max_{I \ge 0} \frac{V}{2}I - K(I)$ and $K(0) = 0$. Thus, $\underline{c}^B < \tilde{c}^B < \overline{c}^B$. Hence, if $c \le \tilde{c}^B$ and agent A invests $\overline{I}^B$, then $\overline{I}^B > \tilde{I}^B$ such that both agents pay the transaction cost and agent A obtains his largest possible utility $\overline{u}_A^B(\overline{I}^B)$. If $c > \tilde{c}^B$ and agent A invests $\underline{I}^B$, then $\underline{I}^B < \tilde{I}^B$ such that neither agent pays the transaction cost and agent A obtains his largest possible utility $\underline{u}_A^B(\underline{I}^B)$. Overall, agent A's optimal investment is $I^B = \overline{I}^B$ if $\frac{V-\beta}{2} < c \le \tilde{c}^B$ and $I^B = \underline{I}^B$ if $c > \tilde{c}^B$.

Joint ownership: The proof for $o=J$ follows in analogy to the proof for $o=B$, with $\beta \equiv 0$. Note that $\tilde{c}^J := \frac{V}{2} + \Gamma\left(\frac{V}{2}\right)$, which, compared to (10), reveals that $\tilde{c}^J > \tilde{c}^B$.□

Proof of Lemma 3. (i) Denote by $\theta(\cdot) = k'^{-1}(\cdot)$ the inverse function of $k'(\cdot)$, where $\theta(0) = 0$, $\theta' > 0$ and $\theta'' \le 0$. Then $\phi(x) = K'^{-1}(x) = \theta\left(\frac{x}{\psi}\right)$. Differentiation of the threshold

$$\tilde{c}^A(\psi) = \frac{V-\alpha}{2} + \left[\theta\left(\frac{V+\alpha}{2\psi}\right)\frac{V+\alpha}{2} - \psi k\left(\theta\left(\frac{V+\alpha}{2\psi}\right)\right)\right] - \left[\theta\left(\frac{\alpha}{\psi}\right)\alpha - \psi k\left(\theta\left(\frac{\alpha}{\psi}\right)\right)\right] \tag{15}$$

with respect to ψ yields

$$\frac{d\tilde{c}^A(\psi)}{d\psi} = -\left[k\left(\theta\left(\frac{V+\alpha}{2\psi}\right)\right) - k\left(\theta\left(\frac{\alpha}{\psi}\right)\right)\right] < 0, \tag{16}$$

where we made use of the fact that $k'(\theta(x)) = x$. Similarly, differentiation of

$$\tilde{c}^B(\psi) = \frac{V-\beta}{2} + \theta\left(\frac{V}{2\psi}\right)\frac{V}{2} - \psi k\left(\theta\left(\frac{V}{2\psi}\right)\right) \tag{17}$$

and

$$\tilde{c}^J(\psi) = \frac{V}{2} + \theta\left(\frac{V}{2\psi}\right)\frac{V}{2} - \psi k\left(\theta\left(\frac{V}{2\psi}\right)\right) \tag{18}$$

yields

$$\frac{d\tilde{c}^B(\psi)}{d\psi} = \frac{d\tilde{c}^J(\psi)}{d\psi} = -k\left(\theta\left(\frac{V}{2\psi}\right)\right) < 0. \tag{19}$$

The statement regarding the respective limit of the thresholds $\tilde{c}^A(\psi)$, $\tilde{c}^B(\psi)$, and $\tilde{c}^J(\psi)$ as $\psi \to \infty$ follows from (15), (17), and

(18) together with $k(0)=0$ and $\lim_{x\to 0}\theta(x)=0$: With

$$\psi k\left(\theta\left(\frac{z}{\psi}\right)\right)=\frac{k\left(\theta\left(\frac{z}{\psi}\right)\right)}{\frac{1}{\psi}}, \tag{20}$$

application of L'Hôpital's rule yields

$$\lim_{\psi\to\infty}\psi k\left(\theta\left(\frac{z}{\psi}\right)\right)=\lim_{\psi\to\infty}\frac{\frac{z}{\psi}\theta'\left(\frac{z}{\psi}\right)\left(-\frac{z}{\psi^2}\right)}{-\frac{1}{\psi^2}}=\lim_{\psi\to\infty}\frac{z^2}{\psi}\theta'\left(\frac{z}{\psi}\right)=0, \tag{21}$$

where we made use of the fact that $\lim_{x\to 0}\theta'(x)$ is bounded above because $k''(0)>0$ by assumption.

