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Asymmetric Spiders:
Supplier Heterogeneity and the Organization of Firms

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Abstract

We consider a property rights model of a firm with two heterogeneous suppliers. The headquarters determine the firm's organizational structure, and we analyze *which* sourcing mode (outsourcing or vertical integration) is chosen for *which* of the asymmetric inputs. If suppliers' investment choices are *strategic complements*, the firm may keep the technologically more important input inside its boundaries and outsource the less important supplier. The firm also tends to keep more sophisticated inputs in-house, while choosing an external supplier organization for simpler and for low-cost components. These theoretical predictions are consistent with numerous case studies and recent empirical evidence on the internal organization of firms.

JEL-Classification: D23, L23, F23

Keywords: Firm organization, outsourcing, intra-firm trade, property rights approach

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1. Introduction

Most final goods require multiple intermediate inputs. Some of those intermediates are technologically more important than others and generate a higher value-added in the production process, some are inherently more sophisticated while others are easier to handle, some are cheaper to produce than others, and so on. For each of these asymmetric inputs, the headquarters in charge of the firm's organization need to decide on the crucial "make or buy" question: Should the component, given its specific characteristics, be manufactured in-house by a subsidiary who is vertically integrated within the firm's boundaries? Or should that input rather be subcontracted to an external supplier over which the firm has no direct control or ownership rights?

In this paper, we study this organizational problem in a property rights model of a firm that deals with heterogeneous suppliers, each providing a unique manufacturing input. The property rights approach, which dates back to the pioneering work by Grossman and Hart (1986) and Hart and Moore (1990), has been extensively used to analyze the internal organization of firms, both from a theoretical and an empirical point of view. It relies on an environment with incomplete contracts and relationship-specific investments. Ownership structures matter in this context, because they shape the bargaining powers and, thus, the investment incentives of the involved parties who anticipate hold-up and renegotiation problems. However, issues of supplier heterogeneity have been mostly ignored so far.

In particular, following the seminal contributions by Antràs (2003) and Antràs and Helpman (2004), various models consider a production process where headquarter services are combined with *one single* manufacturing component. These frameworks investigate the industry- and firm-level determinants of the ownership decision whether to outsource or vertically integrate this unique supplier, but heterogeneity across inputs – by construction – plays no role in those models. Acemoglu et al. (2007) consider a production process with a continuum of inputs, but all components are fully symmetric so that supplier heterogeneity also does not exist in their approach.

The two models that are most closely related to ours are the recent frameworks by Antràs and Chor (2013) and by Schwarz and Suedekum (2014). The former consider a vertical value chain where inputs are passed along various production stages and are refined in each stage. Inputs and their respective suppliers, thus, differ exogenously according to their level of "downstreamness", and the production process resembles a "snake" structure in the terminology of Baldwin and Venables (2013). Antràs and Chor (2013) show that an input's position on the value chain is systematically related to the firm's respective ownership choice. In particular, if supplier investments are "sequential complements" and reinforce each other along the chain, the firm tends to outsource the upstream stages and to integrate the downstream ones. The opposite pattern emerges if inputs are relatively close substitutes so that supplier investments discourage each other ("sequential substitutes").

The model by Schwarz and Suedekum (2014) builds on the setup by Acemoglu et al. (2007) with a continuum of suppliers. All manufacturing components are simultaneously combined with headquarter services to assemble a final good. Their production process therefore resembles a "spider" structure in

Baldwin/Venables-jargon, which is a reasonable approximation for many real-world production processes with only few vertical stages. Schwarz and Suedekum (2014) show that the firm might choose a *hybrid sourcing* structure, with some suppliers vertically integrated and other suppliers outsourced. Such a constellation, where both organizational forms co-exist within the same firm, is an empirically highly relevant phenomenon that – by construction – cannot arise in the baseline frameworks with just a single supplier.[1] However, in Schwarz and Suedekum (2014) all inputs are symmetric along all exogenous dimensions. Hence, they do not investigate if certain input characteristics induce the firm to choose a particular organizational form for the respective supplier.

In this paper, we also consider a "spider" structure, yet we allow for exogenous asymmetries across inputs. Differently from Acemoglu et al. (2007) and Schwarz and Suedekum (2014), we do not assume a continuum, but our model features two discrete inputs/suppliers.[2] These two components can differ in three respects: i) their technological importance as measured by the input intensity in the production process, ii) their degree of sophistication as measured by the input fraction that is usable for the firm even when the respective supplier refuses to collaborate, and iii) their unit costs of production.

The first key prediction of our model is that, when headquarter-intensity is on an intermediate level, the firm finds it optimal to have one integrated and one outsourced supplier.[3] This hybrid sourcing emerges for a similar reason as in Schwarz and Suedekum (2014), because the producer can fine-tune the revenue distribution inside the firm and thereby balance the underinvestment problems of all involved parties. In contrast to that paper, however, our model with two asymmetric manufacturing components allows us to focus on the question *which* sourcing mode is chosen for *which* supplier.

We first analyze technological asymmetries in the components' input intensities. If the two manufacturing inputs are relatively close substitutes, we find that hybrid sourcing always involves outsourcing of the "strong" supplier, who provides the technologically more important input, and vertical integration of the "weak" supplier. The reason is the incentivizing effect of property rights: if hybrid sourcing is optimal for the firm, it gives priority to transferring ownership rights to the supplier whose component input is relatively more intensively used in production. This pattern can change, however, once the elasticity of substitution across components is sufficiently low relatively to the elasticity of demand. Then, we also encounter an ownership pattern where only the weak supplier is outsourced, while the strong supplier is kept in-house. The intuition is that the weak supplier would have too little investment incentives as an integrated affiliate and this can backfire on the incentives of the strong supplier when investment choices are highly complementary. Put differently, in our

[1] Empirical studies by Kohler and Smolka (2012, 2014), Defever and Toubal (2013), Corcos et al. (2013), Tomiura (2007), and others, show that many, if not most firms choose such hybrid sourcing structures.

[2] The theoretical models by Du et al. (2009) and by Van Biesebroeck and Zhang (2011) also study settings with incomplete contracts and multiple suppliers, but they focus on different mechanism than our framework.

[3] For high and low headquarter-intensity, our model makes similar predictions as existing baseline frameworks. In particular, the firm would choose full outsourcing (integration) when the headquarter-intensity of production is sufficiently low (high). The intuition is that, when components are highly important in production, the firm transfers ownership rights to the suppliers, as this raises their bargaining powers and investment incentives. Vice versa, if the headquarter input is most important the producer wants to secure a large revenue share for herself.

"spider" setup, a similar complementarity effect is at work as in the "snake" model by Antràs and Chor (2013), even though production and investment choices are not made sequentially in our framework. In analogy to that paper, we distinguish the cases where suppliers' investment choices are *strategic substitutes* or *strategic complements*, and while they mainly focus on supplier heterogeneity with respect to the level of "downstreamness", we consider other asymmetries across component inputs. We show that the firm's organizational structure is then shaped by a trade-off between the standard incentive effect of property rights, and if applicable, a complementarity effect.

Our theoretical prediction for the case of strong *strategic complements* is consistent with numerous studies from the business literature, which suggest that firms often keep their most important components in-house, and outsource only relatively less important inputs.[4] For example, consider the three premium watchmakers *Glashütte Original*, *Jaeger-LeCoultre* and *Rolex*. All of these firms engage in some outsourcing: *Glashütte* obtains the dial and the watch hands from external suppliers, *Jaeger-LeCoultre* the bracelets, while *Rolex* subcontracts some material for the balance wheel (see Zeiteisen, 2011). Those outsourced inputs are, of course, essential and specific to the design of the final product. Yet, the key component which generates the highest value-added, namely the clockwork, is produced in-house by all three firms. Our model predicts such an ownership pattern if components cannot be easily substituted (which seems to be the case in these example), and if the producer's share of the overall surplus is not too large. The *strategic substitutes* case, by contrast, emerges for lower levels of complementarity and only features the standard incentive effect, according to which suppliers of more important inputs should be incentivized by a transfer of ownership rights.

Turning to the other dimensions of supplier heterogeneity, we show that if components differ in their inherent degree of sophistication, the firm tends to outsource the simpler manufacturing input while keeping the complex one in-house. This prediction is well in line with recent empirical evidence by Costinot et al. (2011) and Corcos et al. (2013), who consistently find that an internal supplier organization is more prevalent for non-routine activities and complex inputs, while outsourcing is typically chosen for simpler tasks. In our model, this ownership choice emerges because the supplier of the simple input would have very low bargaining power as an integrated affiliate, and hence cannot be properly incentivized inside the firm. Finally, if there are differences in unit costs across suppliers, we show that the firm tends to outsource the low-cost, and to integrate the high-cost supplier. Supposing that the high-cost (low-cost) supplier comes from the domestic (a foreign) country, this result implies a positive correlation between outsourcing and offshoring. This implication is well consistent with empirical evidence established by Kohler and Smolka (2014), who find that an internal supplier organization is more likely to occur at home than abroad for Spanish manufacturing firms.

The rest of this paper is organized as follows. Section 2 introduces the model structure, and section 3 analyzes the firm's ownership structure when components differ in their technological importance. Section 4 addresses heterogeneity in sophistication and unit costs across inputs. Section 5 concludes.

[4] See Bengtsson et al. (2009), Chesbrough and Teece (1996), Lakemond et al. (2006), Ulrich and Ellison (2005).

2. The model

2.1. Technology and demand

We consider a firm that produces a final good q. Production of this good requires headquarter services and two different manufacturing components. The headquarter services are denoted by h and are provided by the final goods producer herself. The components are manufactured by suppliers. Specifically, we assume that there are two suppliers A and B who provide x_i ($i = \{A, B\}$) units of their respective component. The inputs are combined according to the following production function:[5]

$$(1) \qquad q = \theta \cdot \left(\frac{h}{\eta^H}\right)^{\eta^H} \cdot \left(\frac{X}{1-\eta^H}\right)^{1-\eta^H}, \qquad \text{where}$$

$$(2) \qquad X = \left[\eta_A \cdot \left(\frac{x_A}{\eta_A}\right)^{\alpha} + \eta_B \cdot \left(\frac{x_B}{\eta_B}\right)^{\alpha}\right]^{\frac{1}{\alpha}}.$$

The upper tier production function (1) is a standard Cobb-Douglas, where θ denotes productivity, η^H is the headquarter-intensity, and $(1-\eta^H)$ is the overall component-intensity of the production process. The aggregate component input X is given by a constant elasticity of substitution (CES) function as in (2), where η_i denotes the input intensity of component i within the aggregate X (with $\eta_A + \eta_B = 1$). The parameter $\alpha \in (0,1)$ measures the substitutability of the two component inputs.[6] On the demand side, the firm faces an iso-elastic demand function for the final product,

$$(3) \qquad q = Y \cdot p^{-\frac{1}{1-\beta}} \qquad \text{with } \beta \in (0,1)$$

where p is the price, $Y > 1$ is a demand shifter, and $1/(1-\beta) > 1$ is the demand elasticity. Combining (1)-(3) yields the firm's revenue which depends on the input levels x_A, x_B, and h:

$$(4) \qquad R = \theta^{\beta} \cdot Y^{1-\beta} \cdot \left[\left(\frac{h}{\eta^H}\right)^{\eta^H} \cdot \left(\frac{\left(\eta_A \cdot \left(\frac{x_A}{\eta_A}\right)^{\alpha} + \eta_B \cdot \left(\frac{x_B}{\eta_B}\right)^{\alpha}\right)^{\frac{1}{\alpha}}}{1-\eta^H}\right)^{1-\eta^H}\right]^{\beta}.$$

2.2. Structure of the game

The producer's key decision in our model concerns the firm's organizational structure. That is, the producer decides for both components whether the respective supplier is an external subcontractor or a

[5] This technology is similar as in Acemoglu et al. (2007) or Schwarz and Suedekum (2014), but assumes a discrete and fixed number of manufacturing components rather than a continuum of inputs.

[6] These technology parameters differ across firms and industries. The headquarter-intensity η^H may, for example, be high in software or pharmaceutical firms and low, say, in firms from the automotive industry. The parameter η_A (with $\eta_B = 1 - \eta_A$) captures the degree of asymmetry of the two components. As an example, consider the production of *Nespresso* coffee capsules. This final good requires two highly specific components: the coffee, and the capsules. Here, substitutability is low, and the coffee tends to have the higher input intensity and generates more value added than the capsules per se. In software firms, inputs like code programming and technical support are more symmetric (η_A and η_B are more similar) and better substitutable (higher α).

vertically integrated affiliate. These organizational decisions are made in an environment with incomplete contracts à la Grossman and Hart (1986) and Hart and Moore (1990). All component and headquarter inputs are fully relationship-specific and non-contractible, as their characteristics cannot be precisely specified ex ante, nor be verified by a third party (e.g., a court) ex post.[7] Formally, we study the following five-stage game that we solve by backward induction:

1. The producer determines the organization of the firm by choosing the ownership structure of production. This decision is represented by a tuple $\Xi = \{\Xi_A, \Xi_B\}$, where $\Xi_i = O$ denotes outsourcing and $\Xi_i = V$ denotes vertical integration of the supplier of component $i = \{A, B\}$.

   Given this organizational decision, the firm offers contracts to potential suppliers. The contracts can include an upfront payment τ_i (positive or negative) to supplier i.
2. There is a huge mass of potential suppliers for both components. They apply for the contract, and the producer chooses one supplier for each component. Potential suppliers have an outside opportunity equal to w_i.
3. The headquarter and the two suppliers decide independently on their non-contractible input provision levels (h and, respectively, x_A and x_B). The unit costs of headquarter services are given by c_H. The unit costs of production for input i are given by c_i.
4. The three players bargain over the surplus value of the relationship.
5. The final good is produced. Revenue is realized and distributed according to the bargaining outcome.

Some comments about this setup are necessary. Most importantly, notice that a hold-up problem arises due to the assumed contract incompleteness. Agents cannot commit on their input provision levels as stipulated in stage 1, so that the two suppliers and the producer end up in a bargaining over the surplus value of the relationship in stage 4, at a time where all input provision costs are already sunk. Anticipating this, all parties tend to under-invest into their input provisions in stage 3.

