Organizational Design, Technology and the Boundaries of the Firm

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Abstract

Focus – specialization and specific technology – improves productivity but leads to more dependency and opens a door for holdup problems. We analyze how organizational design and the choice of technology interact with the allocation of ownership in minimizing the holdup problem. We find a novel motive for job rotation: rotation reduces holdup problems in an integrated firm. We also show that holdup problem in specific *physical* capital is removed in the integrated firm while holdups in specific *human* capital remain. Furthermore, ownership gives incentives to focus human capital on the firm.

JEL classification: D23, L22

1 Introduction

In the property rights theory of the firm ownership is the only instrument used to minimize the holdup problems in specific human capital. In Grossman and Hart (1986) and Hart and Moore (1990) ownership gives power and power improves incentives. While with reputation effects (Baker, Gibbons and Murphy (2002) and Halonen (2002)) or applying a different bargaining model (Chiu (1998) and De Meza and Lockwood (1998)) ownership can demotivate.

The point of this paper is that, in addition to ownership, organizational design can affect the holdups. When the agents specialize, they become indispensable because nobody else can perform their task. That gives holdup power to the agents. If the holdup problems are too great, it is better for the agents to rotate between tasks. Rotation removes the holdup power of the specialized agent because other agents are able to perform the same task. That is the benefit of rotation. Rotation also makes the agents less productive for a given investment in human capital because they are unfocused.[1] This is the cost of rotation. Organizational design and ownership interact in interesting ways in our model as illustrated in the following example.

Consider an IT firm with two programmers, 1 and 2. A typical project of developing a programme consists of two tasks: algorithmic design (task A) and graphic design (task B). Programmer 1 can specialize in one task, say algorithmic design, and learn the skills to develop the algorithms that run the programme. Alternatively he can learn the skills to complete the whole project, algorithmic and graphic design, on his own.[2] We call this rotation. Suppose it is efficient for each programmer to specialize in one task. Organizational design in this example is the choice between specialization and rotation.

Our interest is in how organizational design interacts with ownership. Suppose programmer 1 owns the integrated firm where programmer 2 is his

[1] There can be other benefits to rotation, e.g. learning spillovers, but in this paper we analyze a situation where specialization is first best and there is an interesting trade-off.

[2] Note that the skills required to develop the programme are to a large extent firm-specific. The programmers need to learn to work together so that the two parts of the programme fit together. Even more importantly programming requires a good knowledge of this particular firm's customers. About 50 per cent of programming is understanding the application. For example the firm could be developing a programme to automate production of plastic. This requires understanding of the customer's technology and products and what can be difficult in the production process.

employee. Suppose programmer 1 specializes in algorithms and programmer 2 in graphics. Specialization gives holdup power to programmer 2 because he is the only person who can design graphics and the project cannot be completed without him. Programmer 1 underinvests in algorithmic skills because programmer 2 expropriates part of the marginal value of his skills. Programmer 1 therefore implements rotation for his firm.[3] Rotation removes the holdup power of his employee because the owner is able to complete both parts of the project.[4] Therefore the owner has good incentives in investing in human capital. But now the programmers are unfocused due to rotation and given investments are less valuable than with specialization.

Then consider a situation where there are two small firms (nonintegration): programmer 1 owns a firm that writes the algorithms for the programme and sells it to a firm owned by programmer 2. Programmer 2 completes the project with graphics and sells it to the final customer. Under nonintegration the programmers naturally specialize in one task and task allocation is efficient. This is how organizational design and ownership interact: under integration an inefficient task allocation is chosen to improve the owner's bargaining position while under nonintegration the programmers efficiently specialize.

If tasks A and B are highly complementary to the degree that the firm owned by programmer 2 is the only customer for programmer 1's firm which in turn is the only supplier for 2's firm, then nonintegration results in serious holdup problems. These holdup problems can be avoided if both tasks are performed in one integrated firm. This result is well known. What we add is that this economy comes at the cost of inefficient task allocation. Integrated firm is designed to give power to the owner rather than to employ the best[5] production methods.

We find that the optimal size of the firm is a balance between two counteracting forces. When the returns to specialization are significant a fragmented

[3] An alternative way to reduce the employee's holdup power under specialization is to hire another employee who would also specialize in B. This would reduce the owner's holdup problem but would not eliminate it since the two employees can form a coalition and hold up the owner. We are analyzing a relatively small firm where hiring an additional employee to provide internal competition is not feasible.

[4] It is not necessary that he actually performs both tasks when the firm is working on a project but the point is that he would be able to do that.

[5] Absent holdup problems.

ownership structure with two small firms is optimal. This creates a larger class of owning agents who have the right incentives for specialization. While under concentrated ownership structure the worker is not allowed to obtain the power that specialization gives him. On the other hand, when economies of scope or scale are much more important than returns to specialization, the optimal firm size is large. Separating very complementary assets would not give power to anybody and the holdup problems would be very severe. Then it is better to concentrate ownership in one agent's hands. Having one large firm would provide the best incentives for human capital investments – even if it comes at a cost of inefficient task allocation, namely rotation of the workers. Accordingly, we have identified *a new cost of integration*: inefficient organizational design in an integrated firm.

Economies of scope or scale can depend on the technology choice of the firms. Technology choice therefore also affects the power relationships. Choosing a specific technology and gearing the assets to work together makes them more productive – and more dependent on each other (depending on the ownership structure). While a general technology enables the assets to trade with many equally good trading partners therefore removing the holdup problems (depending on the ownership structure). We further analyze two other versions of our model. In the second version we endogenize technology choice in addition to organizational design. In the third version only the technology choice is endogenous.

In our example the programmers can now choose to produce general packages that can be used by many customers, e.g. a mathematics package consisting of various algorithms and a graphic library. Alternatively they can choose to work on a specific project and tailor the algorithms and graphics for this project. The algorithms and graphics designed for this specific project have no other use. While the results on the technology choice are familiar on their own, it is the interaction with organizational design that is interesting in this version of the model.

Suppose it is first best for the programmers to work on the specific project.[6] We find that nonintegration gives good incentives for task allocation but poor incentives for technology choice. Integration interestingly has the opposite properties and gives good incentives for technology choice

[6] General technology can be efficient in certain situations as it maximizes the number of customers but here we focus on a case where specific technology is efficient, e.g. there is a customer who cannot use general packages but needs a tailor-made project which is very valuable.

but poor incentives for task allocation. Therefore nonintegration is optimal when it is important to implement the efficient task allocation, that is when the returns to specialization are large relative to the returns to the specific technology. While integration is optimal when the returns to the specific technology are relatively large.

In the third version of the model only the technology choice is endogenous. This is the relevant case for example when there is a programming task and an engineering task, which require so different basic education that rotation is not an option. We analyze this version so that we can find the general message from our three models. On their own the results of this version are well known. Under nonintegration the agents choose the inefficient general technology to improve their bargaining positions and in fact remove the holdup problem. While under integration the efficient specific technology is chosen but the agents are subject to holdups. If the specific technology is much more productive than the general one, integration is optimal.

There are two results that arise in all three versions of the model. The first general message of this paper is that specific technology is chosen under integration. This result provides clarification for the Hart-Williamson debate. Hart (1995, 27-28) criticizes the transaction cost theory for assuming that holdup problems are reduced in an integrated firm. When we analyze technology choice – which a lot of Williamson's analysis is about – holdup problem is indeed eliminated in the integrated firm. The reason is not that the agents become less opportunistic but because choosing a specific technology does not make the owner vulnerable as he owns both assets. While Hart analyzes investments in specific human capital for which holdup behaviour does not disappear in the integrated firm, it just changes.

The second general message is that the owner always focuses his human capital inside the firm. The workers may gear their skills to some extent outside the focus of the firm to improve their bargaining position.[7] The owner of the firm faces different incentives and cannot gain anything from learning outside skills. Ownership gives the incentives to focus on the firm.

Our model builds on Hart and Moore (1990). Two important determinants for the optimal ownership structure in their paper are the importance of an agent as a trading partner and the degree of complementarity between the assets. Our point is that these determinants can be endogenous, the first depending on the organizational design and the second on the choice of

[7] Our model analyzes only asset-specific investments.

technology.

Rajan and Zingales (1998) is closely related, in particular their case of complementary investments. Two agents each specializing in one task obtain too much holdup power and the resulting incentives are poor. Their solution to the holdup problem is to allow access to only one agent who performs both tasks. Our solution is for each agent to rotate. Their solution applies when the scale of production is relatively small so that it is indeed feasible for one skilled agent to perform both tasks.

Holmström and Milgrom (1994) analyze ownership and job design as complementary instruments motivating the workers and focus on the interactions arising from the cost function. In their paper ownership gives the same returns whatever the job design while the point of this paper is that job design affects the bargaining outcome within the firm.

Eliminating holdup problems is not the only motivation for job rotation. Rotation improves the firm's ability to deal with change (Koike (1984), Aoki (1986)). There can be learning spillovers between tasks arising either from intertask learning (Lindbeck and Snower (2000)) or knowledge transfer between workers (Lazear (1998), 328-330). Workers may have a preference for a variety of tasks (Cosgel and Miceli (1999)). To our knowledge the power reduction motive for job rotation is novel.

The rest of the paper is organized as follows. In Section 2 we relate our work to the classical literature on the theory of the firm. Section 3 introduces our model of ownership and organizational design. Section 4 analyzes the incentives for organizational design and investments in human capital under various ownership structures while Section 5 derives the optimal ownership structure. Section 6 extends the analysis to the case where both organizational design and technology are endogenous while in Section 7 we examine the case where only technology is endogenous. Section 8 discusses the general message emerging from the three versions of the model. The following two sections show that our assumptions about symmetric task allocation (Section 9) and contractible organizational design and technology (Section 10) are not critical. Section 11 concludes.

2 Related literature

In this section we relate our work to the classical literature on the theory of the firm.