(ii) The existence of $\tilde{\psi}^{AJ}$ and $\tilde{\psi}^{AB}$ follows from the statement in part (i) regarding the limits of $\tilde{c}^A(\psi)$, $\tilde{c}^B(\psi)$, and $\tilde{c}^J(\psi)$ as $\psi\to\infty$. Finally, $\tilde{\psi}^{AJ}\le\tilde{\psi}^{AB}$ follows from $\tilde{c}^B(\psi)<\tilde{c}^J(\psi)$.□

Proof of Lemma 4. (i) If $\tilde{c}^A(\psi)<c\le\tilde{c}^o(\psi)$ with $o\in\{B,J\}$, then $S(A)=\alpha(1+\underline{I}^A)-K(\underline{I}^A)$, whereas $S(o)=V(1+\bar{I}^o)-2c-K(\bar{I}^o)$ for $o\in\{B,J\}$. Recall that $\underline{I}^A=\theta\left(\frac{\alpha}{\psi}\right)$ and $\bar{I}^o=\theta\left(\frac{V}{2\psi}\right)$ for $o\in\{B,J\}$. It follows that $S(o)\gtreqless S(A)$ if and only if $c\lesseqgtr\tilde{c}^S(\psi)$, where

$$\tilde{c}^S(\psi):=\frac{V-\alpha}{2}+\frac{1}{2}\left[\theta\left(\frac{V}{2\psi}\right)V-\psi k\left(\theta\left(\frac{V}{2\psi}\right)\right)\right]-\frac{1}{2}\left[\theta\left(\frac{\alpha}{\psi}\right)\alpha-\psi k\left(\theta\left(\frac{\alpha}{\psi}\right)\right)\right]. \tag{22}$$

Differentiation with respect to ψ yields

$$\frac{d\tilde{c}^S(\psi)}{d\psi}=-\frac{1}{2}\left[k\left(\theta\left(\frac{V}{2\psi}\right)\right)-k\left(\theta\left(\frac{\alpha}{\psi}\right)\right)+\theta'\left(\frac{V}{2\psi}\right)\frac{V^2}{4\psi^2}\right]<0. \tag{23}$$

Finally, the statement regarding the limit of $\tilde{c}^S(\psi)$ as $\psi\to\infty$ follows from $k(0)=0$, $\lim_{x\to 0}\theta(x)=0$, and application of L'Hôpital's rule.

(ii) With

$$\tilde{c}^A(\psi):=\frac{V-\alpha}{2}+\Gamma\left(\frac{V+\alpha}{2}\right)-\Gamma(\alpha) \tag{24}$$

and

$$\tilde{c}^S(\psi):=\frac{V-\alpha}{2}+\Gamma\left(\frac{V}{2}\right)+\frac{1}{2}\psi k\left(\theta\left(\frac{V}{2\psi}\right)\right)-\frac{1}{2}\Gamma(\alpha), \tag{25}$$

we have $\tilde{c}^A(\psi)<\tilde{c}^S(\psi)$ if and only if

$$\frac{1}{2}\psi k\left(\theta\left(\frac{V}{2\psi}\right)\right)>\Gamma\left(\frac{V+\alpha}{2}\right)-\Gamma\left(\frac{V}{2}\right)-\frac{1}{2}\Gamma(\alpha)=:\Omega(\alpha). \tag{26}$$

Remember that $\Gamma(x)=\phi(x)x-K(\phi(x))$ with $\phi=K'^{-1}$ and, hence, $\Gamma(0)=0$. Thus, $\lim_{\alpha\to 0}\Omega(\alpha)=0$. Since $\frac{1}{2}\psi k\left(\theta\left(\frac{V}{2\psi}\right)\right)>0$, this implies existence of a critical threshold $\tilde{\alpha}>0$ such that (26) is satisfied if $\alpha<\tilde{\alpha}$.□