The producer's organizational decision in stage 1 matters, because it affects the bargaining powers of the involved parties in stage 4 and, hence, their investment incentives in stage 3. An outsourced supplier maintains the full property rights over his input, while a vertically integrated supplier is essentially an employee of the producer. As will become clear soon, an external supplier tends to be in a better bargaining position vis-à-vis the producer, as he threatens to withhold his entire input level in stage 4. Following the property rights approach of the firm, we assume that an integrated affiliate may also refuse to collaborate in the ultimate stage of the game. In such a case, owing to her residual control rights, it is then possible for the producer to confiscate the input and to use it at least partly.

[7] This contractual environment is surely an extreme one. It is assumed to stay as close as possible to the baseline model by Antràs and Helpman (2004). In an extension, Antràs and Helpman (2008) allow for partial contractibility of inputs and cross-country differences in contract enforcement. We could introduce these features into our model as well. This would make the exposition considerably more complicated, however.

2.3. Bargaining and Shapley values

Starting with stage 5, each player receives the payment agreed on in the bargaining. We solve the bargaining problem in stage 4 with the Shapley value approach (see Shapley, 1953) which is a standard solution concept in multilateral contexts. A player's Shapley value is "*the average of her contributions to all coalitions that consist of players ordered below her in all feasible permutations*" (Acemoglu et al., 2007). In our model, coalitions can contain one, two or three players. Zero output is produced and no revenue is generated by coalitions consisting only of a single player, or by coalitions of the two suppliers. These coalitions are not feasible. Only coalitions consisting of the producer and at least one input supplier are feasible. Within the set of feasible coalitions, the players can be ordered in different ways, and those orderings are called permutations. For each of those, the respective last player's marginal contribution is determined, i.e., the difference in revenue when the respective player is part of the coalition, and when the respective player is not part of it.

The marginal contributions of the suppliers depend on the ownership structure of the firm. During the bargaining, when supplier i refuses to collaborate, he threatens to withhold the fraction $\delta_i^{\Xi_i}$ of his input while the producer can keep and effectively use the fraction $\left(1-\delta_i^{\Xi_i}\right)$. This parameter $\delta_i^{\Xi_i}$ captures both, property rights and the inherent degree of sophistication of the component. To see this, notice that in case of outsourcing, we have $\delta_i^O = 1$ irrespective of the input characteristics, because external suppliers maintain the full residual control rights. When supplier i is vertically integrated, however, the producer can use the fraction $0 < (1-\delta_i^V) < 1$ even without the respective supplier's cooperation, owing to her property rights. The parameter δ_i^V then becomes a natural measure for the component's *sophistication*. Intuitively, highly complex inputs like software modules or special purpose machines are characterized by a high value of δ_i^V, since they are hardly useable without the specific knowledge of the (internal) supplier. By contrast, simpler relationship-specific components such as uniquely tailored textiles, or the like, are easier to use for the producer even if the supplier refuses to collaborate and are, thus, characterized by a lower sophistication δ_i^V.

Turning to the computation of the Shapley values, at the bargaining stage both the firm's ownership structure $\Xi = \{\Xi_A, \Xi_B\}$ and the players' input contributions $\{x_A, x_B, h\}$ are given. Consider first the marginal contribution of a single supplier $i = \{A, B\}$ to a coalition of size two, i.e., with the producer. We denote this as $m(i,2)^{\Xi_i}$. If supplier i is outsourced, his marginal contribution corresponds to the total revenue of that coalition, since revenue drops to zero if he withholds his input. Formally, this is:

$$m(i,2)^O = \widehat{H} \cdot x_i^{\beta\cdot(1-\eta^H)} \, \eta_i^{\frac{\beta\cdot(1-\alpha)\cdot(1-\eta^H)}{\alpha}} \tag{5}$$

with $\widehat{H} = \theta^\beta \cdot Y^{1-\beta} \cdot h^{\beta\cdot\eta^H} \cdot (1-\eta^H)^{-\beta\cdot(1-\eta^H)} \cdot (\eta^H)^{-\beta\cdot\eta^H}$. If supplier i is integrated, revenue does not drop to zero if he withholds his input, but the firm earns $\widehat{H} \cdot \left(\left(1-\delta_i^V\right) x_i\right)^{\beta(1-\eta^H)} \eta_i^{\frac{\beta\cdot(1-\alpha)\cdot\left(1-\eta^H\right)}{\alpha}}$. Hence, the marginal contribution $m(i,2)^V$ is lower than $m(i,2)^O$ and is given by

(6) $$m(i,2)^V = \hat{H} \cdot \left(x_i^{\beta\cdot(1-\eta^H)} \cdot \eta_i^{\frac{\beta\cdot(1-\alpha)\cdot(1-\eta^H)}{\alpha}} - \left((1-\delta_i^V)\cdot x_i\right)^{\beta\cdot(1-\eta^H)} \cdot \eta_i^{\frac{\beta\cdot(1-\alpha)\cdot(1-\eta^H)}{\alpha}} \right).$$

Finally, a supplier's marginal contribution to the coalition of size three, $\mathrm{m(i,3)}^{\Xi}$, can be written as

(7) $$\mathrm{m(i,3)}^{\Xi} = \hat{H} \cdot \left(\left(x_i^{\alpha} \cdot \eta_i^{1-\alpha} + x_j^{\alpha} \cdot \eta_j^{1-\alpha}\right)^{\frac{\beta\cdot(1-\eta^H)}{\alpha}} - \left(\left((1-\delta_i^{\Xi_i})\cdot x_i\right)^{\alpha} \cdot \eta_i^{1-\alpha} + x_j^{\alpha} \cdot \eta_j^{1-\alpha}\right)^{\frac{\beta\cdot(1-\eta^H)}{\alpha}} \right)$$

with $\mathrm{i} \neq \mathrm{j}$ and $\delta_i^O = 1$, $0 < \delta_i^V < 1$ which depends on supplier i's own input investment, as well as on the contribution (and, hence, the ownership form) of the other supplier j. Using these marginal contributions, the suppliers' Shapley values are calculated according to

(8) $$s_i^{\Xi} = \sum_{T\subseteq N} \frac{(t-1)!\cdot(n-t)!}{n!} \; \mathrm{m(i,t)}^{\Xi} \quad \text{for } i \in \{A,B\},$$

where n is the total number of players, and t the number of players in a coalition ($t \leq n$). The term $(t-1)!\cdot(n-t)!/n!$ captures the probability that a player is in the last position of a feasible permutation. In our context, we have $n = 3$, so that this probability is equal to $1/3$ for the coalition with three players, and $1/6$ for a coalition of two players. Using (8) and the marginal contributions (6) and (7), the Shapley value of supplier i is thus given by

(9) $$s_i^{\Xi} = \frac{1}{6}\cdot m(i,2)^{\Xi_i} + \frac{1}{3}\cdot m(i,3)^{\Xi},$$

so that s_i^{Ξ}/R is the revenue share that supplier i ultimately realizes in the multilateral bargaining. Last, since the headquarter is the only essential player in this setup, her Shapley value is given by the residual, $s_H^{\Xi} = 1 - s_A^{\Xi} - s_B^{\Xi}$, where s_A^{Ξ} and s_B^{Ξ} follow from (9), and her revenue share is s_H^{Ξ}/R.[8]

2.4. Input investments

In stage 3, agents choose their input provision levels, taking into account the Shapley values that they anticipate to receive in the bargaining stage. Due to non-contractibility, each player chooses the investment so as to maximize the individual payoff, which equals the Shapley value minus the production costs. The input contributions of the suppliers and the producer can therefore be written as

(10) $$\tilde{x}_i^{\Xi} = argmax_{x_i}\{s_i^{\Xi} - c_i \cdot x_i\} \quad \text{and} \quad \tilde{h}^{\Xi} = argmax_h\{s_H^{\Xi} - c_H \cdot h\}.$$

Notice that the payoff-maximizing input choices in (10) depend on the anticipated Shapley values from (9), while those Shapley values depend in turn on the players' input provisions. In this setup with two discrete and asymmetric suppliers, we can therefore not solve analytically for the input levels

[8] The sum of the marginal contributions of all suppliers must equal total revenue. However, the allocation of the marginal contributions is not necessarily efficient: the sum of the marginal contributions may deviate from the revenue of the coalition (see Hart and Mas-Colell, 1988). To assure that the total revenue is distributed among the three players, one player is the residual claimant, similar as in Hart and Moore (1990).

$\{\tilde{x}_A^{\Xi}, \tilde{x}_B^{\Xi}, \tilde{h}^{\Xi}\}$ and the Shapley values $\{s_A^{\Xi}, s_B^{\Xi}, s_H^{\Xi}\}$ as functions of the firm's ownership structure Ξ. Instead, we have to rely on a numerical approach.[9] In a Supplementary Appendix, we illustrate this approach and discuss how the players' revenue shares and investment incentives are affected by technology and cost parameters for a given structure Ξ. To summarize some key insights, we find that:

i) Everything else equal, the higher is the headquarter-intensity η^H, the higher is the producer's realized revenue share and the lower are the revenue shares of both suppliers. A higher η^H also leads to a higher input contribution of the producer relative to the two suppliers.

ii) Everything else equal, if supplier A provides the technologically more important input (with higher input intensity $\eta_A > \eta_B$), he realizes the higher revenue share and provides a higher input contribution than the other supplier B ($\tilde{x}_A^{\Xi} > \tilde{x}_B^{\Xi}$).

iii) Everything else equal, if supplier A provides the more sophisticated input ($\delta_A > \delta_B$), he realizes a higher revenue share and makes a higher input contribution than supplier B.

iv) Everything else equal, if supplier A has lower unit costs ($c_A < c_B$), he realizes a larger revenue share and makes a higher input contribution than supplier B.

The intuition for i) is analogous to Antràs and Helpman (2004) or Schwarz and Suedekum (2014): If the headquarter provides a more important input, she has stronger bargaining power which in turn ameliorates her underinvestment problem. The logic behind ii), iii) and iv) is similar, and refers specifically to the novel feature of our framework. With two asymmetric suppliers, the one who provides the technologically more important or more sophisticated input (or is able to produce his component at lower unit costs) also realizes a higher bargaining weight, which in turn incentivizes him to contribute to the relationship.

While results i)-iv) refer to exogenous parameters of the model, the revenue distribution inside the firm and the investment incentives also depend on the firm's organizational structure Ξ, which is predetermined in the production and bargaining stages. In particular, we find that:

v) For given parameter values, the revenue share of supplier A is higher if he is outsourced than if he is vertically integrated. The supplier provides a higher input contribution under outsourcing than under vertical integration, ceteris paribus.

vi) For given parameter values, supplier A realizes a higher revenue share when the other supplier B is integrated than if supplier B is outsourced.

Result v) illustrates the well-known insight by Antràs (2003) that a transfer of property rights via outsourcing has an incentivizing effect for the respective supplier, because it raises his bargaining power as described before. In our model with two asymmetric components, there are also interesting interdependencies, as indicated by result vi): The revenue share of one supplier not only depends on

[9] In Schwarz and Suedekum (2014) it is possible to solve for these variables, because they assume a continuum of technologically symmetric suppliers, where each single supplier has a negligible impact on the average supplier contribution, and in turn, takes this average input level as given. This is different in our setup where

his own organizational form, but also on the organization of the other supplier. Specifically, suppose supplier B is switched from vertical integration to outsourcing, so that he consequently realizes a higher revenue share (see result v). Ceteris paribus, this negatively affects A's realized revenue share, since B now takes out a larger piece of the pie. Whether this switch also has a negative effect on A's investment incentives is a priori not clear, however, because B subsequently contributes more to the relationship, so that the overall size of pie increases. We return to this issue in the next section, where it will play an important role how closely substitutable the two components are.

A direct implication of results v) and vi) is that the producer's residual revenue share is highest when both suppliers are integrated, and lowest when both are outsourced. For the intermediate cases with one integrated and one outsourced supplier (hybrid sourcing), her revenue share ranges in between.

2.5. Contract offers

Finally, after having described the bargaining and the input provision stages, we move towards the producer's organizational decision. Before doing so, notice that in stage 2 suppliers only apply for a contract if the offered payoff at least equals their outside option w_i. Hence, the participation constraint of supplier i reads as $s_i^{\Xi} - c_i \cdot \tilde{x}_i^{\Xi} + \tau_i \geq \mathrm{w}_i$. Since the producer can freely adjust the upfront payments in stage 1, those participation constraints are satisfied with equality, i.e., $\tau_i = \mathrm{w}_i - s_i^{\Xi} + c_i \cdot \tilde{x}_i^{\Xi}$.

Then, in stage 1, the producer chooses the firm's organizational structure in order to maximize her own payoff, $s_H^{\Xi} - c_H \cdot h - \tau_A - \tau_B$. Using the upfront participation fees, and bearing in mind that the sum of all Shapley values is equal to total revenue, this is equivalent to the following problem:

$$(11) \qquad \max_{\Xi} \pi = R\left(\tilde{h}^{\Xi}, \tilde{x}_A^{\Xi}, \tilde{x}_B^{\Xi}\right) - c^H \cdot \tilde{h}^{\Xi} - c_A \cdot \tilde{x}_A^{\Xi} - c_B \cdot \tilde{x}_B^{\Xi} - w_A - w_B \, .$$

In words, the producer chooses the tuple $\Xi = \{\Xi_A, \Xi_B\}$, with $\Xi_i \in \{O, V\}$, so as to maximize the joint payoff of the relationship, anticipating the implications of this organizational decision for the investment incentives of all agents (including herself) and the revenue distribution inside the firm.