2.1 Marglin vs. Williamson

Adam Smith compares two production modes in pinmaking: specialization and separate crafting of each individual pin. He concludes that there are significant returns to specialization. This has been interpreted as a rationale for the rise of capitalist firm. Marglin (1974) points out that there is a third production mode where each worker proceeds from task to task first drawing out enough wire for thousands of pins, then straightening it etc. He proposes that this is as efficient as specialization of each worker in one task since time will not be lost in constantly switching between tasks (and he does not acknowledge the other reasons for returns to specialization). Marglin interprets this as a nonhierarchical organization of production. Since according to him the capitalist and nonhierarchical organizations are equally efficient specialization "was introduced so that capitalist got himself a larger share of the pie at the expense of the worker" – not for efficiency reasons.

However, these alternative production modes could be implemented under various ownership structures. Clearly the separate crafting of each individual pin is inefficient. Marglin's third production mode is in fact a description of rotation. Then there is a choice between specialization and rotation. Specialization does not imply a capitalist mode but could be (and indeed in our model is) implemented in the entrepreneurial mode (nonintegration) where each worker is a boss of his own. According to Marglin rotation would be chosen in nonhierarchical organizations and specialization in capitalist firms. Our model gives exactly the opposite prediction. However, our model is consistent with Marglin in that the capitalist organization (integration) is designed to give a larger share of the pie to the capitalist (choice of rotation to weaken workers' bargaining power) – but in the same time the capitalist firm arises only when it is efficient.

Williamson (1985, Ch. 9) takes the opposite view to Marglin and proposes that capitalist authority relation is the most efficient mode. His federated entrepreneurial mode is like our nonintegration and his capitalist authority relation is like our integration. Specialization is assumed to occur for both modes and there is no discussion of the power that the specialized workers obtain in the capitalist mode.

The point of this paper is that organizational design is endogenous. Specialization does not imply a capitalist firm and rotation does not imply a nonhierarchical firm.

It should be noted that we have a rather special definition of specialization. Under specialization only one agent knows how to perform a particular task and therefore gains power. Specialization often refers to dividing a task into smaller tasks which can be performed by several agents. In such a situation there is competition between agents and specialization does not give much power to a single agent (though as a group they have power). The stylized fact is that this type of specialization occurs in large capitalist firms as per Marglin and Williamson. Our analysis applies when specialization is limited by the extent of the market (small firms where it is not feasible for many workers to specialize in the same task).

2.2 Grocers and employees

Alchian and Demsetz (1972) raised the question why an employee would accept employer's authority any more than a grocer would listen to a consumer. The worst sanction in both cases is firing. The property rights theory shows that the difference is that the grocer walks away with his asset while an employee leaves without any assets. This difference gives the employer leverage (Hart (1995), p. 58).

In this paper there is a further difference. An employee can be fired also ex ante if he does not accept the task allocation. While a grocer can only be fired ex post. Customer can either buy from the grocer or not but he does not have a say for the organizational design in the grocery. While an employer has authority in task allocation although he cannot tell the employee how hard to work on a given task. Therefore the employee accepts a task allocation that does not violate his individual rationality constraint (like Simon's (1951) area of acceptance). This idea is related to Holmström's (1999) view of the firm as an island economy where the CEO has the power to define the rules of the game.

2.3 Empirical literature

There is a large empirical literature on transaction cost theory (for a survey see Shelanski and Klein (1995)) examining how the make or buy decision depends on the asset specificity. The hypothesis is that integration is observed for high asset specificity and nonintegration for low asset specificity. This paper points out a possible endogenity problem in these regressions that leads to biased estimators. When the firm has a choice between specific and general technology, the degree of asset specificity is indeed not exogenous.

3 The model

We analyze a setup where there are two agents, 1 and 2, and two assets, a_1 and a_2. Ex ante the agents learn to operate the assets. The agents can either *specialize* (agent i learns to use only a_i) or *rotate* (each agent learns to use both assets). We denote the level of investment in human capital of agents 1 and 2 by I_1 and I_2 respectively. $I_i \in \left[0, \overline{I}\right]$ $i = 1, 2$ where $\overline{I} > 0$. Organizational design determines whether this is an investment to learn to use both assets or only one.

Our model builds on Hart and Moore (1990). We simplify their setting by having two agents and two assets and endogenize organizational design in their framework.[8]

The cost of the investment is $c(I_i)$ and is assumed to have the following standard properties.

Assumption 1. *$c(0) = 0$. c is twice differentiable. $c'(I_i) > 0$ and $c''(I_i) > 0$ for $I_i \in \left(0, \overline{I}\right)$, with $\lim_{I_i \to 0} c'(I_i) = 0$ and $\lim_{I_i \to \overline{I}} c'(I_i) = \infty$.*

Ex post production and trade occur. The value of production depends on which agent(s) are involved and on which assets they are using. The value of production depends also on organizational design and on the human capital of the included agents. Under rotation a coalition S of agents with a set of assets A and given investments $I = (I_1, I_2)$ can generate a value $v(S, A \mid I)$. While under specialization a value $V(S, A; \alpha \mid I)$ can be obtained, where $\alpha \geq 1$. Parameter α is a measure of the returns to specialization; how much higher value the specialized agents can generate for given investments.

In what follows we simplify notation by not explicitly writing the investments in the value functions: $v(S, A \mid I) \equiv v(S, A)$ and $V(S, A; \alpha \mid I) \equiv V(S, A; \alpha)$. We make the following assumptions about the value function under specialization.

Assumption 2. $V(S, A; \alpha) = v(S, A)$ if and only if $\alpha = 1$ for all $S \neq \emptyset$ and $A \neq \emptyset$. $\frac{\partial V(S,A;\alpha)}{\partial \alpha} > 0$.

In other words, when there are no returns to specialization given investments generate the same value under both rotation and specialization.

[8] In Hart and Moore (1990) organizational design (the degree of indispensability of an agent) is exogenous.

Furthermore, the value of production under specialization is increasing in the returns to specialization.

We further make the following assumptions about the marginal values of investments. We adopt notation $\frac{\partial}{\partial I_i} v(S, A) \equiv v^i(S, A)$ and $\frac{\partial}{\partial I_i} V(S, A; \alpha) \equiv V^i(S, A; \alpha)$. $A \backslash a_i$ denotes a set of assets that does not include a_i.

Assumption 3. *Under specialization* $V^i(S, A \backslash a_i; \alpha) = 0$ *and* $V^i(i, \{a_1, a_2\}; \alpha) = V^i(i, \{a_i\}; \alpha)$.

Assumption 4. *Under rotation* $v^i(S, \emptyset) = 0$ *and* $v^i(i, \{a_1, a_2\}) = v^i(12, \{a_1, a_2\})$.

Assumption 5. $V(i, \emptyset; \alpha) = v(i, \emptyset)$.

We assume that the investments are asset specific, that is the skills have no value unless the agent has access to the relevant asset/s. This explains the first part of Assumptions 3 and 4 and Assumption 5. Assumption 3 further says that when the agents specialize the marginal value of agent i's investment without the contribution of agent j is the same whether he has or has not access to asset a_j. Agent i's skills are geared to operating asset a_i only and therefore a_j does not enhance the value of his skills at the margin. In other words, specialization makes agent j indispensable to a_j. While according to Assumption 4 under rotation the marginal value of i's investment is not enhanced by agent j joining the coalition. Agent i knows how to operate both assets and therefore j is not important at the margin. In other words, rotation makes the agents dispensable.

Additionally we make the following assumptions as in Hart and Moore (1990). The assumptions are for simplicity written only for $v(S, A)$ but also $V(S, A; \alpha)$ is assumed to have the same properties.

Assumption 6. $v(S, A) \geq 0$ *and* $v(\emptyset, A) = 0$. $v(S, A)$ *is twice differentiable in* I. $v^i(S, A) \geq 0$ *for* $I_i \in [0, \overline{I}]$. $v(S, A)$ *is concave in* I.

Assumption 7. $v^i(S, A \mid I) = 0$ *if* $i \notin S$.

Assumption 8. $\frac{\partial}{\partial I_j} v^i(S, A \mid I) \geq 0$ *for* $j \neq i$.

Assumption 9. *For all subsets* $S' \subseteq S$, $A' \subseteq A$, $v(S, A) \geq v(S', A') + v(S \backslash S', A \backslash A')$.

Assumption 10. *For all subsets* $S' \subseteq S$, $A' \subseteq A$, $v^i(S, A) \geq v^i(S', A')$.

Assumption 6 gives the standard properties for the value function (increasing and concave) taking into account that agent i's investment does not affect the value of *all* coalitions. Assumption 7 follows on this and states that agent i's investment increases the value of only those coalitions of which he is a member. According to Assumption 8 the agents' investments are (weakly) complementary. Assumption 9 ensures that it is ex post efficient for the agents to produce together with both assets. According to Assumption 10 the marginal value of investment is nondecreasing in the number of agents and assets in the coalition.

One final assumption:

Assumption 11. $v(12, \{a_1, a_2\} \mid I_1 = I', I_2 = I'') = v(12, \{a_1, a_2\} \mid I_1 = I'', I_2 = I')$, $v(1, \{a_1, a_2\} \mid I_1 = I') = v(2, \{a_1, a_2\} \mid I_2 = I')$, $v(1, \{a_1\} \mid I_1 = I') = v(2, \{a_2\} \mid I_2 = I')$

Assumption 11 says that the investments enter symmetrically in the value functions. Since also the cost functions are symmetric, the agents are identical.

3.1 Contracts

We assume that ex ante contracts can only be written on the ownership structure and organizational design. (Section 10 shows that our results are robust to noncontractible organizational design.) As is standard in this literature investments in human capital are assumed to be observable for the agents but not verifiable in courts. Furthermore contracts on trade can only be written ex post.

The ex ante contract determines the ownership structure and organizational design. The assets can be either *nonintegrated* (1 owns a_1 and 2 owns a_2) or *integrated* (one agent owns both assets). The agents either *specialize* in operating one asset or *rotate* between the assets.[9] The agents have symmetric information and therefore suitable transfer payments ex ante guarantee that a joint surplus maximizing ownership structure and organizational design are chosen.

[9] In the main model we do not allow for one agent to specialize and the other agent to rotate. See Section 9 for discussion of asymmetric task allocation.