Proof of Proposition 3. For $o\in\{B,J\}$, if $\psi>\psi^{Ao}$, then $\tilde{c}^A(\psi)<\tilde{c}^o(\psi)$—by Lemma 3(ii). Furthermore, $\tilde{c}^A(\psi)<\tilde{c}^S(\psi)$ for $\alpha<\tilde{\alpha}$—by Lemma 4(ii). Together these observations imply that the set $\mathcal{C}^o(\psi):=\{c|\tilde{c}^A(\psi)<c<\min\{\tilde{c}^o(\psi),\tilde{c}^S(\psi)\}\}$ is not empty if $\psi>\psi^{Ao}$ and $\alpha<\tilde{\alpha}$. Lemma 4(i) then yields that $S(o)>S(A)$ for all $c\in\mathcal{C}^o(\psi)$.□

Proof of Corollary 2. First, note that for a quadratic investment cost function we have

$$\underline{I}^A=\frac{\alpha}{\psi},\quad \bar{I}^A=\frac{V+\alpha}{2\psi},$$
$$\underline{I}^B=0,\quad \bar{I}^B=\frac{V}{2\psi},$$
$$\underline{I}^J=0,\quad \bar{I}^J=\frac{V}{2\psi},$$

and

$$\tilde{c}^A(\psi)=\frac{V-\alpha}{2}+\frac{(V-\alpha)(V+3\alpha)}{8\psi}, \tag{27}$$

$$\tilde{c}^B(\psi)=\frac{V-\beta}{2}+\frac{V^2}{8\psi}, \tag{28}$$

$$\tilde{c}^J(\psi) = \frac{V}{2} + \frac{V^2}{8\psi}. \tag{29}$$

Note that $\partial\tilde{c}^o(\psi)/\partial\psi < 0$ and $\partial^2\tilde{c}^o(\psi)/\partial\psi^2 > 0$ for all $o \in \{A, B, J\}$. Also note that $\tilde{c}^A(\psi)$ intersects exactly once with $\tilde{c}^J(\psi)$ and $\tilde{c}^B(\psi)$, respectively:

$$\tilde{c}^A(\psi) \lesseqqgtr \tilde{c}^J(\psi) \iff \psi \gtreqqless \tilde{\psi}^{AJ} := \frac{1}{2}\left(V - \frac{3}{2}\alpha\right) \tag{30}$$

and

$$\tilde{c}^A(\psi) \lesseqqgtr \tilde{c}^B(\psi) \iff \psi \gtreqqless \tilde{\psi}^{AB} := \frac{\alpha}{\alpha-\beta}\tilde{\psi}^{AJ}. \tag{31}$$

These observations are depicted in Fig. 3.

Next, let us derive the total surplus for the different ownership structures given agent A's optimal investment behavior:

$$S(A) = \begin{cases} V\left(1 + \frac{V+\alpha}{2\psi}\right) - 2c - \frac{\psi}{2}\left(\frac{V+\alpha}{2\psi}\right)^2 & \text{if } c \le \tilde{c}^A(\psi) \\ \alpha\left(1 + \frac{\alpha}{\psi}\right) - \frac{\psi}{2}\left(\frac{\alpha}{\psi}\right)^2 & \text{if } c > \tilde{c}^A(\psi) \end{cases} \tag{32}$$

$$S(B) = \begin{cases} V\left(1 + \frac{V}{2\psi}\right) - 2c - \frac{\psi}{2}\left(\frac{V}{2\psi}\right)^2 & \text{if } c \le \tilde{c}^B(\psi) \\ \beta & \text{if } c > \tilde{c}^B(\psi) \end{cases} \tag{33}$$

$$S(J) = \begin{cases} V\left(1 + \frac{V}{2\psi}\right) - 2c - \frac{\psi}{2}\left(\frac{V}{2\psi}\right)^2 & \text{if } c \le \tilde{c}^J(\psi) \\ 0 & \text{if } c > \tilde{c}^J(\psi) \end{cases} \tag{34}$$