3. The firm's organizational choice

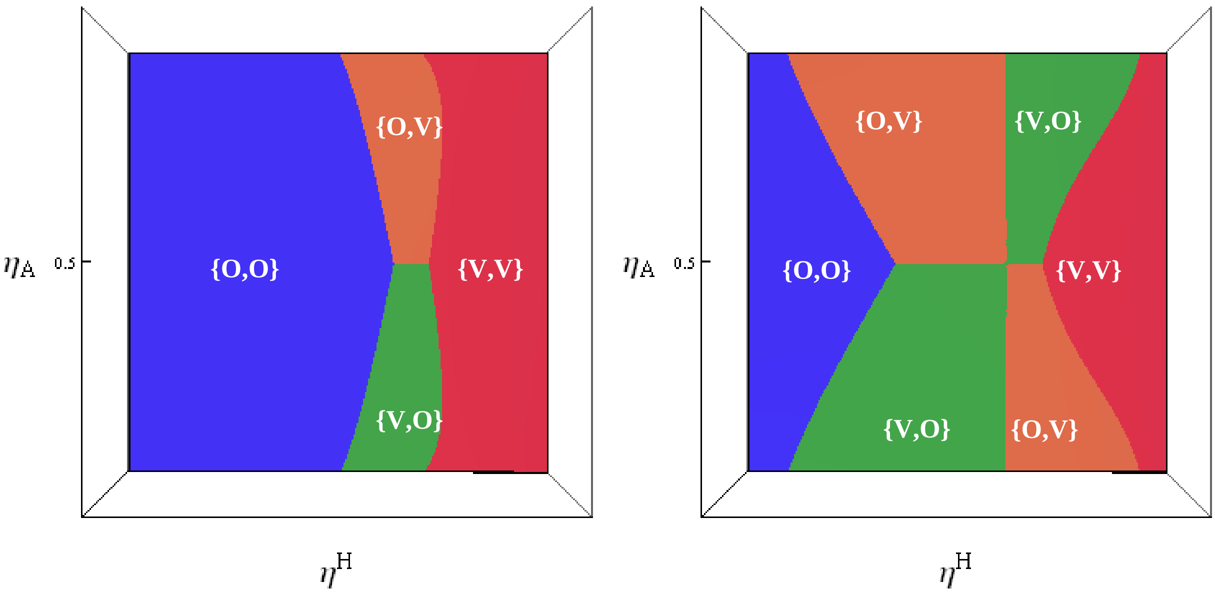
The producer's final ownership choice is illustrated in Figure 1.[10] We display headquarter-intensity η^H on the horizontal, and component A's input intensity η_A on the vertical axis. With $\eta_A = 1/2$ components are symmetric, and the technological asymmetry is larger the further away η_A is from $1/2$. Panels 1 and 2 show two examples which assume identical parameter values, except for the component substitutability α. In the left (right) panel, α is relatively high (low), meaning that

suppliers are asymmetric and have a non-negligible impact on each coalition.

[10] Since we cannot solve explicitly for the input contributions and Shapley values, we also have to rely on a numerical approach to solve for the final ownership decision. We further illustrate this approach in the Supplementary Appendix. As a further Supplement, we provide a customized MATHEMATICA 9.0 file to compute the final ownership decision, as well as input contributions and Shapley values for different parameter constellations. In the main text, we focus on the explanation of the underlying economic intuition.

components are relatively good (bad) substitutes. The different colored areas specify which ownership structure is payoff-maximizing for the firm in different ranges of η^H and η_A.

Figure 1: Ownership choice for varying headquarter-intensity and technological asymmetry



1: High substitutability ($\alpha = 0.35$) ***2: Low substitutability*** ($\alpha = 0.1$)

Common parameters: $c_A = c_B = 1$, $c^H = 1$, $\delta_A^O = \delta_B^O = 1$, $\delta_A^V = \delta_B^V = 0.85$, $\beta = 0.8$, $\theta = 1$, $Y = 1$, $w_A = w_B = 0$

In both panels, we observe that the producer decides to outsource both suppliers when the headquarter-intensity η^H is sufficiently low (blue color). Analogously, if η^H is sufficiently high, the producer chooses to keep both suppliers vertically integrated (red color). This pattern, with a positive correlation of vertical integration and headquarter-intensity, is well understood from property rights models à la Antràs (2003): Low headquarter-intensity implies that components are technologically very important in the production process. It is thus optimal to transfer ownership rights to them in order to tackle their underinvestment problems. Analogously, for high η^H, the producer provides the most important input to the production process herself. By choosing complete vertical integration, she can realize the highest possible residual revenue share to tackle her own underinvestment problem.

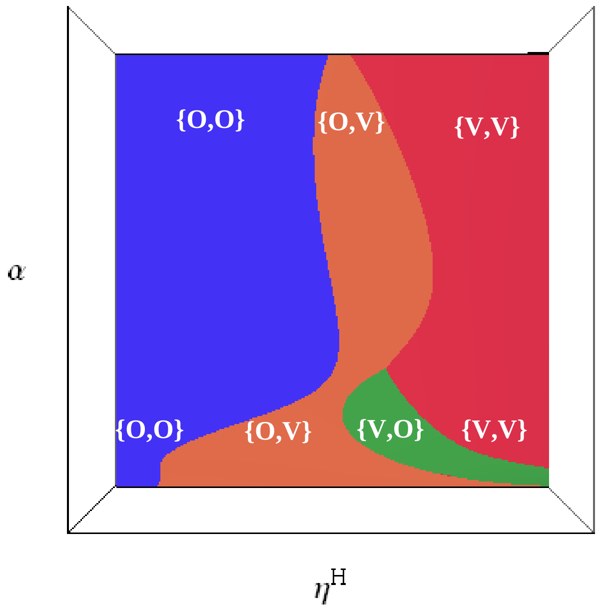
3.1. Hybrid sourcing: Which sourcing mode for which input?

Importantly, and turning to the main novel feature of our model, for intermediate values of η^H we find that the producer chooses hybrid sourcing: one supplier is outsourced, while the other one is integrated. The reason is that, for intermediate values of η^H, the uniform organizational structures $\{O, O\}$ and $\{V, V\}$ are not payoff-maximizing, as they exacerbate the underinvestment problem for the producer or, respectively, for the suppliers to an undue extent. Hybrid sourcing leads to a better balance of these underinvestment problems, and the producer uses her organizational decision to fine-tune the revenue distribution and the investment incentives inside the firm. Figure 1 also shows that a stronger technological asymmetry across the two components makes the occurrence of hybrid sourcing more likely. This can be seen by noting that the parameter range of η^H, where hybrid sourcing is chosen, expands the further away η_A is from the symmetrical value of $1/2$.

The key question for the hybrid sourcing constellations is then: Which organizational mode is chosen for which supplier? Here, the two examples in Figure 1 make partly different predictions. Focus at first on panel 1 where the two components are relatively good substitutes (α is relatively high). Here we find that the producer always outsources the supplier of the technologically more important component. This can be seen by noting that only the organizational form $\{O, V\}$ (orange) exists if $\eta_A > 1/2$, but never the form $\{V, O\}$. Vice versa, for $\eta_A < 1/2$ we only observe $\{V, O\}$ (green) but never $\{O, V\}$. The intuition is the standard incentive effect of property rights. Given that the producer finds it optimal to choose hybrid sourcing, it is more urgent for her to properly incentivize the supplier of the technologically more important input, by leaving him the ownership of his assets.

Now focus on panel 2, where we assume a lower degree of substitutability. For low-to-intermediate values of η^H, we first have a range of hybrid sourcing with the same properties as in panel 1. Then, at intermediate-to-high levels of η^H this pattern is reversed, and the producer now chooses $\{V, O\}$ for $\eta_A > 1/2$, and $\{O, V\}$ for $\eta_A < 1/2$. That is, she would now vertically integrate the strong supplier who provides the relatively more important component and outsource the weak supplier.

Figure 2: Ownership choice for varying headquarter-intensity and component substitutability



Parameters: $\eta_A = 0.8$, $c_A = c_B = 1$, $c^H = 1$, $\delta_A^O = \delta_B^O = 1$, $\delta_A^V = \delta_B^V = 0.85$, $\beta = 0.8$, $\theta = 1$, $Y = 1$, $w_a = w_b = 0$

Figure 2 illustrates the two different hybrid sourcing patterns from a different angle. Here we impose that component A is technologically more important by setting $\eta_A = 4/5$, and we then depict the payoff-maximizing ownership structure for varying levels of headquarter-intensity (horizontal axis) and component substitutability (vertical axis). If α is large, we find that the ownership structure changes over the range of η^H from $\{O, O\}$ to $\{O, V\}$ to $\{V, V\}$. In other words, when components are relatively close substitutes, the hybrid sourcing mode at intermediate levels of η^H is always such that the strong supplier A is outsourced and the weak supplier B is integrated. This case corresponds to panel 1 in Figure 1. Yet, when α is low enough, also the other hybrid sourcing pattern $\{V, O\}$ emerges at slightly higher levels of η^H, which corresponds to panel 2 of Figure 1. For high complementarity of the two component inputs, the producer may thus find it optimal to transfer ownership rights only to the weak supplier but not the strong one. In the next two subsections, we explain the intuition why this ownership pattern can be payoff-maximizing for the firm.

3.2. Input investments as strategic complements or substitutes

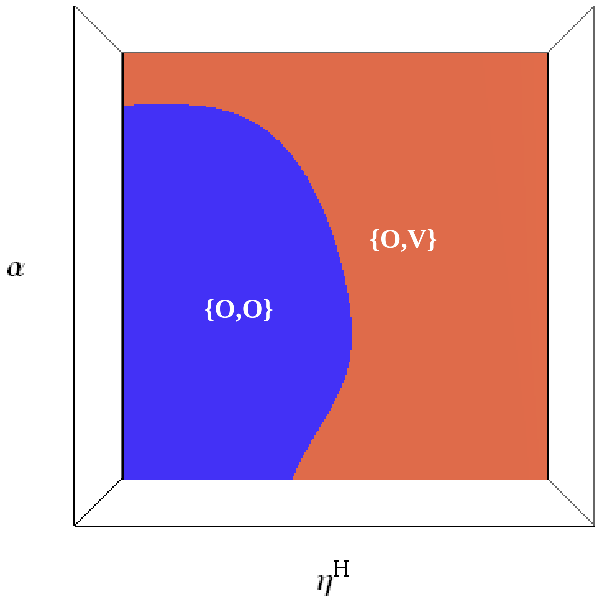
Recall from results v) and vi) above that, in terms of realized revenue shares, there is a clear ranking from the perspective of the strong supplier A, namely $\{O, V\} > \{O, O\} > \{V, V\} > \{V, O\}$. Analogously, from the perspective of the weak supplier B, this ranking is $\{V, O\} > \{O, O\} > \{V, V\} > \{O, V\}$. When the producer chooses $\{V, O\}$, she thus assigns the lowest (highest) possible revenue share to the strong (the weak) supplier, and thereby apparently acts against the standard logic of the property rights approach, according to which suppliers of more important inputs should be incentivized more.

The reason is that the above rankings might not apply with respect to the suppliers' investment incentives. That is, the organizational structure that yields a higher revenue share to a particular supplier might not necessarily induce also a higher input contribution of that supplier, if the two inputs are strongly complementary. Figure 3 further illustrates this complementarity effect.

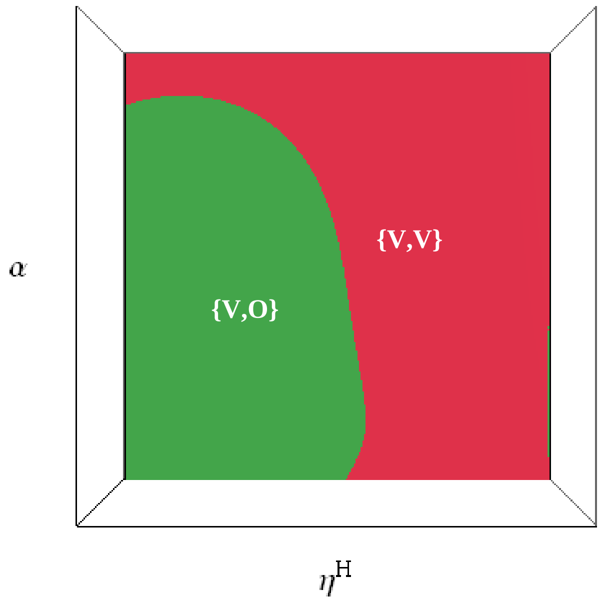
Recall from result v) above that a supplier's input provision is strictly higher if he is outsourced than if he is integrated. Hence, panel 1 of Figure 3 assumes that the strong supplier A is outsourced. It then compares, for different constellations of η^H and α, if supplier A would contribute more (in absolute terms) under the ownership structure $\{O, V\}$ that leaves him the highest possible revenue share, or under $\{O, O\}$ where his own realized revenue share is lower, but where the revenue share and the input contribution of the other supplier B are higher. In panel 2 we respectively compare the two "low-stake" structures $\{V, V\}$ and $\{V, O\}$ in terms of A's input contributions, and panels 3 and 4 are constructed analogously for the weak supplier B.

Starting with panel 1 of Figure 3, and assuming a high value of α (good substitutability), we observe that supplier A would generally contribute more under the $\{O, V\}$ structure. In that case, the structure that yields him the highest revenue share also gives him the best investment incentives. For lower values of α, however, this is no longer true if η^H is sufficiently small. Here we find that supplier A may actually contribute more under the $\{O, O\}$ structure, despite the fact that he would then receive a lower revenue share. The reason is that $\{O, O\}$ provides much better investment incentives to the weak supplier B than $\{O, V\}$. Since the two components are complementary, this in turn encourages A to also invest more, provided that the producer's revenue share is not too large, i.e., provided that a large enough piece of the cake is left for the suppliers overall (η^H not too large).