The timing of the model is illustrated in Figure 1. Ex ante the agents write a contract on the ownership structure and organizational design. Then the agents choose their investments in human capital noncooperatively. Ex post production occurs and spot contracts on trade are negotiated. We assume that the agents divide the gains from trade according to Nash bargaining.

3.2 First best

The first best is for each agent to specialize in one task and to choose the level of investment in human capital according to:

$$V^i(12, \{a_1, a_2\}; \alpha) = c(I_i^*) \qquad i = 1, 2 \tag{1}$$

Because investments are not contractible they will be chosen noncooperatively and typically first best does not obtain. Our aim is to find an ownership structure and organizational design that give second best incentives for human capital investments.

3.3 Technology

Technology is one of the driving forces behind our results. We now work out some basic properties of the value functions with respect to the technology. In our model the assets can be either vertically or horizontally related and to ease the discussion we define a concept of *joint economies* to describe either economies of scale or scope. When there are no joint economies (constant returns to scale or no economies of scope) we have[10]:

$$v(12, \{a_1, a_2\}) = v(1, \{a_1\}) + v(2, \{a_2\}). \tag{2}$$

Equation (2) implies that the marginal value of investment is the same whether the assets are used together or separately:

$$v^i(12, \{a_1, a_2\}) = v^i(i, \{a_i\}) \qquad i = 1, 2. \tag{3}$$

While with extreme joint economies the assets are useless separately:

$$v(1, \{a_1\}) + v(2, \{a_2\}) = 0 \tag{4}$$

and therefore the marginal value of investment is zero with only one asset:

[10] We discuss $v(S, A)$ but $V(S, A; \alpha)$ is assumed to have similar properties.


contract on ownership
and organizational
design
investments in
human capital
production,
spot contract
on trade

Figure 1

$$v^i(i, \{a_i\}) = 0 \qquad i = 1, 2. \tag{5}$$

For the intermediate case of some joint economies we have:

$$v(12, \{a_1, a_2\}) > v(1, \{a_1\}) + v(2, \{a_2\}) > 0. \tag{6}$$

We assume that in this case also the marginal value of investment is intermediate:

$$v^i(12, \{a_1, a_2\}) > v^i(i, \{a_i\}) > 0 \qquad i = 1, 2. \tag{7}$$

We introduce a parameter μ to measure the joint economies, $\mu \in [0, 1]$. $\mu = 0$ denotes extreme joint economies so that $v^i(i, \{a_i\}) = 0$ while $\mu = 1$ stands for no joint economies and $v^i(i, \{a_i\}) = v^i(12, \{a_1, a_2\})$. The lower is μ, the higher the degree of joint economies. The degree of joint economies is one of the driving forces in our model.

4 Organizational design and choice of investments

We start by analyzing how the incentives to invest depend on the organizational design and the ownership structure. This allows us to determine whether specialization or rotation will be chosen under a given ownership structure. Section 5 follows by examining the optimal ownership structure.

4.1 Integration

Suppose agent 1 owns both assets. What are the agents' incentives to invest under specialization and rotation? When we know the answer to this question we can determine whether specialization or rotation will be chosen under integration.

We start the analysis from *specialization,* i.e. agent i learns to operate only asset a_i, $i = 1, 2$. The default payoffs are important in determining the bargaining outcome. In this case agent 1's default payoff is $V(1, \{a_1, a_2\}; \alpha)$, the value she can generate with the assets she owns but without the contribution of agent 2. While agent 2's default payoff is $V(2, \emptyset; \alpha)$; if the agents split 2 does not have access to the assets since he does not own them. The bargaining results in the following payoffs, P_1 and P_2, to the agents:

$$P_1 = \frac{1}{2}\left[V\left(12, \{a_1, a_2\}; \alpha\right) + V\left(1, \{a_1, a_2\}; \alpha\right) - V\left(2, \emptyset; \alpha\right)\right] - c\left(I_1\right) \quad (8)$$

$$P_2 = \frac{1}{2}\left[V\left(12, \{a_1, a_2\}; \alpha\right) - V\left(1, \{a_1, a_2\}; \alpha\right) + V\left(2, \emptyset; \alpha\right)\right] - c\left(I_2\right) \quad (9)$$

Each agent chooses investment noncooperatively foreseeing the outcome of ex post bargaining. Accordingly, agent 1's incentives are given by the following first-order condition.

$$\frac{1}{2}V^1\left(12, \{a_1, a_2\}; \alpha\right) + \frac{1}{2}V^1\left(1, \{a_1, a_2\}; \alpha\right) - c'\left(I_1\right) = 0 \quad (10)$$

Under specialization the second asset does not enhance the marginal value of 1's investment since she does not know how to operate it (Assumption 3) and (10) is equivalent to:

$$\frac{1}{2}V^1\left(12, \{a_1, a_2\}; \alpha\right) + \frac{1}{2}V^1\left(1, \{a_1\}; \alpha\right) - c'\left(I_1\right) = 0 \quad (11)$$

Agent 2's incentives are given by:

$$\frac{1}{2}V^2\left(12, \{a_1, a_2\}; \alpha\right) - c'\left(I_2\right) = 0 \quad (12)$$

Each agent foresees that part of the surplus he generates by his investment is expropriated in ex post bargaining while he pays the full cost of investment. Therefore underinvestment (holdup) typically arises. Agent 2 receives only half of the marginal return on his investment and therefore underinvests significantly. Agent 1's incentives depend on the degree of joint economies. When joint economies are very strong so that $V^1\left(1, \{a_1\}; \alpha\right) = 0$, ownership does not improve incentives at all since specialization gives so much power to the worker. Ownership of the second asset does not increase the value of the owner's skills since she cannot operate the second asset. Ownership of the first asset does not enhance agent 1's incentives either since in this case one asset is useless without the other. While when there are no joint economies ($V^1\left(1, \{a_1\}; \alpha\right) = V^1\left(12, \{a_1, a_2\}; \alpha\right)$) the owner receives the full marginal return on her investment and therefore chooses first best investment. When the productivity of asset a_1 is independent of a_2, the worker has no power over the owner's skills. Therefore the weaker are the joint economies, the better are the owner's incentives because the worker's holdup power is decreased.

We then analyze *rotation,* i.e. each agent learns to operate both assets. The payoffs are given by equations (8) and (9) by setting $\alpha = 1$ and the owner's incentives for investing are[11]:

$$\frac{1}{2}v^1(12, \{a_1, a_2\}) + \frac{1}{2}v^1(1, \{a_1, a_2\}) - c'(I_1) = 0 \tag{13}$$

Since agent 1 has the skills to operate both assets, agent 2 is dispensable (Assumption 4) and (13) is equivalent to:

$$v^1(12, \{a_1, a_2\}) - c'(I_1) = 0 \tag{14}$$

And the worker's incentives are:

$$\frac{1}{2}v^2(12, \{a_1, a_2\}) - c'(I_2) = 0 \tag{15}$$

The owner can operate both assets and therefore the marginal value of her investment does not depend on whether or not the worker is in the same coalition. The owner has all the power and chooses efficient investment *for rotation*, the inefficient task allocation. The worker has to share the value of his investment 50:50 with the owner to gain access to the assets whether he has specialized or rotated and therefore faces a significant holdup.

Above we have analyzed the incentives to invest in specific human capital for a given task allocation. Moving one step backward we now examine optimal *organizational design.*

The benefit of specialization is that given investments have higher value. The cost of specialization is that it gives power to the worker and he can hold up the owner. The owner's incentives are accordingly diluted. The stronger are the joint economies, the more power the worker obtains. This is because one asset in more dependent on the other and only the worker knows how to operate the second asset. This tradeoff determines the choice of task allocation under integration.

Proposition 1 *There exists $\widehat{\alpha}$ such that under integration specialization is chosen if and only if $\alpha \geq \widehat{\alpha}$. The greater is the degree of joint economies, the higher is $\widehat{\alpha}$.*

[11] Remember that $V(S, A; \alpha) = v(S, A)$ if and only if $\alpha = 1$.

Proof. The agents contract on the joint surplus maximizing task allocation. Denote the joint surplus under integration and specialization by $J^{I,S}$ and with rotation $J^{I,R}$.

Under specialization $\partial I_i / \partial \alpha > 0$ for $i = 1, 2$ (equations (11) and (12)) and $\lim_{\alpha \to \infty} I_i = \bar{I}$ by Assumption 1. Therefore the investment costs are finite and $\lim_{\alpha \to \infty} J^{I,S} = \infty$. Clearly $J^{I,S} > J^{I,R}$ in the limit.

If $\alpha = 1$ there is no benefit to specialization, only the cost of lower incentives for the owner, equations (11) and (14), (and there is no cost either if there are no joint economies). Therefore $J^{I,S} \leq J^{I,R}$ for $\alpha = 1$.

By continuity there exists a $\alpha = \hat{\alpha} \geq 1$ such that $J^{I,R} = J^{I,S}$. This proves the first part of Proposition 1. The critical value for α is defined by:

$$J^{I,S}(\hat{\alpha}) = J^{I,R} \tag{16}$$

When the joint economies become stronger (lower μ), $J^{I,S}$ decreases.

$$\begin{aligned} \frac{\partial J^{I,S}}{\partial \mu} &= \left[V^1(12, \{a_1, a_2\}; \alpha) - c'(I_1) \right] \frac{\partial I_1}{\partial \mu} \\ &= \frac{1}{2} \left[V^1(12, \{a_1, a_2\}; \alpha) - V^1(1, \{a_1\}; \alpha) \right] \frac{\partial I_1}{\partial \mu} > 0 \end{aligned} \tag{17}$$

To increase $J^{I,S}$ so that (16) is satisfied requires a higher α. This proves the second part of Proposition 1.

■

When α is very large, the returns to specialization are significant. Even if specialization gives a lot of power to the worker the value of specialized skills is so large that specialization will be chosen. While when α is close to one, the returns to specialization are negligible. Specialization would only give power to the worker without any counteracting gain. Clearly the agents then choose rotation. This is the intuition for the first part of Proposition 1: specialization is chosen for high α.