First, suppose that $c \le \tilde{c}^A(\psi)$ such that both agents pay the transaction cost under A-ownership. If $c \le \tilde{c}^o(\psi)$, where $o \in \{J, B\}$, then both agents pay the transaction cost also under o-ownership. Comparison of the upper line in (32) with the upper line in (33) or (34) shows that $S(A) > S(o)$ holds as $V > \frac{\alpha}{2}$ by assumption. If, on the other hand, $c > \tilde{c}^o(\psi)$, where $o \in \{J, B\}$, then c is paid under A-ownership but not under o-ownership. Comparison of the upper line in (32) with the lower lines in (33) and (34) yields

$$S(A) > S(B) \iff c < \tilde{c}^A(\psi) + \frac{\alpha-\beta}{2} + \frac{V(V-2\alpha)+5\alpha^2}{16\psi} \tag{35}$$

and

$$S(A) > S(J) \iff c < \tilde{c}^A(\psi) + \frac{\alpha}{2} + \frac{V(V-2\alpha)+5\alpha^2}{16\psi}. \tag{36}$$

As $c \le \tilde{c}^A(\psi)$ by hypothesis, these two conditions are always satisfied under our assumptions. Thus, whenever c is paid for A-ownership but not for o-ownership, where $o \in \{B, J\}$, the total surplus is higher under A-ownership than under o-ownership. Overall, we thus have $S(A) > S(o)$, where $o \in \{B, J\}$, whenever $c \le \tilde{c}^A(\psi)$.

Second, suppose $c > \max\{\tilde{c}^A(\psi), \tilde{c}^J(\psi)\}$, such that c is not paid irrespective of the ownership structure. Comparison of the lower line in (32) with the lower lines in (33) and (34) shows that $S(A) > S(B) > S(J)$ holds, because $\frac{1}{2\psi}\alpha^2 + \alpha > \beta > 0$.

Finally, suppose that $\tilde{c}^A(\psi) < c \le \tilde{c}^o(\psi)$, such that c is paid under $o \in \{B, J\}$ but not under $o = A$. Then

$$S(o) \gtreqqless S(A) \iff c \lesseqqgtr \tilde{c}^S(\psi) = \frac{V-\alpha}{2} + \frac{3V^2 - 4\alpha^2}{16\psi}, \tag{37}$$

where $\partial\tilde{c}^S(\psi)/\partial\psi < 0$ and $\partial^2\tilde{c}^S(\psi)/\partial\psi^2 > 0$. Furthermore, with $V > \alpha(2+\sqrt{2})$ by assumption, we have $\tilde{c}^S(\psi) > \tilde{c}^A(\psi)$. Finally, $\tilde{c}^{SA}(\psi)$ intersects exactly once with $\tilde{c}^J(\psi)$ and $\tilde{c}^B(\psi)$, respectively:

$$\tilde{c}^S(\psi) \gtreqqless \tilde{c}^J(\psi) \iff \psi \lesseqqgtr \tilde{\psi}^{SJ} := \frac{V^2 - 4\alpha^2}{8\alpha} \tag{38}$$

and

$$\tilde{c}^S(\psi) \gtreqqless \tilde{c}^B(\psi) \iff \psi \lesseqqgtr \tilde{\psi}^{SB} := \frac{\alpha}{\alpha-\beta}\tilde{\psi}^{SJ}, \tag{39}$$

where, with $V > \alpha(2+\sqrt{2})$, we have $\tilde{\psi}^{AJ} < \tilde{\psi}^{SJ}$ and $\tilde{\psi}^{AB} < \tilde{\psi}^{SB}$. These observations are depicted in Fig. 4.

It then follows that the sets $\mathcal{C}^J := \{(c,\psi) | \max\{\tilde{c}^A(\psi), \tilde{c}^B(\psi)\} < c < \min\{\tilde{c}^J(\psi), \tilde{c}^S(\psi)\}\}$ and $\mathcal{C}^{BJ} := \{(c,\psi) | \tilde{c}^A(\psi) < c < \min\{\tilde{c}^B(\psi), \tilde{c}^S(\psi)\}\}$ are not empty. The proof then is completed by the following observations: for $c \in \mathcal{C}^J$

or $c=\tilde{c}^J(\psi)\in(\tilde{c}^A(\psi),\tilde{c}^S(\psi))$, we have $S(J)>S(A)>S(B)$; for $c\in\mathcal{C}^{BJ}$ or $c=\tilde{c}^B(\psi)\in(\tilde{c}^A(\psi),\tilde{c}^S(\psi))$, we have $S(J)=S(B)>S(A)$; for $c\in[\tilde{c}^S(\psi),\tilde{c}^J(\psi)]$, $S(A)\geq\max\{S(J),S(B)\}$.□

Appendix B. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.euroecorev.2016.04.013.

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