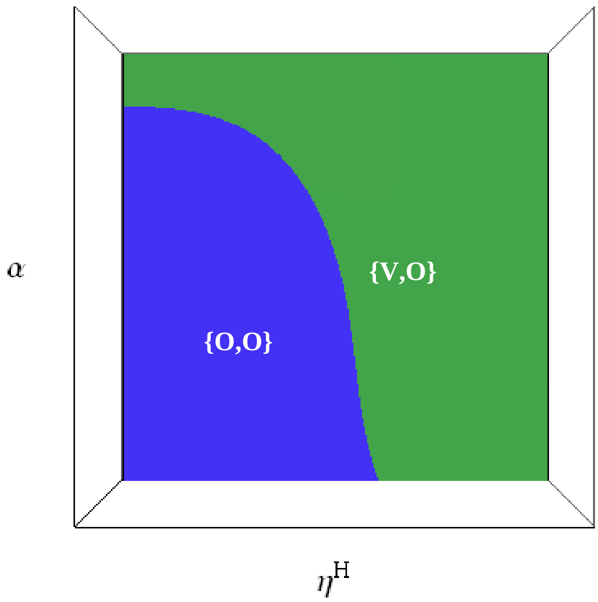
Figure 3: Absolute input provisions of the two suppliers



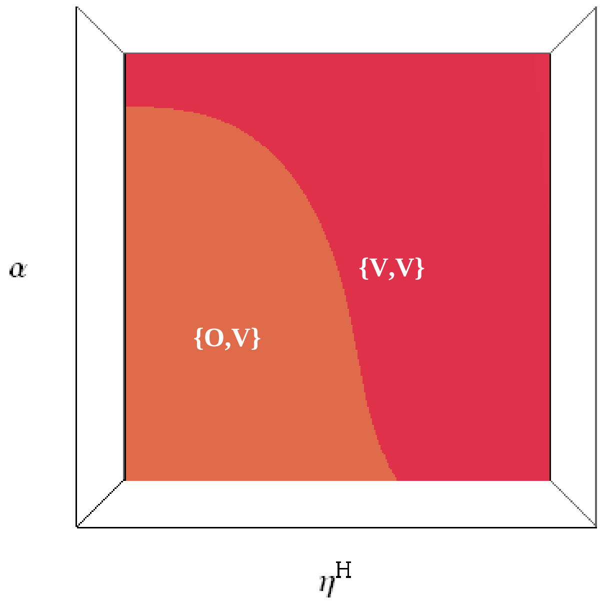
1: Supplier A – {O,O} vs. {O,V}



2: Supplier A – {V,O} vs. {V,V}



3: Supplier B – {O,O} vs. {V,O}



4: Supplier B – {O,V} vs. {V,V}

Parameters: $\eta_A = 0.8$, $c_A = c_B = 1$, $c^H = 1$, $\delta_A^O = \delta_B^O = 1$, $\delta_A^V = \delta_B^V = 0.85$, $\beta = 0.8$, $\theta = 1$, $Y = 1$, $w_A = w_B = 0$

Analogously, comparing in panel 2 the two "low-stake" structures from A's perspective, we find that he always invests more under $\{V,V\}$ than under $\{V,O\}$ if α is sufficiently high, as he generally realizes a higher revenue share with $\{V,V\}$. Yet, for low enough values of α and η^H, the strong supplier A actually invests more under $\{V,O\}$ than under $\{V,V\}$, because $\{V,O\}$ strongly encourages the weak supplier B to invest. Interestingly, this complementarity effect only kicks in if $\alpha < \beta$, i.e., if the elasticity of substitution across components is lower than the elasticity of demand for the final product. Moreover, it can again be seen that this effect eventually fades away if η^H becomes too large, because the producer then takes out too much of the overall surplus for herself and leaves too little room for the mutual cross-fertilization of the suppliers' investment incentives to play out. [11]

The relative size of the two elasticities (adjusted for headquarter-intensity) plays a key role in the recent model by Antràs and Chor (2013). In their sequential ("snake") setup, suppliers are differentiated by their position on a vertical value chain. If α is relatively low compared to β, supplier investments are *sequential complements*, in the sense that higher downstream investments raise the marginal investment return for upstream suppliers and thereby encourage upstream contributions. Vice versa, if α is relatively high compared to β, supplier investments are *sequential substitutes*, and higher downstream investments discourage upstream suppliers since marginal revenue for the final product is decreasing at a rapid pace. Our model features a "spider" structure, where components are asymmetric in their technological importance but are placed on the same stage of the value chain and, thus, enter the production process simultaneously. Still, there is a similar intuition how the suppliers' investment incentives are interrelated, which shows that this mechanism, per se, does not crucially hinge on the sequentiality of the production process. In particular, for low values of α relative to β and η^H we may call supplier investments *strategic complements* as they reinforce each other. Vice versa, if α is relatively large, supplier investments are *strategic substitutes*.

3.3. Why might be firm keep the important component in-house?

This distinction between complements and substitutes is then key to understand the payoff-maximizing ownership pattern as depicted in Figure 2. Suppose at first that $\alpha > \beta$, so that components are always strategic substitutes. For intermediate levels of η^H the producer then outsources the strong and vertically integrates the weak supplier (recall that $\eta_A = 4/5$ in Figure 2, so that component A is technologically more important than B). Intuitively, hybrid sourcing optimally balances the two "aggregate" underinvestment problems between the producer and the suppliers at large. Since the investment incentives of each single supplier are strictly increasing in the anticipated revenue share in the strategic substitutes case, it is then more important for the firm to provide the best incentives to the strong supplier. This is achieved by the organizational decision $\{O, V\}$.

Now consider the opposite extreme where α is very low, and the two components are close to essential in production. Similar as in the substitutes case, for low η^H the organizational decision is still $\{O, O\}$, and for high η^H it is still $\{V, V\}$. Moreover, for low-to-intermediate levels of η^H the producer continues choosing $\{O, V\}$. Clearly, that organizational choice provides rather bad investment incentives for the weak supplier B, but since the producer takes out only a relatively small headquarter revenue share for

[11] Notice that the value of β is set to 4/5 in Figure 3. For very low headquarter-intensity ($\eta^H \to 0$), both suppliers contribute more under their respective revenue share-maximizing ownership structure if $\alpha>\beta=4/5$, while they contribute more under the respective other structure if $\alpha<\beta$. At higher levels of η^H, α must be *sufficiently* smaller than β so that suppliers invest less under their respective revenue share-maximizing ownership structure.

herself, enough is left to induce a sufficiently high contribution x_B. As η^H rises even further, however, the pattern eventually switches from $\{O, V\}$ to $\{V, O\}$.
The intuition for this shift is the following: Eventually, it is clear that the producer will revert to the $\{V, V\}$ structure if η^H is high enough. However, an immediate switch from $\{O, V\}$ to $\{V, V\}$ is not optimal, because this would lead to a stronger discouragement of both suppliers than the switch from $\{O, V\}$ to $\{V, O\}$. For the weak supplier B this is straightforward to see, but it also holds for the strong supplier A who still contributes more under $\{V, O\}$ than under $\{V, V\}$ as the two components are strongly complementary (see panel 2 in Figure 3). The transition towards the $\{V, V\}$ structure only occurs at even higher levels of η^H where an ever smaller piece of the pie is left for the suppliers, and the strategic complementarity at some point fades away.
Summing up, the organizational decision in our "spider" model is driven by two forces that we may call the *incentive effect* from property rights and the *complementarity effect*. If the former effect prevails, our model predicts that firms tend to outsource the suppliers of their technologically most important components, while keeping only relatively unimportant components vertically integrated. Yet, if the latter effect is sufficiently strong, our model can predict a different ownership structure where firms keep their technologically most important components in-house. Apparently, this latter case is empirically very relevant as highlighted in the introduction. Our model structure is, unfortunately, too complex to delineate the exact analytical conditions under which this happens, but the above discussion makes clear that the single component inputs must be (close to) essential, and that the importance of headquarter services must neither be too high nor too low.

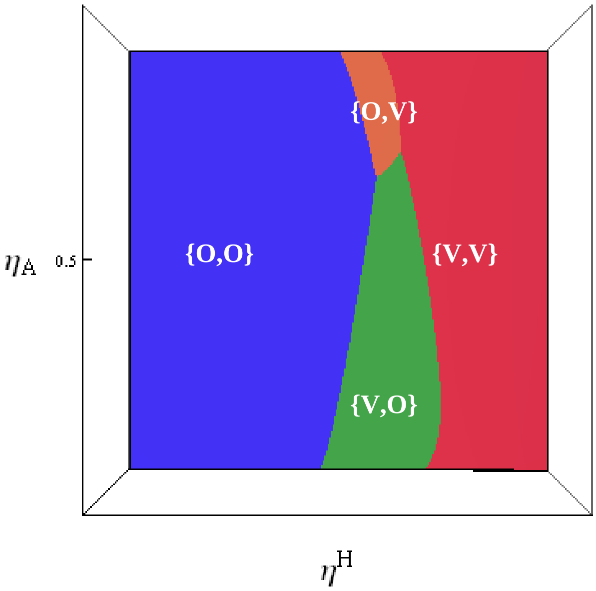
4. Asymmetries in component sophistication and unit costs

4.1. Asymmetries in the components' degree of sophistication

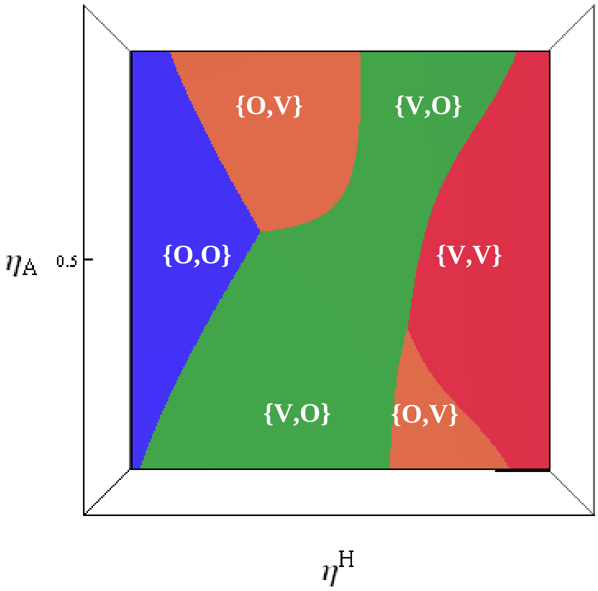
Now suppose that the suppliers' components also differ in their degree of sophistication. More precisely, we assume $\delta_A^V > \delta_B^V$, which implies that supplier A provides a more sophisticated input than B, in the sense that A threatens to withhold a higher input fraction if he refused to collaborate under vertical integration. The producer's ownership decision for this case is depicted in Figure 4. As before we display η^H on the horizontal, and η_A on the vertical axis. Moreover, the left panel assumes that the two inputs are relatively good substitutes, while substitutability α is lower in the right panel.
As before, the producer chooses outsourcing (vertical integration) of both suppliers for sufficiently low (high) values of the headquarter-intensity. Also similarly as before, for intermediate values of η^H, the producer chooses hybrid sourcing, and the level of substitutability crucially affects *which* hybrid sourcing constellation is chosen.
Turning to the new feature in Figure 4, it predicts that the firm tends to keep the more sophisticated input in-house. To see this, focus at first on the left panel, where inputs are relatively good substitutes. Compared to the left panel in Figure 1, we observe that the area $\{O, V\}$ (orange) becomes smaller

while the area $\{V, O\}$ (green) becomes larger. In particular, there are now constellations in the hybrid sourcing range where $\{V, O\}$ is chosen also for values of η_A larger than $1/2$. That is, given that input A is more sophisticated ($\delta_A^V > \delta_B^V$) and technologically mildly more important ($\eta_A > \eta_B$), the producer finds it profitable to integrate this input, and to outsource the less important, less sophisticated input B.[12] Only if the technological asymmetry becomes very strong, would the producer return to the ownership form $\{O, V\}$.

Figure 4: Asymmetries in the degree of sophistication



1: High substitutability ($\alpha = 0.35$)



2: Low substitutability ($\alpha = 0.1$)

Common parameters: $c_A = c_B = 1$, $c^H = 1$, $\delta_A^O = \delta_B^O = 1$, $\delta_A^V = 0.9$, $\delta_B^V = 0.85$, $\beta = 0.8$, $\theta = 1$, $Y = 1$, $w_A = w_B = 0$

What is the intuition for this organizational decision? Recall from result iii) above that a higher sophistication implies, ceteris paribus, a higher revenue share and a higher input provision of the respective supplier, because he can exploit the fact that his physical input is hardly usable for the firm without his collaboration. In other words, due to the high sophistication of his component, supplier A has high bargaining power and good incentives even as an affiliate of the firm. The transfer of ownership rights is thus not as urgently required. For supplier B, by contrast, incentives under vertical integration are worse since he has lower bargaining power vis-à-vis the producer, owing to the fact that his input is rather standard and easy to utilize even without his cooperation. The provision of ownership rights is therefore more effective as an incentivizing device for this supplier.

In short, in panel 1 of Figure 4, the final ownership choice is driven by two forces: the standard *incentive effect* and a new *sophistication effect*, according to which simple inputs should be outsourced

[12] Remember that this would not happen with equal sophistication. In that case, we would only observe {O,V} in that range with $\eta_A > 1/2$.