The second part of Proposition 1 states that the weaker are the joint economies, the smaller have the returns to specialization be for specialization to be chosen. If there are no joint economies, specialization does not give any power to the worker. Since there is no cost, specialization is chosen for any α. When joint economies are very strong, specialization gives a lot of power to the worker. Returns to specialization have to be significant for specialization to pay.

4.2 Nonintegration

Now suppose the assets are nonintegrated. What are the agents' incentives when they specialize?

Under nonintegration and specialization agent i's default payoff is $V(i, \{a_i\}; \alpha)$, the value he can generate with the asset he owns. The agents' payoffs and the incentives to invest are:

$$P_i = \frac{1}{2}\left[V(12, \{a_1, a_2\}; \alpha) + V(i, \{a_i\}; \alpha) - V(j, \{a_j\}; \alpha)\right] - c(I_i) \tag{18}$$

$$\frac{1}{2}V^i(12, \{a_1, a_2\}; \alpha) + \frac{1}{2}V^i(i, \{a_i\}; \alpha) - c'(I_i) = 0 \text{ for } i = 1, 2 \tag{19}$$

The incentives depend on the degree of joint economies. When there are no joint economies ($V^i(i, \{a_i\}; \alpha) = V^i(12, \{a_1, a_2\}; \alpha)$) the agents have first best incentives. While with extreme joint economies ($V^i(i, \{a_i\}; \alpha) = 0$) the agents receive only half of the marginal return on their investment at the margin. The holdup problems are severe since the firms are very dependent on each other. This shows that under nonintegration and specialization the agents' incentives are the worse, the stronger are the joint economies.

What remains to be analyzed is rotation. By definition rotation means that agent i learns to operate the asset she owns, a_i, and additionally acquires skills to operate a_j owned by agent j. This sounds like a strange arragement and indeed in equilibrium it is never chosen. Rotation would not improve the agents' bargaining position. If the agents fail to reach an agreement, each agent has access only to the asset she owns and that value does not depend on whether she could operate the other asset. Therefore with rotation equations (18) and (19) apply with α set equal to one.

Since there is no cost of specialization it is clear that:

Proposition 2 *Under nonintegration the agents will specialize.*

5 Optimal ownership structure

In Section 4 we analyzed organizational design and investments for a given ownership structure. We now examine the optimal ownership structure.

Let us start by analyzing the ownership structures under specialization. Comparing equations (11), (12) and (19) we see that agent 1's incentives are the same in both structures while agent 2's investment is greater under nonintegration. Therefore given specialization nonintegration dominates. The second asset does not improve agent 1's incentives under integration since she cannot operate that asset – while allocating that asset to agent 2 (nonintegration) improves 2's incentives. Accordingly the agents would never choose integration if they want to implement specialization.

We know from Propositions 1 and 2 that rotation is only ever chosen under integration. Above we have shown that given specialization nonintegration dominates. Therefore when we choose ownership structure and organizational design pair optimally we only need to compare nonintegration with specialization and integration with rotation.

To make the comparison clear we rewrite the incentives for human capital investments. Under integration and rotation we have:

$$v^1\left(12,\{a_1,a_2\}\right)-c'\left(I_1\right)=0 \tag{20}$$

$$\frac{1}{2}v^2\left(12,\{a_1,a_2\}\right)-c'\left(I_2\right)=0 \tag{21}$$

And under nonintegration and specialization the incentives are:

$$\frac{1}{2}V^i\left(12,\{a_1,a_2\};\alpha\right)+\frac{1}{2}V^i\left(i,\{a_i\};\alpha\right)-c'\left(I_i\right)=0 \qquad \text{for } i=1,2 \tag{22}$$

The benefit of integration is that agent 1's holdup problem is removed. The cost of integration is that rotation will be chosen and agent 2 has worse incentives. We have identified *a new cost of integration*: inefficient organizational design. Integrated firm is designed to give power to the owner rather than to employ the best[12] production methods.

The optimal ownership structure depends on both α and μ. When there are no joint economies ($\mu=1$ and $V^i\left(i,\{a_i\};\alpha\right)=V^i\left(12,\{a_1,a_2\};\alpha\right)$) first

[12] Absent power problems.

best obtains under nonintegration and therefore nonintegration is optimal for any α.

With extreme joint economies ($\mu = 0$ and $V^i(i, \{a_i\}; \alpha) = 0$) the agents are very dependent on each other under nonintegration and the holdup problems are severe. While under integration the owner receives the full marginal return on her investment but given investments have a lower value under rotation. Then the optimal ownership structure depends on α.[13] When α is close to one the returns to specialization are negligible. Integration dominates because agent 1 has better incentives and agent 2 has no worse incentives. While when α is large there are significant returns to specialization and the ownership structure is chosen to implement efficient task allocation. Nonintegration is optimal even it results in higher holdup for agent 1.[14]

Proposition 3 shows how the optimal ownership structure depends on the returns to specialization and on the degree of joint economies.

Proposition 3 *There exists* **æ** *such that the optimal ownership structure is*

(i) integration (and rotation) if and only if $\alpha <$ **æ**,

(ii) nonintegration (and specialization) if and only if $\alpha \geq$ **æ**.

æ *is increasing in the degree of joint economies.*

Proof. Denote the joint surplus under nonintegration and specialization by $J^{NI,S}$.

For $\alpha = 1$ and $\mu = 0$ $J^{I,R} > J^{NI,S}$. Agent 1 has higher incentives under integration ((20) vs. (22)) and agent 2's incentives are the same ((21) vs. (22)). For $\alpha = 1$ and $\mu = 1$ $J^{I,R} < J^{NI,S}$ since first best obtains under nonintegration while under integration the worker is subject to a holdup. Since $J^{I,R}$ does not depend on μ and $\partial J^{NI,S}/\partial\mu > 0$ (from equation (22)) by continuity there exists a $\mu = \mu'$, where $0 < \mu' < 1$, for which $J^{I,R} = J^{NI,S}$ at $\alpha = 1$.

From equation (22) it is clear that $\lim_{\alpha\to\infty} J^{NI,S} = \infty$. $J^{I,R}/\partial\alpha = 0$.

Therefore for $\mu \geq \mu'$ $J^{NI,S} \geq J^{I,R}$ for all $\alpha \geq 1$.

[13] In Hart and Moore (1990) integration is optimal for $\mu = 0$. The result changes when organizational design is endogenous.

[14] Note that agent 1's investment may be greater under nonintegration than under integration even under integration agent 1 is not subject to a holdup. With specialization α affects the marginal value of the investment and if α is large enough agent 1's investment will be greater under nonintegration than under integration. Agent 2's investment is always greater under nonintegration.

For $\mu < \mu'$ $J^{NI,S} > J^{I,R}$ if and only if $\alpha > \hat{\alpha}$. The critical value for α is defined by

$$J^{NI,S}(\hat{\alpha}) = J^{I,R} \tag{23}$$

When the joint economies become stronger (lower μ) $J^{NI,S}$ decreases. To increase $J^{NI,S}$ so that (23) is restored requires a higher α. This explains why $\frac{\partial \hat{\alpha}}{\partial \mu} < 0$. ■

The optimal ownership structure depends on the relative importance of the returns to specialization and the degree of joint economies. When the returns to specialization are significant fragmented ownership structure with two small firms is optimal. This creates two owners who have the right incentives for specialization. While when the joint economies are much more important than the returns to specialization, it is optimal to have one large firm. Separating very complementary assets would not give power to anybody and holdup problems would be severe under nonintegration. Bringing the assets under common ownership minimizes the holdup problems as in Hart and Moore (1990). Our contribution is to identify a new cost of integration: inefficient organizational design. In the integrated firm the agents rotate so that the owner's holdup problem is minimized.

It is interesting to note that the returns to specialization are a property of human capital while the joint economies relate to the physical capital. We can restate our results by saying that when the emphasis is on human capital, entrepreneurship emerges while dominant physical capital properties lead to a large integrated firm.

In equilibrium the scope of the agent's human capital is as wide as the scope of the firm. In an integrated firm the agents rotate and learn to operate both assets of the firm. While in a nonintegrated firm the agent specializes in operating the only asset of the firm.

6 Choice of technology and organizational design

The degree of joint economies was one of the driving forces in the previous analysis. The agents can often determine the degree of joint economies by their technology choice. With a *specific technology* the assets are geared to be used together and a_1 is the only trading partner for a_2. While with a *general technology* there are many equally good trading partners. For example a software developer can design a program to tailor it for the specific needs of one company or sell it as packaged software suitable for numerous customers. The case of no joint economies is equivalent to the general technology and extreme joint economies are equivalent to the specific technology.

In this section we endogenize also the technology choice and analyze its interaction with organizational design.

We have four combinations of technology and task allocation and therefore four productions functions. They are:

$$\underline{v}(S, A) \text{ with rotation and general technology}$$

$$\mathbf{e}(S, A; \alpha) \text{ with specialization and general technology}$$

$$\mathbf{b}(S, A; \beta) \text{ with rotation and specific technology}$$

$$\overline{v}(S, A; \alpha, \beta) \text{ with specialization and specific technology}$$

When asset a_1 is geared to asset a_2 the assets are more productive together compared to the case where the assets have a general technology. Parameter β is a measure of the returns to the specific technology, $\beta \geq 1$. With the specific technology the assets can only be used together and therefore $\mathbf{b}(i, \{a_i\}; \beta) = \overline{v}(i, \{a_i\}; \alpha, \beta) = 0$.

All the productions functions are assumed to satisfy Assumptions 6-11. The equivalent of Assumption 2 is now:

Assumption 2'. $\underline{v}(S, A) = \mathbf{e}(S, A; \alpha)$ if and only if $\alpha = 1$. $\underline{v}(S, A) = \mathbf{b}(S, A; \beta)$ if and only if $\beta = 1$. $\mathbf{e}(S, A; \alpha) = \overline{v}(S, A; \alpha, \beta)$ if and only if $\beta = 1$. $\mathbf{b}(S, A; \beta) = \overline{v}(S, A; \alpha, \beta)$ if and only if $\alpha = 1$. $\frac{\partial \mathbf{e}}{\partial \alpha} > 0$, $\frac{\partial \mathbf{b}}{\partial \beta} > 0$, $\frac{\partial \overline{v}}{\partial \alpha} > 0$, $\frac{\partial \overline{v}}{\partial \beta} > 0$ and $\frac{\partial^2 \overline{v}}{\partial \alpha \partial \beta} \geq 0$ for all $S \neq \emptyset$and $A \neq \emptyset$.

Furthermore the production functions with rotation, $\underline{v}(S, A)$ and $\mathbf{b}(S, A; \beta)$, are assumed to satisfy the properties in Assumption 4 and the production functions with specialization, $\mathbf{e}(S, A; \alpha)$ and $\overline{v}(S, A; \alpha, \beta)$, are assumed to fulfill Assumption 3. Finally, the production functions with general technology, $\underline{v}(S,A)$ and $\mathbf{e}(S,A;\alpha)$, are assumed to have the property equivalent to no joint economies: $\underline{v}^i(i,\{a_i\}) = \underline{v}^i(12,\{a_1,a_2\})$ and $\mathbf{e}^i(i,\{a_i\};\alpha) = \mathbf{e}^i(12,\{a_1,a_2\};\alpha)$.

The detailed analysis can be found in the Appendix. Here we report our main results and the intuition behind them.

Since we have two technologies, two organizational designs and two ownership structures we have 8 structures to compare. We show in the Appendix that only four structures are relevant, others are dominated. The relevant structures are given below.

(i) Specialization and specific technology under nonintegration or integration. The incentives are:

$$\frac{1}{2}\overline{v}^i(12,\{a_1,a_2\};\alpha,\beta) - c'(I_i) = 0 \qquad \text{for } i = 1,2 \tag{24}$$

There is maximal holdup under nonintegration since the assets have a specific technology and the firms are fully dependent on each other. Also under integration ownership does not give any power since the owner has specialized in operating one asset which is useless without the second asset. Therefore with specialization and specific technology the holdup problem is maximal whatever the ownership structure.

(ii) Specialization and general technology under nonintegration

$$\mathbf{e}^i(12,\{a_1,a_2\};\alpha) - c'(I_i) = 0 \qquad \text{for } i = 1,2 \tag{25}$$

Since the assets have a general technology, the nonintegrated firms are fully independent and the holdup problem is removed.

(iii) Rotation and specific technology under integration

$$\mathbf{b}^1(12,\{a_1,a_2\};\beta) - c'(I_1) = 0 \tag{26}$$

$$\frac{1}{2}\mathbf{b}^2(12,\{a_1,a_2\};\beta) - c'(I_2) = 0 \tag{27}$$

Rotation makes the worker dispensable under integration and therefore the owner is not held up.

The main result of this Section is given in Proposition 4 and in Figure 2.

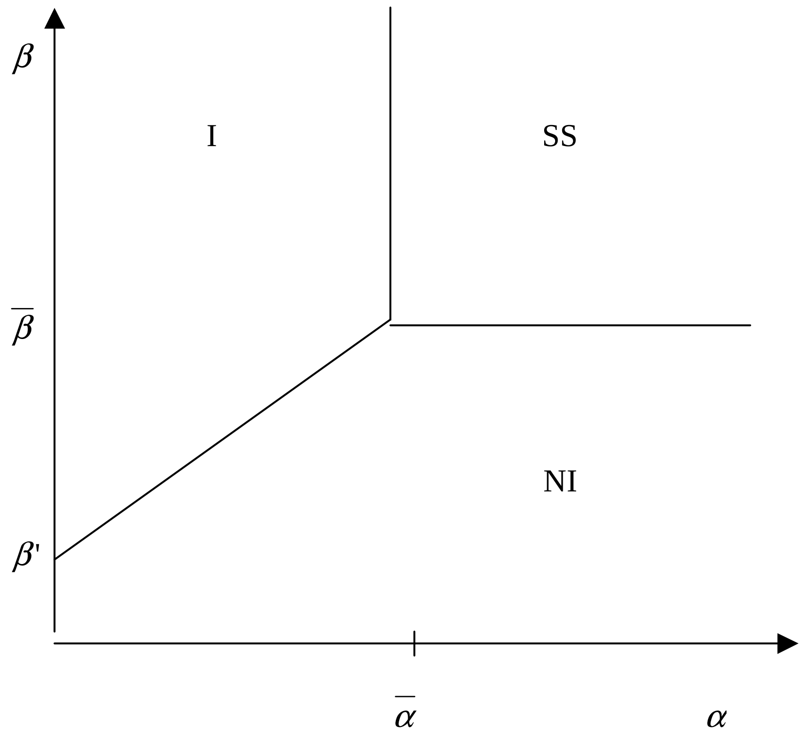

Figure 2

Proposition 4 *There exist* $\overline{\alpha}$, $\overline{\beta}$ *and* $\beta = \widehat{\beta}(\alpha)$, *where* $\widehat{\beta}'(\alpha) > 0$, *such that the optimal ownership structure is:*

(i) nonintegration (with specialization and general technology) if and only if $\beta \leq \widehat{\beta}(\alpha)$ *and* $\beta \leq \overline{\beta}$.

(ii) integration (with rotation and specific technology) if and only if $\beta > \widehat{\beta}(\alpha)$ *and* $\alpha \leq \overline{\alpha}$.

(iii) nonintegration or integration (with specialization and specific technology) if and only if $\alpha > \overline{\alpha}$ *and* $\beta > \overline{\beta}$.

Focus (specialization and specific technology) improves productivity but leads to dependency. The agents may choose rotation or general technology to improve their bargaining positions.

If both α and β are very large, the agents will implement both specialization and specific technology – even it means that the agents are fully dependent on each other. Whatever the ownership structure the agents can realize the value of their human capital only by working together and holdup problems are maximal. But the returns to specialization and specific technology are so significant that they outweigh the holdup problems.

When either α or β is not very large organization is designed so that at least one agent has power. Suppose agent 1 owns both assets. Agent 1 can improve her bargaining position by choosing rotation. General technology on the other hand does not increase bargaining power under integration. Gearing internal assets to each other does not make the owner vulnerable and accordingly specific technology is chosen under integration. Therefore the relevant structure for integration is rotation and specific technology.

Then suppose the assets are nonintegrated. General technology allows the agents to be fully independent and the holdup problem is removed. Rotation on the other hand does not increase bargaining power under nonintegration. Specialization does not make the owner dependent on the other agent and accordingly under nonintegration specialization is chosen. Therefore specialization and general technology will be chosen under nonintegration.

If either α or β is bounded the agents will implement either specialization or specific technology but not both. Nonintegration gives good incentives for task allocation but poor incentives for technology choice. Integration has the opposite properties and gives good incentives for technology choice but poor incentives for task allocation. The optimal ownership structure depends on whether it is more important to achieve focus in human capital or in technology. If α/β is small it is important that the specific technology is chosen. Integration is then optimal. While for large α/β the agents should specialize. Accordingly, the agents contract on nonintegration.

The irrelevance of the ownership structure in the parameter range where both α and β are very large results from our assumptions. Ownership would matter if we assume that the skills are somewhat transferable. Then even with specialization the agent could operate the second asset to some degree $\left(\overline{v}^1(1,\{a_1,a_2\};\alpha,\beta) > \overline{v}^1(1,\{a_1\};\alpha,\beta)\right)$. Transferable skills improve the owner's bargaining position under integration and accordingly integration is optimal. Alternatively, if the specific technology allows some trade with other firms $\left(\overline{v}^i(i,\{a_i\};\alpha,\beta) > 0\right)$ the bargaining positions are improved under nonintegration and nonintegration dominates.

7 Choice of technology

We finally analyze the case where the agents can choose the technology but the organizational design is given. This is relevant when the tasks are so similar that the skills are fully transferable (e.g. operating two similar welding machines). Then specialization does not give power. Alternatively the tasks are so different that it is not feasible for one worker to acquire both skills (e.g. an engineering and a legal task). In both cases the agents always specialize but they may still be able to choose the technology.

We analyze this case so that we can find the general message from our three cases. On their own the results of this section are well-known (Riordan and Williamson (1985)).

With a general technology the value of production is $f(S,A)$ where $f^i(i,\{a_i\}) = f^i(12,\{a_1,a_2\})$. While a specific technology gives value $F(S,A;\beta)$ where $F^i(i,\{a_i\};\beta) = 0$. We assume that $\partial F(S,A;\beta)/\partial\beta > 0$ and $f(S,A) = F(S,A;\beta)$ if and only if $\beta = 1$. Both functions are also assumed to fulfill Assumptions 6-11.

Suppose the assets are *nonintegrated.* Under specific technology the incentives are:

$$\frac{1}{2}F^i(12,\{a_1,a_2\};\beta) - c'(I_i) = 0 \qquad i = 1,2 \tag{28}$$

Holdup problem is maximal because the assets, and the firms, are fully dependent on each other.

General technology results in the following incentives:

$$f^i(12,\{a_1,a_2\}) - c'(I_i) = 0 \qquad i = 1,2 \tag{29}$$

The agents have no power over each other as there are many equally good trading partners.

When *agent 1 owns both assets* which have the specific technology investments are determined by

$$\frac{1}{2}F^1(12,\{a_1,a_2\};\beta) + \frac{1}{2}F^1(1,\{a_1,a_2\};\beta) - c'(I_1) = 0 \tag{30}$$

$$\frac{1}{2}F^2(12,\{a_1,a_2\};\beta) - c'(I_2) = 0 \tag{31}$$

For the general technology equations (30) and (31) apply with β set equal to one. General technology does not improve bargaining positions under integration. Therefore specific technology is chosen under integration.

It is easy to see from (28) , (30) and (31) that given the specific technology integration dominates as agent 1 has better incentives under integration and agent 2 has no worse incentives. We therefore compare nonintegration and general technology with integration and specific technology to determine the optimal ownership structure.