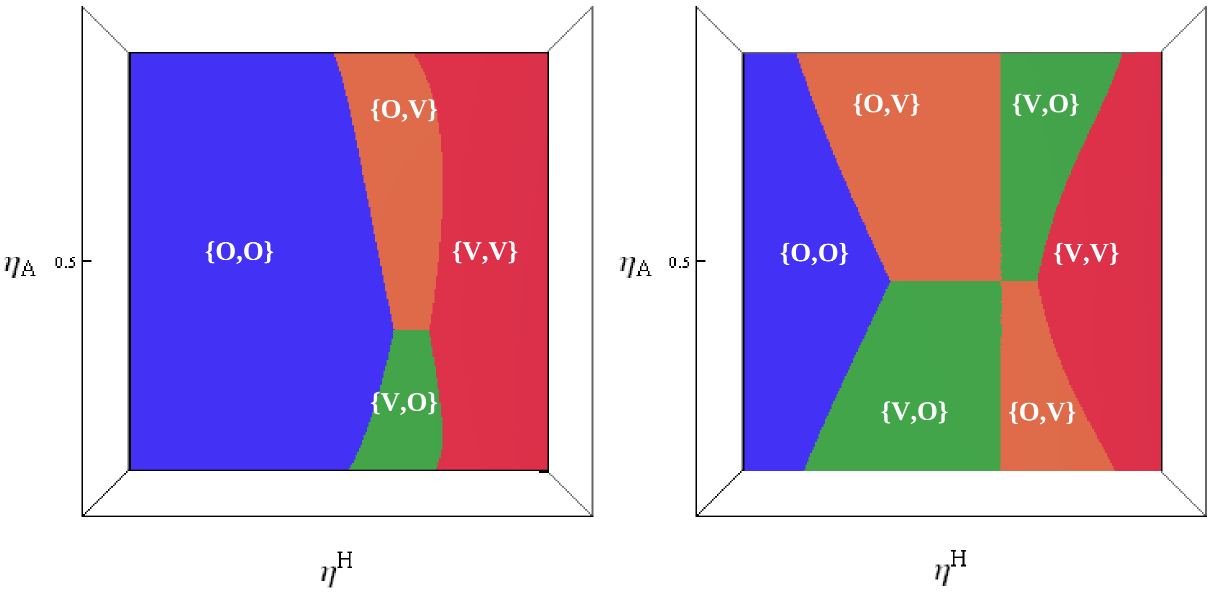
since the respective suppliers cannot be properly incentivized inside the firm.

Finally, in panel 2 of Figure 4, the previously described *complementarity effect* is added to the picture. Even without the heterogeneous sophistication, the firm would now sometimes choose to integrate the technologically more important input (see right panel of Figure 1). If, in addition, input A is also more sophisticated, this only reinforces that choice. To see this, note that the $\{V, O\}$ choice in the right panel of Figure 4 is much more pervasive than in the right panel of Figure 1, where components are equally sophisticated. Especially in the range of η_A mildly above $1/2$, we see that the $\{V, O\}$ pattern percolates, which is partly driven by the complementarity and partly by the sophistication effect.

4.2. Asymmetries in the suppliers' unit costs

Finally, suppose that supplier A now faces lower unit costs of input provision than supplier B, i.e., $c_A < c_B$, while again assuming an equal degree of sophistication. Figure 5 is analogous to Figure 1 and depicts the resulting ownership decision.

Figure 5: Asymmetries in the suppliers' unit costs



1: High substitutability ($\alpha = 0.35$) ***2: Low substitutability*** ($\alpha = 0.1$)

Common parameters: $c_A = 1$, $c_B = 3$, $c^H = 1$, $\delta_A^O = \delta_B^O = 1$, $\delta_A^V = \delta_B^V = 0.85$, $\beta = 0.8$, $\theta = 1$, $Y = 1$, $w_A = w_B = 0$

Focus again on the left panel at first, which depicts the case of high substitutability. Comparing it with Figure 1, we see that the $\{O, V\}$ area now expands and the $\{V, O\}$ area shrinks. More specifically, the producer might now choose $\{O, V\}$ even if $\eta_A < 1/2$. That is, she might vertically integrate supplier B even if his input is technologically more important, if that supplier also has relatively higher unit costs. Vice versa, the firm tends to outsource the low-cost supplier A, even if his input is technologically slightly less important. The intuition behind this choice is clear from result iv) described above: The lower unit costs c_A raise supplier A's input provision, and increase his Shapley value. Since supplier investments are strategic substitutes, it thus becomes more important for the firm to further boost A's incentives, hence the greater outsourcing tendency for that input. The producer only reverts to the ownership choice $\{V, O\}$ in the hybrid sourcing range if η_A becomes very small. This comes from the fact that the asymmetry in technological importance is then so strong relative to the difference in unit costs, that the firm finds it optimal to incentivize supplier B who produces a highly important input.

The strategic complements case depicted in the right panel of Figure 5 follows a similar logic. Comparing it to the right panel in Figure 1, we observe that the critical level of η_A where the hybrid sourcing constellations switch, is now no longer at $\eta_A = 1/2$ but at a lower level of η_A. In other words, also in this case we observe the increased tendency to outsource the low-cost supplier A.

One possible reason *why* a component supplier could have lower unit costs than the other is the location of the two suppliers. Suppose the low-cost supplier A is foreign, while supplier B comes from the domestic country where wages and production costs are generally higher. Our results can then be rephrased such that there is a positive correlation of outsourcing and offshoring: All else equal (i.e., for $\eta_A = 1/2$), and for medium headquarter-intensity, the firm would choose an external supplier organization for its foreign supplier, while the domestic supplier is integrated.

Another aspect is that the suppliers' unit costs may be systematically related to the technological asymmetry across components. To understand this point, suppose that supplier A provides the technologically more important input ($\eta_A > 1/2$), but because of this has higher unit costs ($c_A > c_B$). Which ownership form the producer chooses in the hybrid sourcing range then depends on the relative size of the two asymmetries. The technological asymmetry tends to push the $\{O, V\}$ structure, and unambiguously so in the strategic substitutes case, while the cost asymmetry pushes $\{V, O\}$.

5. Conclusion

In this paper we have introduced supplier heterogeneity into a property rights model. The firm operates a "spider" production process where two asymmetric inputs are simultaneously combined with headquarter services to a final product. Our model extends the seminal framework by Antràs (2003) and Antràs and Helpman (2004), and captures the empirically highly relevant scenario of "hybrid sourcing" where the firm chooses a different sourcing mode for some suppliers than for others. In particular, and in contrast to the recent model by Schwarz and Suedekum (2014), it allows us to analyze *which* sourcing mode is chosen for *which* of the asymmetric inputs.

Depending on the elasticity of substitution across components and the price elasticity of final goods demand, the supplier investments can be either *strategic substitutes* or *strategic complements* in our model. If they are substitutes, our model predicts that the firm tends to outsource the technologically more important input, in order to shift bargaining power to the respective suppliers and incentivize him to contribute to the relationship. Yet, many case studies from the business literature show that firms often choose a different hybrid sourcing pattern in production processes that can be reasonably well approximated by a “spider” setup. For example, firms like *Glashütte Original*, *Jaeger-LeCoultre*, *Rolex*, and many others, tend to keep their most important inputs in-house, and only outsource relatively less important components.

At first glance, such an ownership decision appears to be at odds with the received logic of the property rights approach. Yet, our model can fully rationalize this firm behavior within a property rights framework. The key factor is strong complementarity across inputs. If both components are close to essential, it can be optimal for the firm to shift property rights only to the relatively weak supplier, because his incentives would be very low inside the firm, which in turn backfires on the strong supplier if the degree of complementarity is high. Relatedly, if components differ in their inherent degree of sophistication, the firm tends to outsource the relatively simpler input. The more sophisticated component, however, is typically kept in-house. That result is consistent with firm-level empirical findings by Corcos et al. (2013) and Costinot et al. (2011). Finally, our model predicts that low-cost suppliers are more likely to be outsourced. This may rationalize the empirical finding by Kohler and Smolka (2014) that Spanish manufacturing firms tend to choose outsourcing more often when dealing with (low-cost) foreign than with (high-cost) domestic suppliers.

The major shortcoming of our framework is that we have to rely on a numerical approach. This is due to the fact, that in our setup with multilateral bargaining among asymmetric agents, we cannot come up with closed-form solutions for the optimal input investments and the resulting revenue shares (Shapley values). To resolve this issue of analytical non-tractability, we would have to impose symmetry at various point. This, however, would run exactly opposite to our main aim of studying the realistic scenario of a firm that contracts with multiple *heterogeneous* suppliers. Still, we believe that our model structure is useful as it allows us to separate the single forces that govern the firm’s ultimate ownership decision, and to discuss their economic intuition.

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Asymmetric Spiders:
Supplier Heterogeneity and the Organization of Firms

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April 2014

Supplementary Appendix – Not for publication!

<u>Outline of the Supplementary Appendix</u>

This Supplementary Appendix consists of two parts.

In part I, we illustrate the results spelled out in section 2.4. of the main text (see page 8). Those results refer to the payoff-maximizing input contributions of the three agents (the producer and the two suppliers A and B) and their realized revenue shares (Shapley value over total revenue) in the multilateral bargaining. For each result, we illustrate the respective realized revenue shares or input contributions (in either absolute or relative terms) for various parameter constellations reported next to each specific figure.

In part II, we illustrate the producer's ownership decision analogously as in Figure 1-5 in the main text. We assume different parameter constellations as in the main text and thereby illustrate the robustness of our findings discussed there. For each figure in this Supplementary Appendix, we mention the analogous figure in the main text.

We have produced all figures with the MATHEMATICA 9.0 file that is provided as a further supplement to this paper.

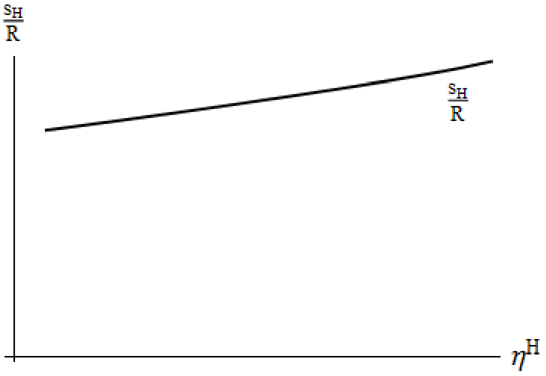
I. Revenue shares and input contributions

i) higher headquarter-intensity η^H

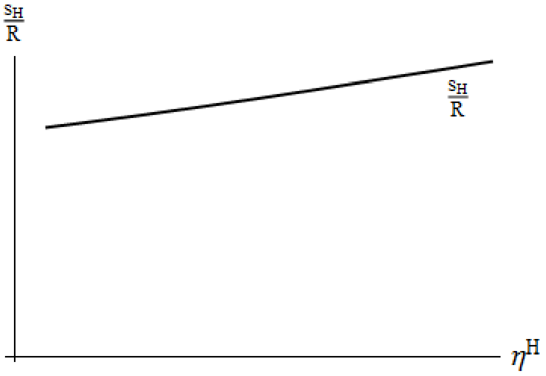
Common parameters: $c_A = c_B = 1$, $c^H = 1$, $\delta_A = \delta_B = 0.85$, $\eta_A = 0.5$, $\theta = 1$, $Y = 1$, $w_A = w_B = 0$

- The higher is the headquarter-intensity η^H, the higher is the producer's realized revenue share.

$\alpha < \beta$, low substitutability

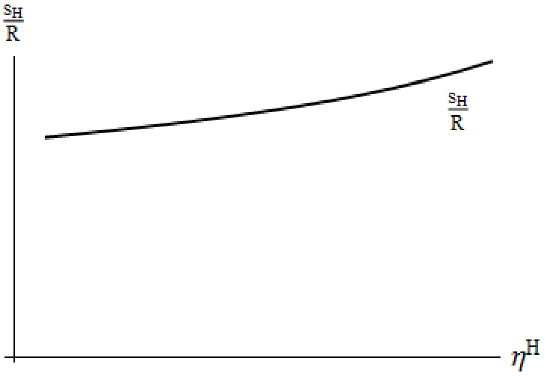


$\alpha = 0.1$, $\beta = 0.8$

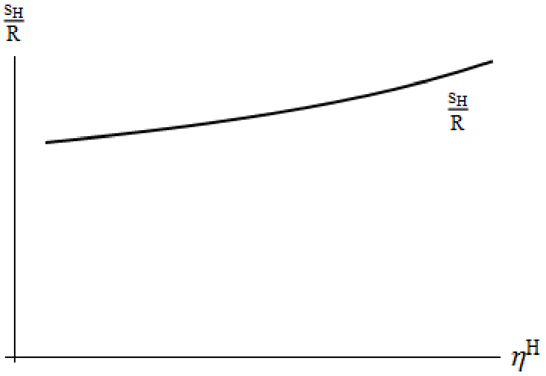


$\alpha = 0.05$, $\beta = 0.7$

$\alpha < \beta$, high substitutability

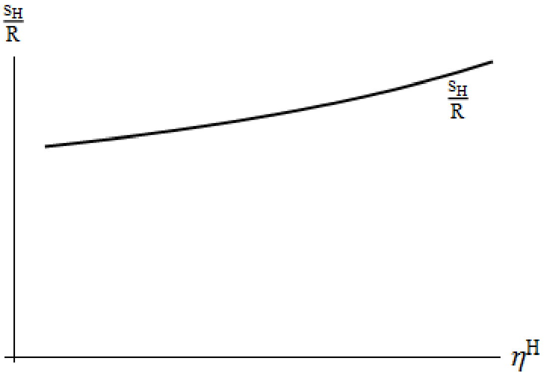


$\alpha = 0.35$, $\beta = 0.8$

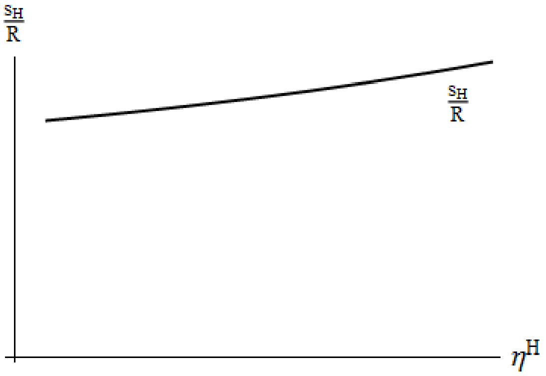


$\alpha = 0.5$, $\beta = 0.8$

$\alpha > \beta$, very high substitutability



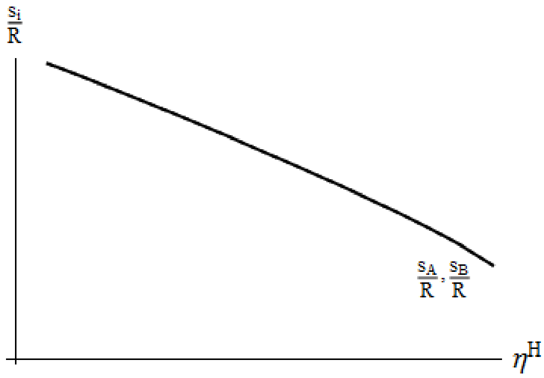
$\alpha = 0.9$, $\beta = 0.8$



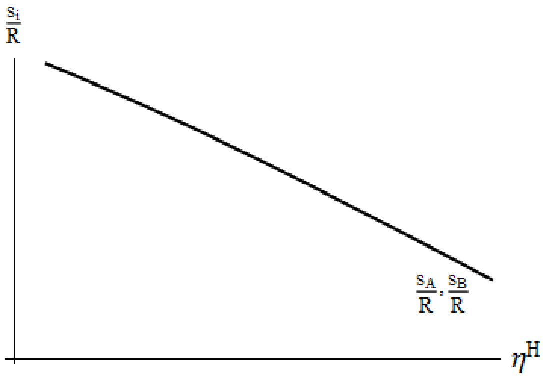
$\alpha = 0.7$, $\beta = 0.4$

- The higher is the headquarter-intensity η^H, the lower are the revenue shares of the two suppliers $\left(\frac{s_A}{R}, \frac{s_B}{R}\right)$.