Proposition 5 *There exists β^* such that the optimal ownership structure is*
(*i*) *nonintegration (and general technology) if and only if $\beta \leq \beta^*$,*
(*ii*) *integration (and specific technology) if and only if $\beta > \beta^*$.*

Proof. For $\beta = 1$ $J^{NI,G} > J^{I,S}$ and for $\beta \to \infty$ $J^{NI,G} < J^{I,S}$. By continuity there exists β^* for which $J^{NI,G} \geq J^{I,S}$ if and only if $\beta \leq \beta^*$.
■

The tradeoff is by now familiar. Under nonintegration the agents choose the inefficient general technology to improve their bargaining positions and in fact remove the holdup problem. Under integration the efficient specific technology is chosen but the agents are subject to holdups. If the specific technology is much more productive than the general one, integration is optimal.

8 General message

We have analyzed three versions of the model and in this section we examine the general message emerging from the analysis. In all the versions we observe specific technology under integration (Propositions 4 and 5). In other words holdup problem in technology choice disappears under integration. It is interesting to relate this result to earlier literature. Hart (1995, 27-28) discusses the transaction cost theory of Williamson (1975), (1985) and Klein et al. (1978) and points out that this literature is unclear about the way holdup behavior is reduced in a single firm. Hart writes that it is unsatisfactory to suppose that the agents automatically become less opportunistic as a result of merger. Now it is important to use Williamson's classification of asset specific investments: site-specific investment, specific physical investment and specific investment in human capital. Hart analyzes investments in specific human capital and then indeed the holdup behavior does not disappear in the integrated firm, it just changes. A lot of Williamson's analysis is about site-specific investments and specific physical investments. For these types of investments holdup problem disappears in the integrated firm, not because opportunism is reduced but because choosing specific technology does not make the owner vulnerable as he owns both assets.[15]

The second message relates to human capital. We observe specialization with nonintegration in all the versions of the model (Propositions 3 and 4). In other words the skills are focused *inside* the firm. In this model the agents never learn skills outside the focus of the firm. Our model analyzes only asset-specific investments, i.e. $v^i(i, \emptyset) = 0$. If we included investments in outside skills in our analysis we would find that the non-owning agent would invest in skills that improve his default payoff $v(i, \emptyset)$, i.e. in skills outside the focus of the firm. However, the *owner* always focuses his skills inside the firm. The owner of the integrated firm can improve his bargaining position, $v(1, \{a_1, a_2\})$, by rotating between internal tasks, not by learning outside skills. (This is true even if we have more assets and agents in the model.) The owner of the nonintegrated firm can improve his default payoff

[15] In Proposition 4(*iii*) where both α and β are high specific technology does make the owner vulnerable due to specialization but the returns are so high that they outweigh the holdup problem. The point is that general technology is never chosen in equilibrium under integration. Therefore the holdup problem *in technology choice* is removed in the integrated firm.

$v(i, \{a_i\})$ by choosing a general technology, again not by learning outside skills. Accordingly, ownership gives the incentives to focus on the firm. One implication of this result is that if it is crucial for a particular agent to concentrate their human capital on the firm, he should be the owner of the firm.

9 Asymmetric task allocation

In the main model task allocation is symmetric. This is relevant when the assets are such that only one agent can work at an asset at a time and the assets are fully utilized. If we allow for asymmetric task allocation, it would dominate full rotation under integration. The owner would rotate and the worker would specialize.[16] Rotation improves the owner's bargaining position as the worker is not important at the margin. Rotation by the worker does not improve the worker's incentives at all since he is in any case dependent on the owner to gain access to the asset.

The situation changes when we have 3 agents. To simplify notation suppose there is one asset, a, and agent 1 owns the asset. Shapley value gives the following payoffs to the agents:

$$\begin{aligned} P_1 &= \frac{1}{3}\left[v(123, a) - v(23, \varnothing)\right] + \frac{1}{6}\left[v(12, a) - v(2, \varnothing)\right] + \frac{1}{6}\left[v(13, a) - v(3, \varnothing)\right] \\ &\quad + \frac{1}{3}v(1, a) - c(I_1) \qquad (32) \end{aligned}$$

$$\begin{aligned} P_i &= \frac{1}{3}\left[v(123, a) - v(1j, a)\right] + \frac{1}{6}\left[v(1i, a) - v(1, a)\right] + \frac{1}{6}\left[v(23, \varnothing) - v(j, \varnothing)\right] \\ &\quad + \frac{1}{3}v(i, \varnothing) - c(I_i) \qquad (33) \\ i, j &= 2, 3, i \neq j \end{aligned}$$

The incentives are:

$$\frac{1}{3}v^1(123, a) + \frac{1}{6}v^1(12, a) + \frac{1}{6}v^1(13, a) + \frac{1}{3}v^1(1, a) = c'(I_1) \qquad (34)$$

[16] One interpretation is that the owner coordinates the specialized employees' work.

$$\frac{1}{3}v^i(123, a) + \frac{1}{6}v^i(1i, a) = c'(I_i) \qquad i = 2, 3 \tag{35}$$

If there are three tasks and all the agents learn all the tasks, equations (34) and (35) change to:

$$v^1(123, a) = c'(I_1) \tag{36}$$

$$\frac{1}{2}v^i(123, a) = c'(I_i) \qquad i = 2, 3 \tag{37}$$

Rotation by the owner again removes the holdup problem for her. What is new is that rotation improves the workers' incentives too. Workers cannot hold up each other because they all have the same skills. Therefore rotation can reduce power problems not just for the owner but among the workers too. Asymmetric task allocation, accordingly, does not dominate full rotation under integration.

10 Noncontractible organizational design and technology

In the main model we have assumed that organizational design and technology are contractible. Therefore the ex ante contract on ownership structure determines also the organizational design and technology. In this section we show that our results are robust to this assumption. The driving force in our model is the noncontractible *human* capital.

Suppose organizational design and technology are noncontractible and the owner has the right to choose them. The natural timing is after the contract on ownership has been written but before the investments in human capital are made. The owner chooses them to maximize his own payoff, not the joint surplus. How does this affect our results? Let us take Proposition 5 which states that nonintegration and general technology maximize joint surplus if and only if $\beta \leq \beta^*$. To verify that nonintegration is still optimal for $\beta \leq \beta^*$ we need to prove that the owner of the nonintegrated firm would choose general technology for $\beta \leq \beta^*$ and the owner of the integrated firm would choose specific technology for $\beta > \beta^*$. We know from our previous analysis that the owner of the integrated firm always chooses specific technology because it does not increase vulnerability. Now Proposition 5 holds as long as the owners of the nonintegrated firms would indeed choose general technology for $\beta \leq \beta^*$, i.e. $P_i^{NI,G} > P_i^{NI,S}$ if $\beta \leq \beta^*$. In what follows we prove that this is true.

First note that $J^{I,S} > J^{NI,S}$ for all β as stated in Section 7. Second, Proposition 5 obtains that $J^{I,S} \leq J^{NI,G}$ if and only if $\beta \leq \beta^*$. Third, since the agents are identical we have $J^{NI,S} = 2P_i^{NI,S}$ and $J^{NI,G} = 2P_i^{NI,G}$. Combining these all we have $J^{NI,G} = 2P_i^{NI,G} \geq J^{I,S} > J^{NI,S} = 2P_i^{NI,S}$ for $\beta \leq \beta^*$ which implies that $P_i^{NI,G} > P_i^{NI,S}$ for $\beta \leq \beta^*$. Therefore the owner chooses general technology under nonintegration for $\beta \leq \beta^*$. Accordingly Proposition 5 holds also with noncontractible technology.

Then we analyze noncontractible organizational design. Proposition 3 states that integration and rotation maximize joint surplus if and only if $\alpha < \hat{\alpha}$ while nonintegration and specialization are joint surplus maximizing for $\alpha \geq \hat{\alpha}$. We know that specialization is always chosen under nonintegration. To find out whether Proposition 3 is robust to noncontractible organizational design we examine if the owner of the integrated firm chooses rotation for $\alpha < \hat{\alpha}$. We analyze this question in Figures 3 and 4. The solid line in the figures represents the critical boundary $\hat{\alpha}(\mu)$. Below the solid line integration and rotation maximize joint surplus while above it nonintegration and specialization are joint surplus maximizing.

The owner of the integrated firm chooses rotation if and only if $P_1^{I,R} > P_1^{I,S}$. The two possibilities for this critical boundary are presented in Figures 3 and 4 as broken lines.[17] Below the broken line the owner of the integrated firm chooses rotation. If the critical boundary lies above $\hat{\alpha}$, as in Figure 3, then Proposition 3 does not change at all. The owner indeed chooses rotation for $\alpha < \hat{\alpha}$. While in the situation of Figure 4 in region A the owner of the integrated firm would choose specialization. Therefore the critical boundary between integration and nonintegration shifts and becomes the thick line. Although the critical boundary shifts, the basic tradeoff is not changed: nonintegration emerges for high α and high μ.

11 Conclusions

We have analyzed three versions of our basic model. In the first version we endogenize organizational design in the property rights theory of Hart and

[17]See Appendix for how the figures were constructed.

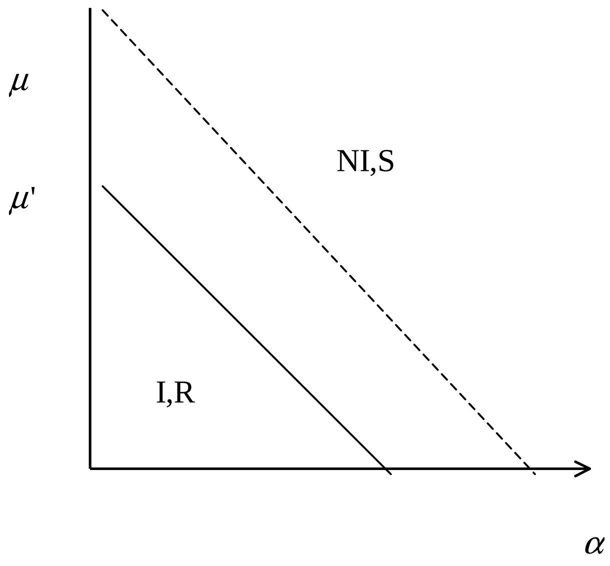

Figure 3

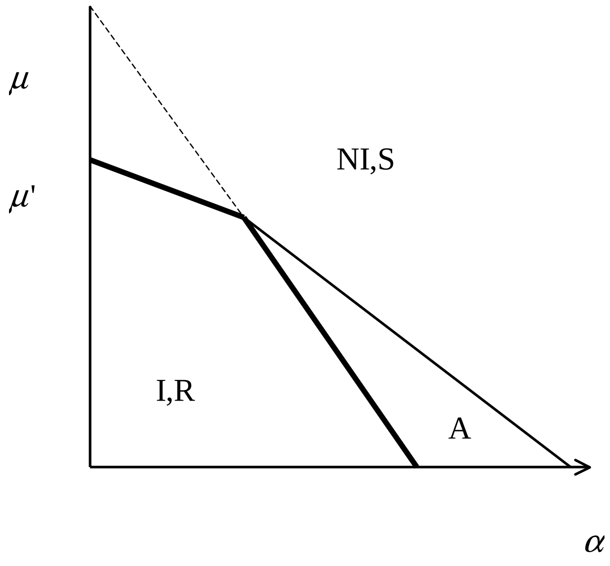

Figure 4

Moore (1990). In our model with two agents and two assets the agents can either specialize in operating one asset or rotate between the assets. Specialization increases productivity but (depending on the ownership structure) also increases holdup problems because a specialized agent is indispensable. Hart and Moore (1990) show that when an agent is indispensable to an asset, it is optimal for him to own it. Our analysis broadly confirms this correlation[18] but changes the causal relationship. It is not because the agent is indispensable that he owns the asset but ownership gives the agent incentives to become indispensable.

It is well known that strong joint economies make integration optimal. What we are adding is that it comes at the cost of inefficient organizational design. Under integration the worker is not allowed to obtain the power that specialization gives him; the agents rotate. While under nonintegration each agent is a boss of his own and specialization does not cause power problems; the agents specialize. Therefore nonintegration is optimal when the returns to specialization are high (the cost of inefficient organizational design under integration is high) and the joint economies are weak (holdup problems arising from separating the assets are low).

In the second version of the model we further endogenize the technology choice and analyze its interaction with organizational design. The agents can choose between a general and a specific technology. Specific technology is more productive but (depending on the ownership structure) increases holdup problems because the assets can only be used together. Under integration specific technology does not increase holdup problems because both assets have the same owner. Therefore a specific technology is chosen under integration. While under nonintegration (for a wide parameter range) the agents improve their bargaining position by minimizing dependency and choose a general technology. We are particularly interested in how the technology choice interacts with organizational design.

We find that when both the returns to specialization, α, and the returns to specific technology, β, are large the agents choose both specialization and specific technology even it leads to maximal holdup problems. The agents are completely dependent on each other whatever the ownership structure but the returns to specialization and to specific technology are so large that they outweigh the power problems. While when either α or β is bounded the agents design the organization so that at least one agent has power.

[18] It is violated in Proposition 4(iii).

The agents implement either specialization or specific technology but not both. For high α/β the agents choose an ownership structure to ensure specialization. Thus nonintegration is optimal. While for low α/β it is important to implement the specific technology and therefore integration is optimal. The ownership structure is chosen so that it gives appropriate incentives for organizational design and technology choice.

In the third version of the model only technology choice is endogenous. We find that when the returns to the specific technology are high, integration is optimal. While for low β nonintegration is chosen. This is not a novel result but we have included it in the paper so that we can find a general message from the three versions of the model.

There are two results that arise in all three versions of the model. The first general message of this paper is that specific technology is chosen under integration. The second general message is that ownership gives the incentives to focus human capital on the firm.

There are other dimensions to organizational design and technology than those analyzed here. Their effect on power relationships inside and between the firms remains an open question.

Trust is important in relationships where dependency leads to vulnerability. In the future it is interesting to explore how building and maintaining trust interacts with organizational design, choice of technology and ownership.

A Appendix

In this Appendix we analyze the case where both technology and organizational design are endogenous (Section 6).

A.1 Integration

We will first analyze the incentives to invest when agent 1 owns both assets. Since we have two technologies and two organizational designs we have four possible combinations and we analyze each in turn.

With specialization and specific technology (SS) the incentives are given by:

$$\frac{1}{2}\overline{v}^i\left(12,\{a_1,a_2\};\alpha,\beta\right)-c'\left(I_i\right)=0 \qquad \text{for } i=1,2 \tag{38}$$

$\overline{v}^1\left(1,\{a_1,a_2\};\alpha,\beta\right)=\overline{v}^1\left(1,\{a_1\};\alpha,\beta\right)$ because the agents have specialized and $\overline{v}^1\left(1,\{a_1\};\alpha,\beta\right)=0$ since the assets have the specific technology. The owner does not have any power because she only knows how to operate one asset (specialization) and one asset is useless without the other (specific technology). Therefore both agents are subject to a maximal holdup. On the other hand, given investments have the maximal value arising from the returns to specialization and the value of the specific technology.

Under specialization and general technology (SG) the incentives are:

$$\mathbf{e}^1\left(12,\{a_1,a_2\};\alpha\right)-c'\left(I_1\right)=0 \tag{39}$$

$$\frac{1}{2}\mathbf{e}^2\left(12,\{a_1,a_2\};\alpha\right)-c'\left(I_2\right)=0 \tag{40}$$

The owner is not subject to a holdup with a general technology. $\mathbf{e}^1\left(1,\{a_1,a_2\};\alpha\right)=\mathbf{e}^1\left(1,\{a_1\};\alpha\right)$ due to specialization and $\mathbf{e}^1\left(1,\{a_1\};\alpha\right)=\mathbf{e}^1\left(12,\{a_1,a_2\};\alpha\right)$ with the general technology. Specialization does not give any power the worker because the assets (and the tasks) are independent.

With rotation and specific technology (RS) the first-order conditions become:

$$\mathbf{b}^1\left(12,\{a_1,a_2\};\beta\right)-c'\left(I_1\right)=0 \tag{41}$$

$$\frac{1}{2}\mathbf{b}^2(12,\{a_1,a_2\};\beta)-c'(I_2)=0 \tag{42}$$

With rotation $\mathbf{b}^1(1,\{a_1,a_2\};\beta)=\mathbf{b}^1(12,\{a_1,a_2\};\beta)$ and the owner receives the full marginal value of her investment. Worker does not have any power because the owner has similar skills.

Finally, with rotation and general technology (RG) the incentives are:

$$\underline{v}^1(12,\{a_1,a_2\})-c'(I_1)=0 \tag{43}$$

$$\frac{1}{2}\underline{v}^2(12,\{a_1,a_2\})-c'(I_2)=0 \tag{44}$$

The owner is not subject to a holdup because rotation makes the worker dispensable.

RG is clearly dominated by SG and RS. The owner is not subject to a holdup problem in any of these structures and in RG both the task allocation and the technology are inefficient.

The agents will choose between SS, SG and RS. Under SS the owner has no power but both the organizational design and the technology are efficient. With SG and RS the owner has power but either the task allocation or the technology is inefficient. We will analyze these choices in detail in Section A.3.

A.2 Nonintegration

In this subsection we examine how the incentives under nonintegration depend on the technology and organizational design.

Under SS the incentives are:

$$\frac{1}{2}\overline{v}^i(12,\{a_1,a_2\};\alpha,\beta)-c'(I_i)=0 \qquad \text{for } i=1,2 \tag{45}$$

With specific technology $\overline{v}^i(i,\{a_i\};\alpha,\beta)=0$. Ownership does not give any power to the agents because the assets are fully dependent on each other. The holdup problem is maximal.

When the general technology is chosen $\mathbf{e}^i(i,\{a_i\};\alpha)=\mathbf{e}^i(12,\{a_1,a_2\};\alpha)$. Therefore under SG we have:

$$\mathbf{e}^i(12,\{a_1,a_2\};\alpha)-c'(I_i)=0 \qquad \text{for } i=1,2 \tag{46}$$

The agents have no power over each other as there are many equally good alternative trading partners.

Under RS the incentives are:

$$\frac{1}{2}\mathbf{b}^i\left(12,\{a_1,a_2\};\beta\right)-c'\left(I_i\right)=0 \qquad \text{for } i=1,2 \qquad (47)$$

Because of specific technology the agents have no alternative trading partner and are subject to maximal holdup. This structure is dominated by SS. The agents have no power in either structure but under SS task allocation is efficient.

Finally under RG $\underline{v}^i\left(i,\{a_i\}\right)=\underline{v}^i\left(12,\{a_1,a_2\}\right)$ due to the general technology and the incentives are:

$$\underline{v}^i\left(12,\{a_1,a_2\}\right)-c'\left(I_i\right)=0 \qquad \text{for } i=1,2 \qquad (48)$$

The agents are not subject to a holdup problem because the assets are technologically independent. SG dominates RG since in both structures there are no holdup problems and under SG the task allocation is efficient.

The relevant structures are SS and SG. Rotation is not chosen under nonintegration. Rotation does not improve the agents' bargaining positions. The power relationship depends only on the technology choice. The specific technology makes the agents dependent on each other but gives higher value for given investments. The general technology removes power problems but given investments have lower value.

A.3 Optimal ownership structure

We start by comparing the ownership structures for a given choice of technology and task allocation. Then we determine the optimal ownership structure.

RG is dominated under both integration and nonintegration. Accordingly RG does not arise in equilibrium. Under SS the ownership structures are equivalent ((38) vs. (45)). Neither agent has any power.

Under SG nonintegration dominates integration ((39) and (40) vs. (46)). General technology removes the holdup problem under nonintegration while under integration the worker is subject to a holdup.

For RS integration generates a higher surplus ((41) and (42) vs. (47)). Because of the specific technology the agents have no power under nonintegration while rotation removes the owner's holdup problem under integration.