$\alpha < \beta$, low substitutability

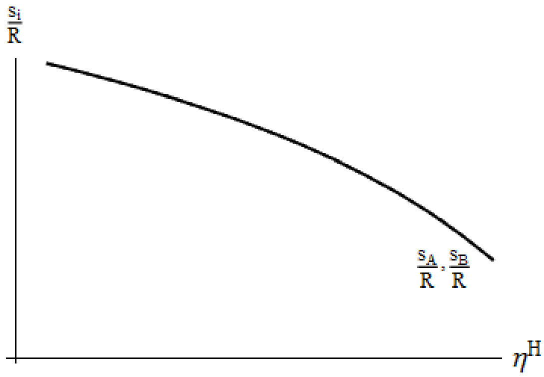


$\alpha \ = \ 0.1, \beta = 0.8$

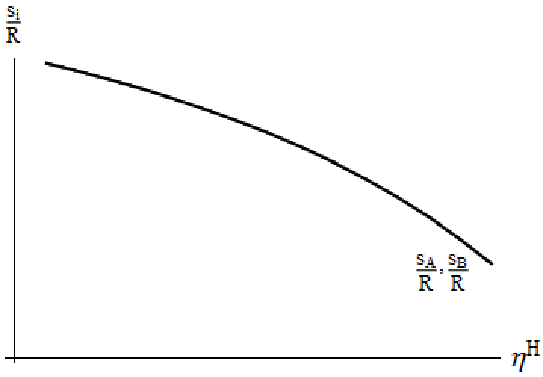


$\alpha \ = \ 0.05, \beta = 0.7$

$\alpha < \beta$, high substitutability

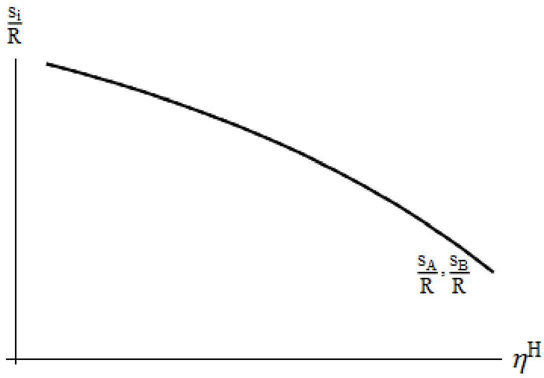


$\alpha \ = \ 0.35, \beta = 0.8$

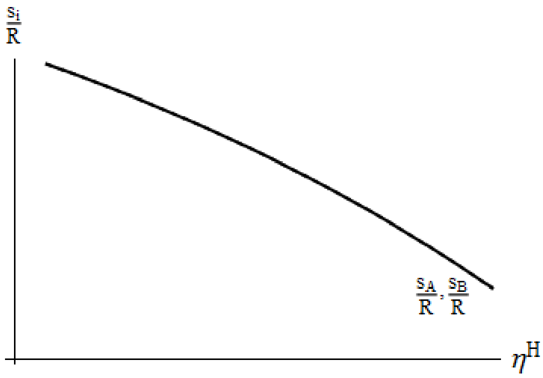


$\alpha \ = \ 0.5, \beta = 0.8$

$\alpha > \beta$, very high substitutability



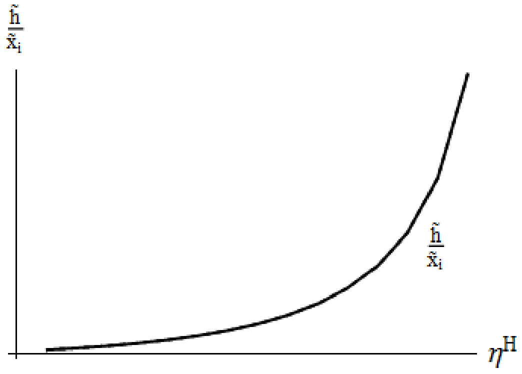
$\alpha \ = \ 0.9, \beta = 0.8$



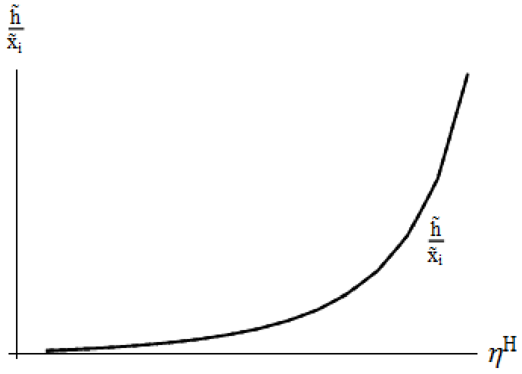
$\alpha \ = \ 0.7, \beta = 0.4$

- The higher is the headquarter-intensity η^H, the higher is the input contribution of the producer relative to the two suppliers $\frac{\tilde{h}}{\tilde{x}_i}$.

α < β*, *low substitutability

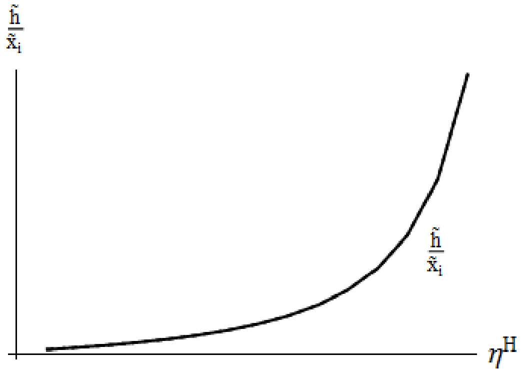


$\alpha = 0.1, \beta = 0.8$

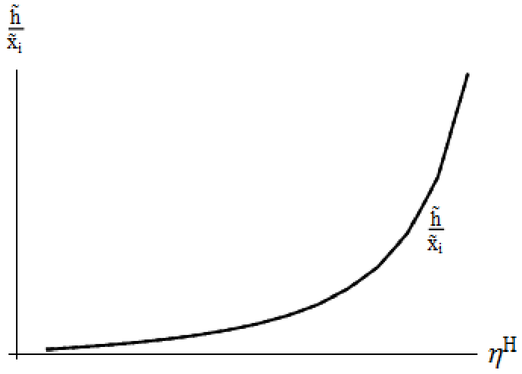


$\alpha = 0.05, \beta = 0.7$

α < β*, *high substitutability

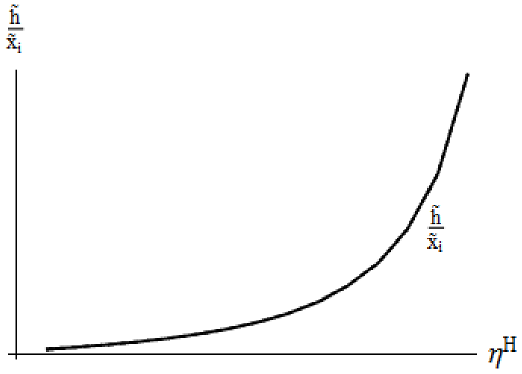


$\alpha = 0.35, \beta = 0.8$

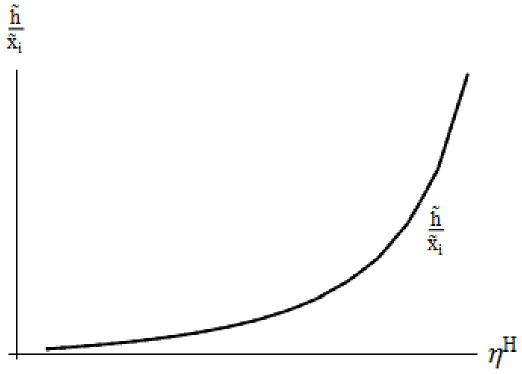


$\alpha = 0.5, \beta = 0.8$

α > β*, *very high substitutability



$\alpha = 0.9, \beta = 0.8$



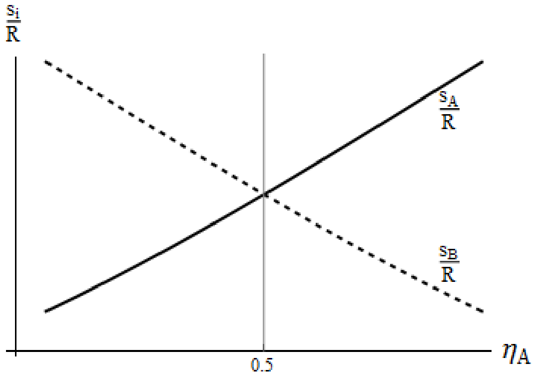
$\alpha = 0.7, \beta = 0.4$

ii) higher technological importance of supplier A's input ($\eta_A > \eta_B$)

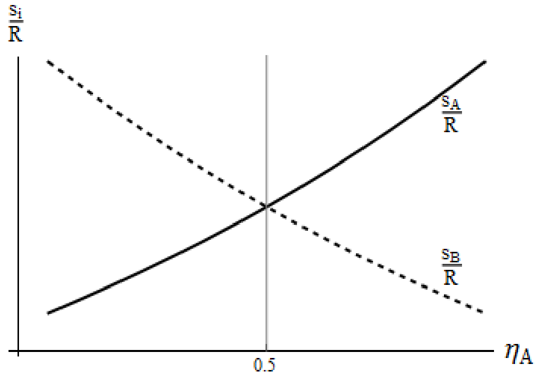
Common parameters: $c_A = c_B = 1$, $c^H = 1$, $\delta_A = \delta_B = 0.85$, $\eta^H = 0.8$, $\theta = 1$, $Y = 1$, $w_A = w_B = 0$

- If supplier A's input has a higher input intensity than supplier B's input, i.e. $\eta_A > \eta_B$, supplier A realizes a higher revenue share than supplier B, i.e. $\frac{s_A}{R} > \frac{s_B}{R}$. For the opposite case with $\eta_A < \eta_B$, results are analogous and we obtain $\frac{s_A}{R} < \frac{s_B}{R}$

$\alpha < \beta$, low substitutability

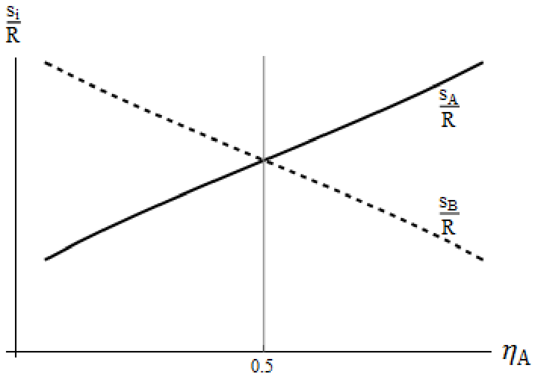


$\alpha = 0.1, \beta = 0.8$

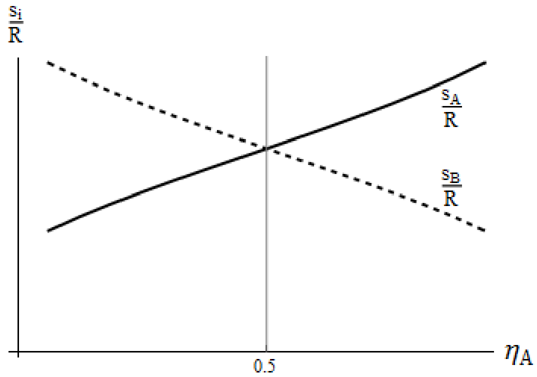


$\alpha = 0.05, \beta = 0.7$

$\alpha < \beta$, high substitutability

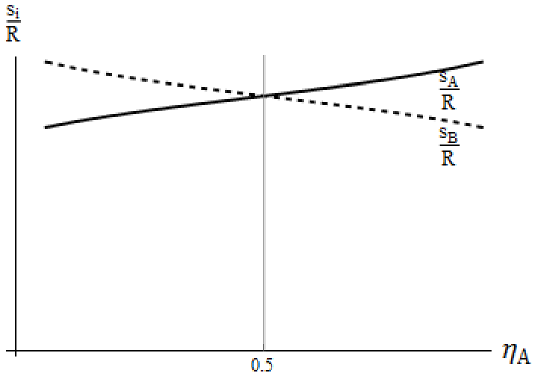


$\alpha = 0.35, \beta = 0.8$

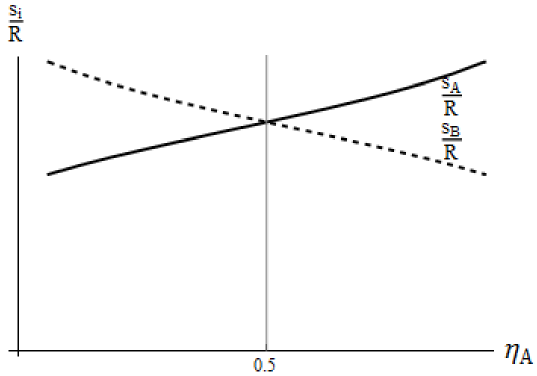


$\alpha = 0.5, \beta = 0.8$

$\alpha > \beta$, very high substitutability



$\alpha = 0.9, \beta = 0.8$

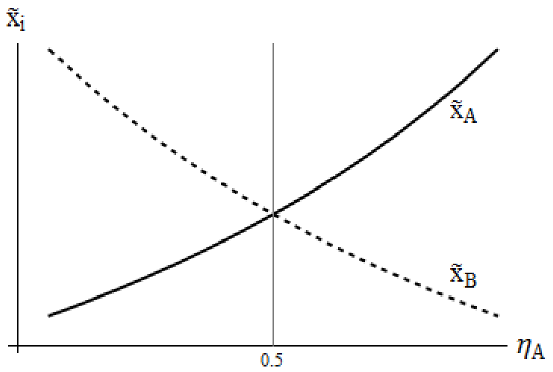


$\alpha = 0.7, \beta = 0.4$

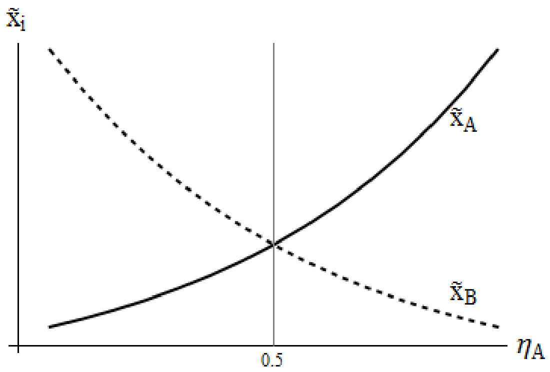
- If supplier A's input has a higher input intensity than supplier B's input, , i.e. $\eta_A > \eta_B$, supplier A makes a higher input contribution than supplier B , i.e. $\tilde{x}_A > \tilde{x}_B$. Vice versa, $\tilde{x}_A < \tilde{x}_B$ for $\eta_A < \eta_B$.