Therefore the relevant structures are:

(i) specialization and specific technology under nonintegration or integration

$$\frac{1}{2}\overline{v}^i\left(12,\{a_1,a_2\};\alpha,\beta\right)-c'\left(I_i\right)=0 \qquad \text{for } i=1,2 \tag{49}$$

(ii) specialization and general technology under nonintegration

$$\mathbf{e}^i\left(12,\{a_1,a_2\};\alpha\right)-c'\left(I_i\right)=0 \qquad \text{for } i=1,2 \tag{50}$$

(iii) rotation and specific technology under integration

$$\mathbf{b}^1\left(12,\{a_1,a_2\};\beta\right)-c'\left(I_1\right)=0 \tag{51}$$

$$\frac{1}{2}\mathbf{b}^2\left(12,\{a_1,a_2\};\beta\right)-c'\left(I_2\right)=0 \tag{52}$$

Proof of Proposition 4. Compare first SS and nonintegration with SG ((49) vs. (50)). For $\beta=1$ nonintegration dominates and $J^{SS}<J^{NI,SG}$. For $\beta\to\infty$ clearly $J^{SS}>J^{NI,SG}$. By continuity there exists $\overline{\beta}$ for which $J^{SS}>J^{NI,SG}$ if and only if $\beta>\overline{\beta}$.

Then compare SS with integration under RS ((49) vs. (51) and (52)). For $\alpha=1$ $J^{I,RS}>J^{SS}$ and for $\alpha\to\infty$ $J^{I,RS}<J^{SS}$. By continuity there exists $\overline{\alpha}$ for which $J^{I,RS}<J^{SS}$ if and only if $\alpha>\overline{\alpha}$.

Next we divide the parameter space into four regions.

(i) $\alpha>\overline{\alpha}$ and $\beta>\overline{\beta}$. We have found that $J^{SS}>J^{NI,SG}$ and $J^{SS}>J^{I,RS}$. Therefore SS is optimal in this region.

(ii) $\alpha\le\overline{\alpha}$ and $\beta>\overline{\beta}$. In this region $J^{I,RS}\ge J^{SS}>J^{NI,SG}$ and integration is optimal.

(iii) $\alpha>\overline{\alpha}$ and $\beta\le\overline{\beta}$. We have $J^{NI,SG}\ge J^{SS}>J^{I,RS}$ and nonintegration is optimal.

(iv) $\alpha\le\overline{\alpha}$ and $\beta\le\overline{\beta}$. We have shown that $J^{I,RS}\ge J^{SS}$ and $J^{NI,SG}\ge J^{SS}$. We still need to compare integration and nonintegration to find out the optimal structure ((50) vs. (51) and (52)).

For $\alpha=\beta=1$ $J^{NI,SG}>J^{I,RS}$. While for $\alpha=1$ and $\beta\to\infty$ $J^{NI,SG}<J^{I,RS}$. Therefore there exists β' for which $J^{NI,SG}=J^{I,RS}$ at $\alpha=1$. (See Figure 2.) We further know that $\beta'<\overline{\beta}$ since for $\alpha=1$ and $\beta>\overline{\beta}$ $J^{I,RS}>J^{NI,SG}$.

The next step is to prove that the slope of the critical boundary between nonintegration with SG and integration with RS is positive. Since $\frac{\partial J^{NI,SG}}{\partial \alpha} > 0$, $\frac{\partial J^{NI,SG}}{\partial \beta} = 0$, $\frac{\partial J^{I,RS}}{\partial \alpha} = 0$ and $\frac{\partial J^{I,RS}}{\partial \beta} > 0$ clearly the value of β for which $J^{NI,SG} = J^{I,RS}$ is increasing in α.

Finally, we show that this critical boundary ends at $\alpha = \overline{\alpha}$ and $\beta = \overline{\beta}$. Suppose it does not. The two possibilities are presented in Figure 5. Here we draw the critical boundary between nonintegration and integration for all values of α and β. First consider the lower curve. In area A according to this figure $J^{I,RS} > J^{NI,SG}$ but this cannot be true since we know that for $\alpha > \overline{\alpha}$ and $\beta \leq \overline{\beta}$ $J^{NI,SG} > J^{I,RS}$. Now consider the higher curve. In area B according to this figure $J^{I,RS} < J^{NI,SG}$ but this cannot be true since for $\alpha \leq \overline{\alpha}$ and $\beta > \overline{\beta}$ $J^{I,RS} > J^{NI,SG}$.Therefore the only possibility is that the curve goes through $\left(\overline{\alpha}, \overline{\beta}\right)$.

To sum up we have proved that $J^{NI,SG} = J^{I,RS}$ maps a function $\beta = \hat{\beta}(\alpha)$ such that $\hat{\beta}(1) = \beta'$, $\hat{\beta}(\overline{\alpha}) = \overline{\beta}$ and $\hat{\beta}'(\alpha) > 0$.

Therefore the optimal ownership structure is:

(i) Nonintegration with SG if and only if $\beta \leq \hat{\beta}(\alpha)$ and $\beta \leq \overline{\beta}$.

(ii) Integration with RS if and only if $\beta > \hat{\beta}(\alpha)$ and $\alpha \leq \overline{\alpha}$.

(iii) SS if and only if $\alpha > \overline{\alpha}$ and $\beta > \overline{\beta}$.

■

A.4 Constructing Figures 3 and 4

The solid line in Figures 3 and 4 shows the critical boundary $\hat{\alpha}(\mu)$ derived in Proposition 3. From the proof of the Proposition we know that the critical boundary between integration with rotation and nonintegration with specialization cuts the vertical axis at μ', where $0 < \mu' < 1$, and that it is downward sloping.

The broken line is the critical boundary for the owner of the integrated firm when organizational design in noncontractible. Above it the owner chooses specialization and below it rotation. Denote this critical boundary by $\alpha = \underline{\alpha}(\mu)$. We will first prove that $\underline{\alpha}'(\mu) < 0$.

Total differentiation of the owner's payoff function with respect to α gives:

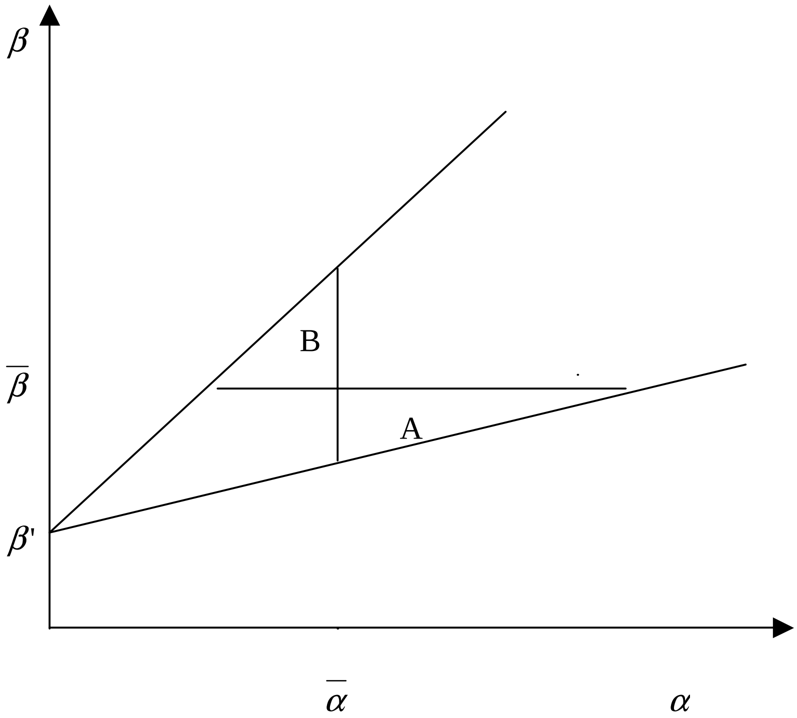

Figure 5

$$
\begin{aligned}
\frac{dP_1^{I,S}}{d\alpha} &= \frac{\partial P_1^{I,S}}{\partial I_2}\frac{\partial I_2}{\partial \alpha} + \frac{\partial P_1^{I,S}}{\partial \alpha} \\
&= \frac{1}{2}V^2\left(12, \{a_1, a_2\}; \alpha\right)\frac{\partial I_2}{\partial \alpha} + \frac{1}{2}\left(\frac{\partial}{\partial \alpha}V\left(12, \{a_1, a_2\}; \alpha\right) + \frac{\partial}{\partial \alpha}V\left(1, \{a_1, a_2\}; \alpha\right)\right) > 0
\end{aligned}
$$

$0\frac{\partial I_2}{\partial \alpha} > 0$ from equation (12) and therefore the owner's payoff under specialization is increasing in α.

Then differentiate the owner's payoff with respect to μ.

$$
\begin{aligned}
\frac{dP_1^{I,S}}{d\mu} &= \frac{\partial P_1^{I,S}}{\partial I_2}\frac{\partial I_2}{\partial \mu} + \frac{\partial P_1^{I,S}}{\partial \mu} \\
&= \frac{\partial}{\partial \mu}V\left(1, \{a_1, a_2\}; \alpha\right) > 0 \qquad (53)
\end{aligned}
$$

The worker's investment does not depend on the degree of joint economies (equation (12)). Therefore there is only the direct effect. The only term that is changed in the payoff function is $V\left(1, \{a_1, a_2\}; \alpha\right)$ because when agent 1 is on her own the assets are separated in a sense since she only knows how to operate one asset. The higher is the degree of joint economies (the lower is μ), the lower is agent 1's default payoff.

Since $\frac{dP_1^{I,S}}{d\alpha} > 0$, $\frac{dP_1^{I,S}}{d\mu} > 0$, $\frac{dP_1^{I,R}}{d\alpha} = 0$, $\frac{dP_1^{I,R}}{d\mu} = 0$ $P_1^{I,S} = P_1^{I,R}$ maps a function $\alpha = \underline{\alpha}(\mu)$ such that $\underline{\alpha}'(\mu) < 0$.

We finally prove that $\underline{\alpha}(1) = 1$. Suppose $\alpha = \mu = 1$. From equations (12) and (15) we see that agent 2's investment is the same with rotation or specialization. Equations (11) and (14) show that agent 1's investments are the same too. Since for $\alpha = 1$ the value functions are the same, the owner must be indifferent between specialization and rotation when $\alpha = \mu = 1$. Therefore this critical boundary cuts the vertical axis at $\mu = 1$, above μ'. Accordingly the two possibilities for this critical boundary are presented in Figures 3 and 4.

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