Absolute input contributions

***α* < *β*, low substitutability**

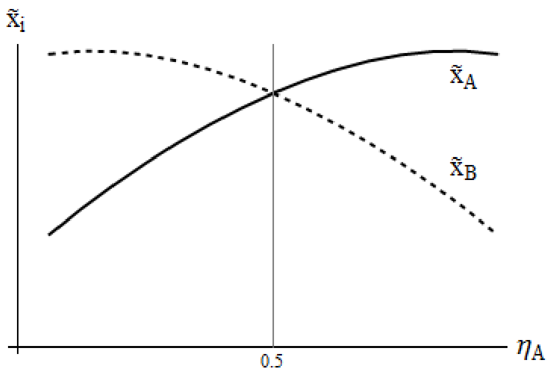


$\alpha = 0.1, \beta = 0.8$

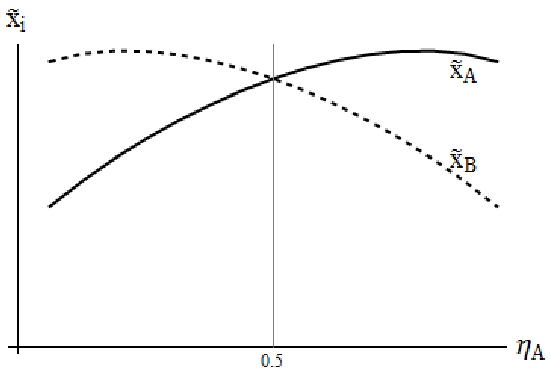


$\alpha = 0.05, \beta = 0.7$

***α* < *β*, high substitutability**

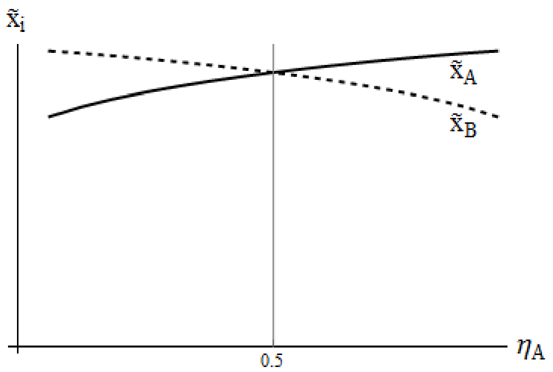


$\alpha = 0.35, \beta = 0.8$

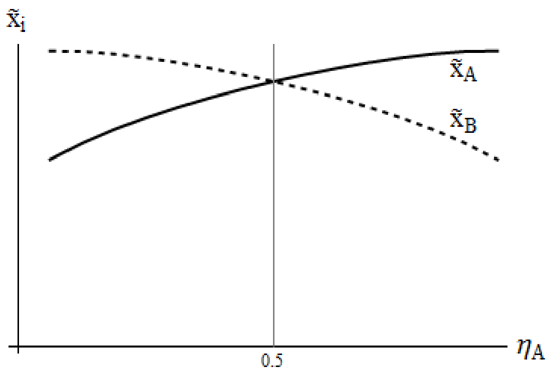


$\alpha = 0.5, \beta = 0.8$

***α* > *β*, very high substitutability**



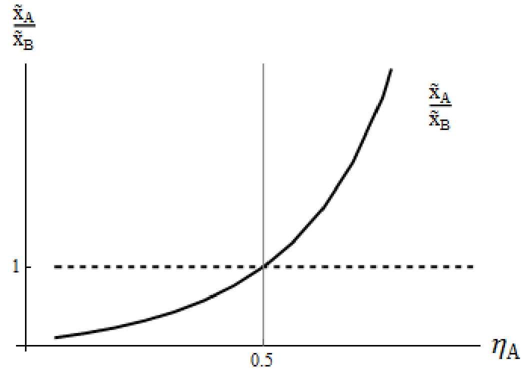
$\alpha = 0.9, \beta = 0.8$



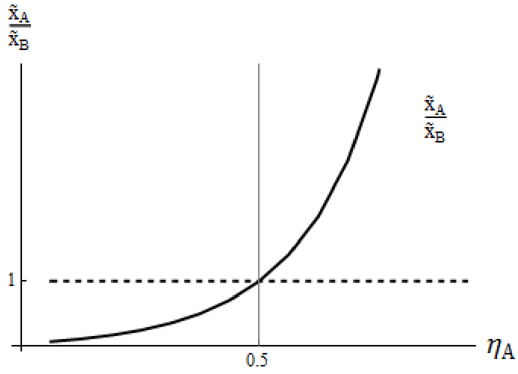
$\alpha = 0.7, \beta = 0.4$

Relative supplier input contributions

α < β, low substitutability

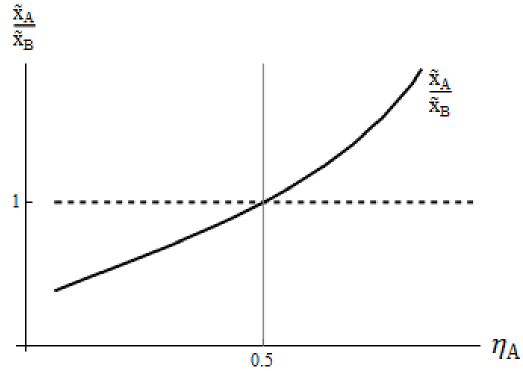


$\alpha = 0.1, \beta = 0.8$

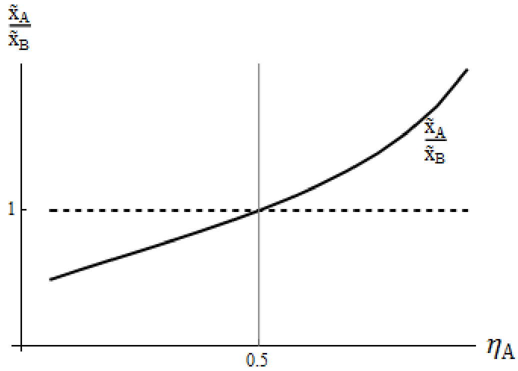


$\alpha = 0.05, \beta = 0.7$

α < β, high substitutability

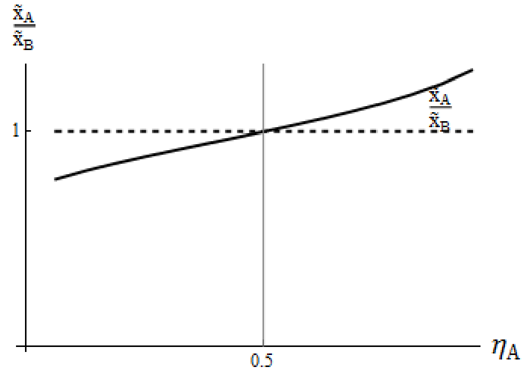


$\alpha = 0.35, \beta = 0.8$

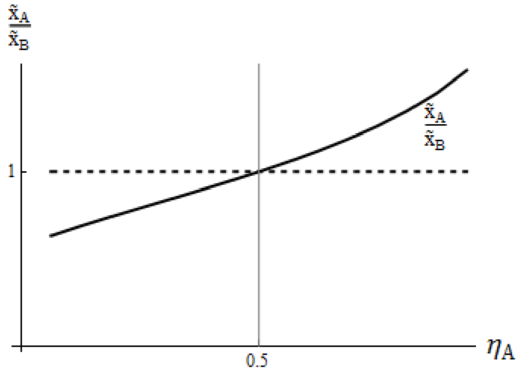


$\alpha = 0.5, \beta = 0.8$

α > β, very high substitutability



$\alpha = 0.9, \beta = 0.8$



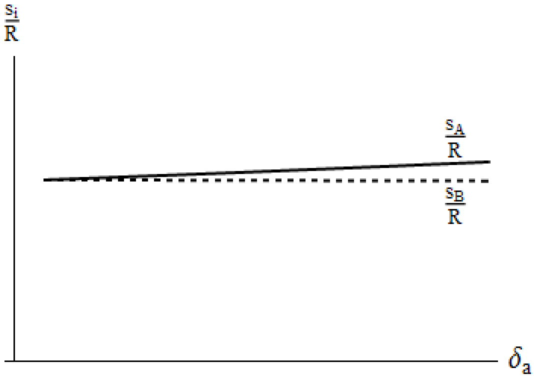
$\alpha = 0.7, \beta = 0.4$

iii) higher sophistication of supplier A's input ($\boldsymbol{\delta_A > \delta_B}$)

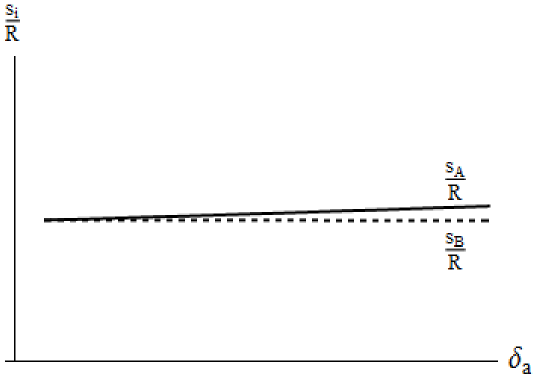
Common parameters: $c_A = c_B = 1$, $c^H = 1$, $\delta_A \geq 0.85$, $\delta_B = 0.85$, $\eta_A = 0.5$, $\eta^H = 0.8$, $\theta = 1$, $Y = 1$, $w_A = w_B = 0$

- If supplier A's input is more sophisticated than supplier B's input ($\delta_A > \delta_B$), supplier A realizes a higher revenue share than supplier B $\left(\frac{s_A}{R} < \frac{s_B}{R}\right)$.

***$\alpha < \beta$*, low substitutability**

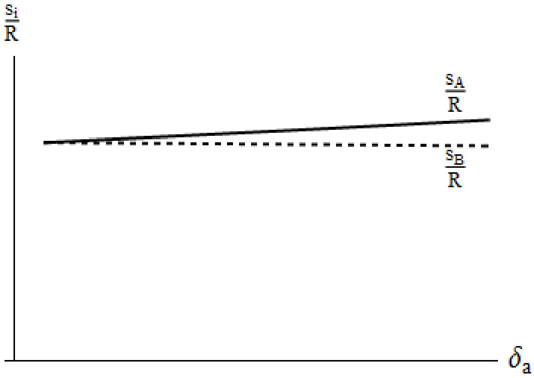


$\alpha = 0.1, \beta = 0.8$

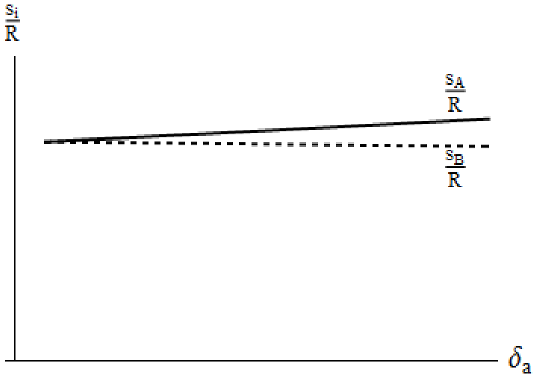


$\alpha = 0.05, \beta = 0.7$

***$\alpha < \beta$*, high substitutability**

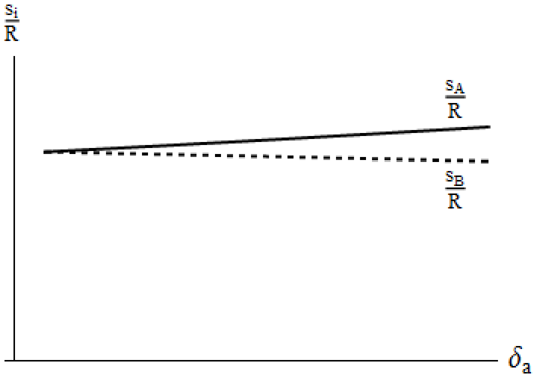


$\alpha = 0.35, \beta = 0.8$

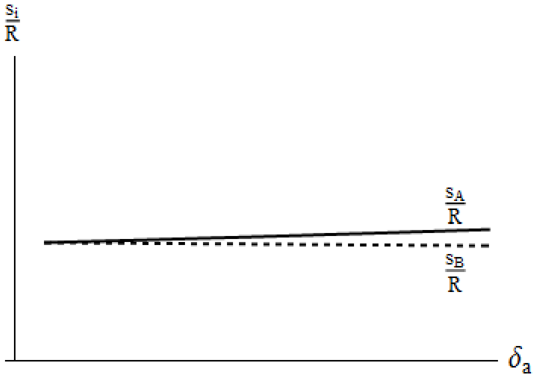


$\alpha = 0.5, \beta = 0.8$

***$\alpha > \beta$*, very high substitutability**



$\alpha = 0.9, \beta = 0.8$

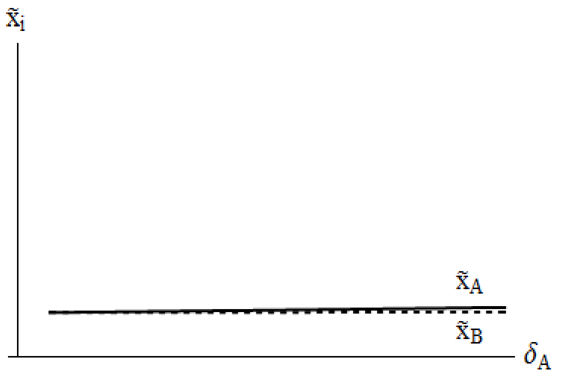


$\alpha = 0.7, \beta = 0.4$

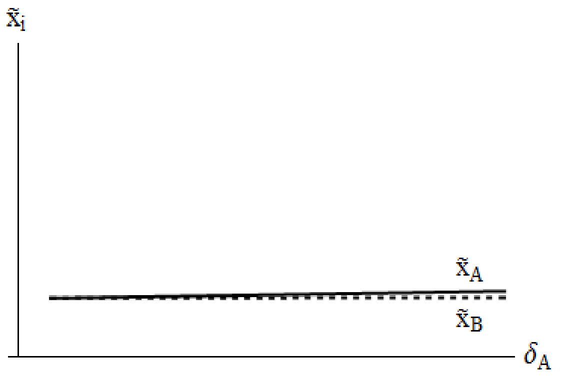
- If supplier A's input has a higher sophistication than supplier B's input ($\delta_A > \delta_B$), supplier A makes a higher input contribution than supplier B ($\tilde{x}_A > \tilde{x}_B$).

<u>Absolute input contributions</u>

α < β, low substitutability

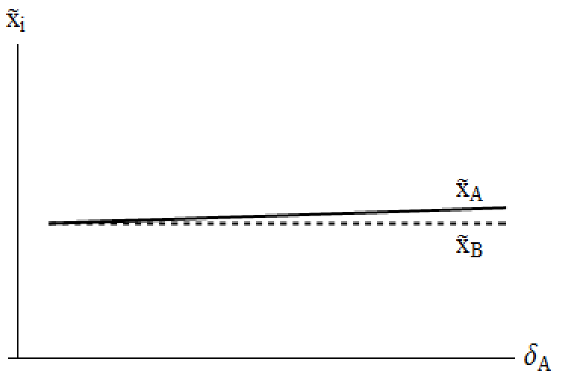


$\alpha = 0.1, \beta = 0.8$

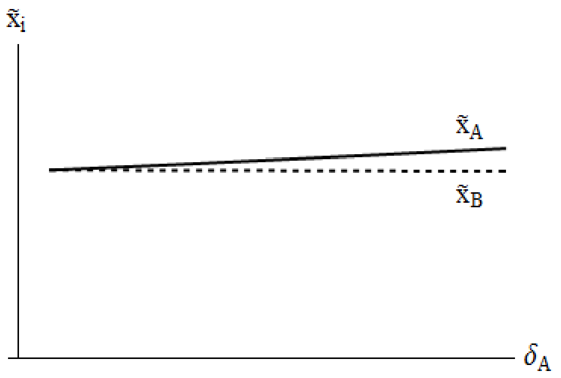


$\alpha = 0.05, \beta = 0.7$

α < β, high substitutability

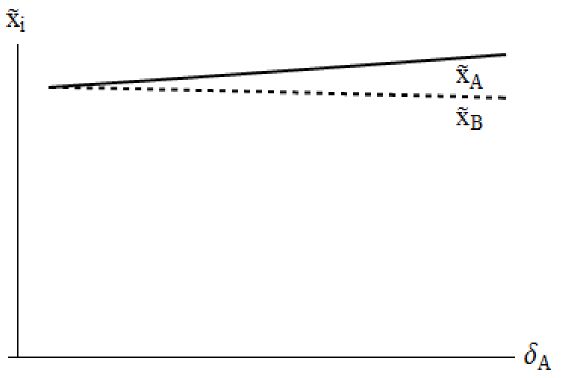


$\alpha = 0.35, \beta = 0.8$

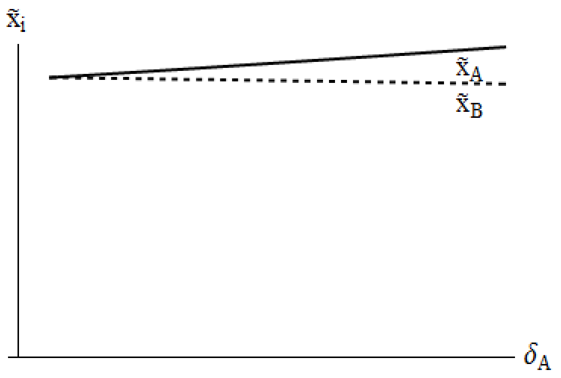


$\alpha = 0.5, \beta = 0.8$

α > β, very high substitutability



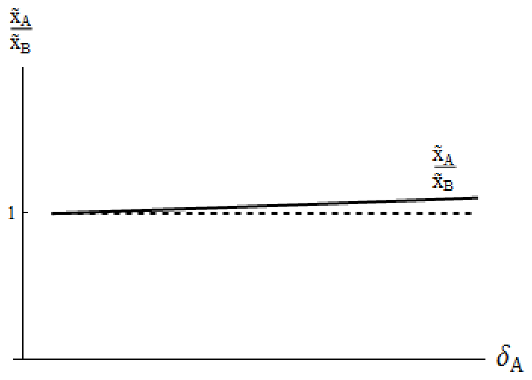
$\alpha = 0.9, \beta = 0.8$



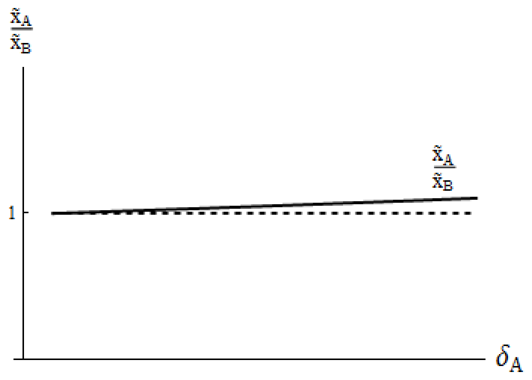
$\alpha = 0.7, \beta = 0.4$

Relative supplier input contributions

***α < β*, low substitutability**

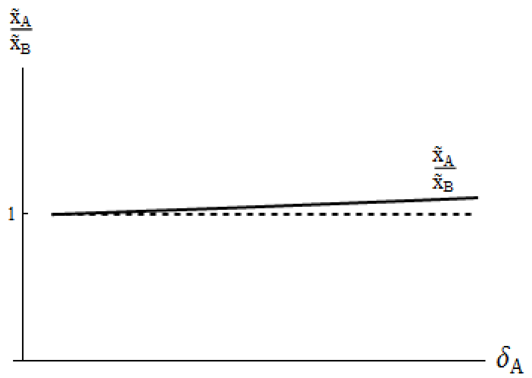


$\alpha = 0.1, \beta = 0.8$

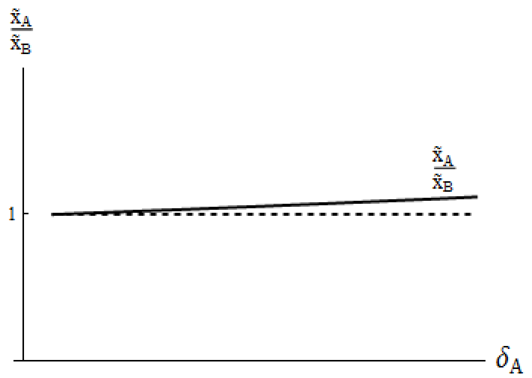


$\alpha = 0.05, \beta = 0.7$

***α < β*, high substitutability**

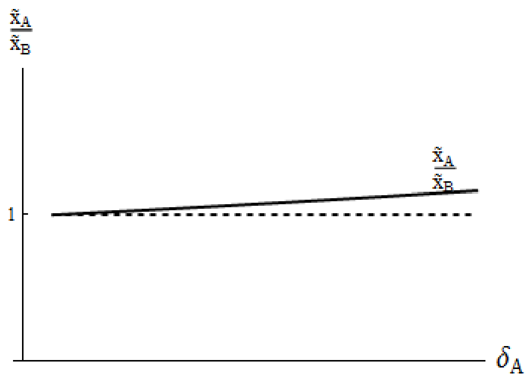


$\alpha = 0.35, \beta = 0.8$

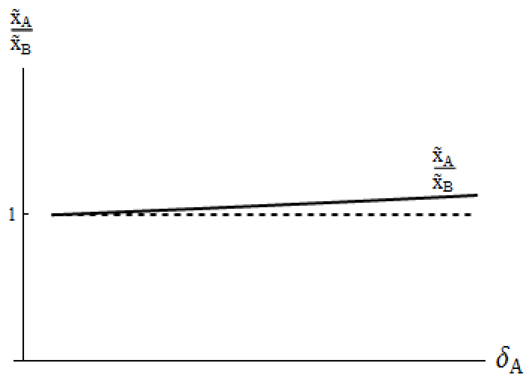


$\alpha = 0.5, \beta = 0.8$

***α > β*, very high substitutability**



$\alpha = 0.9, \beta = 0.8$



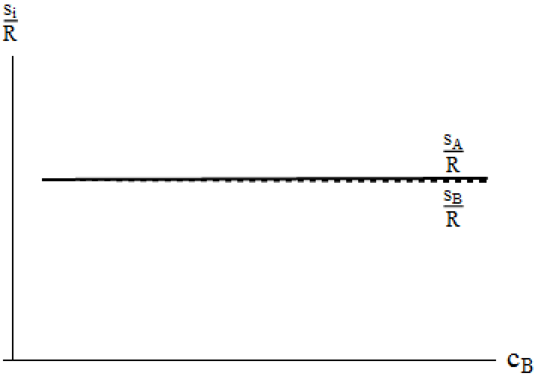
$\alpha = 0.7, \beta = 0.4$

iv) lower input costs of supplier A ($c_A < c_B$)

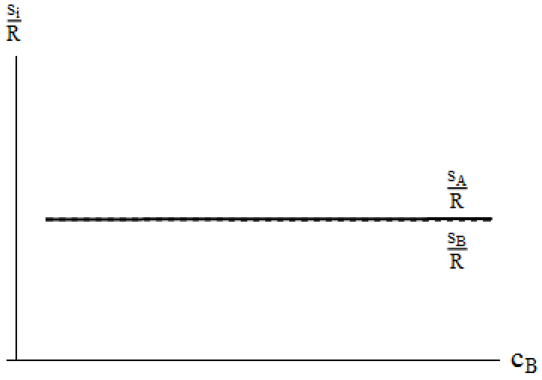
Common parameters: $c_A = 1$, $c_B \geq 1$, $c^H = 1$, $\delta_A = \delta_B = 0.85$, $\eta_A = 0.5$, $\eta^H = 0.8$, $\theta = 1$, $Y = 1$, $w_A = w_B = 0$

- If supplier A has lower unit costs than supplier B, supplier A realizes a higher revenue share than supplier B.

***$\alpha < \beta$*, low substitutability**

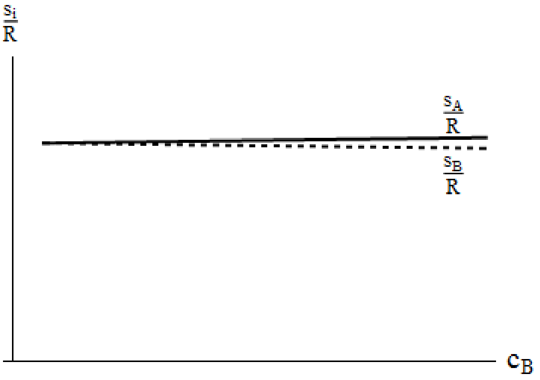


$\alpha = 0.1, \beta = 0.8$

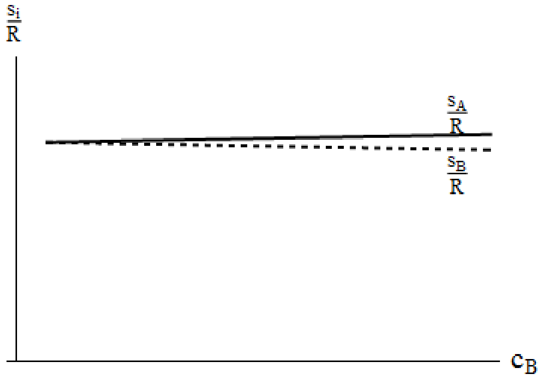


$\alpha = 0.05, \beta = 0.7$

***$\alpha < \beta$*, high substitutability**

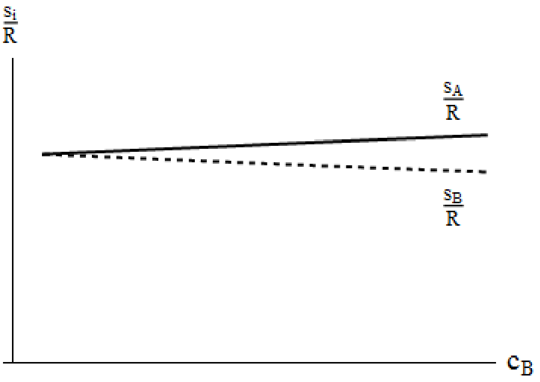


$\alpha = 0.35, \beta = 0.8$

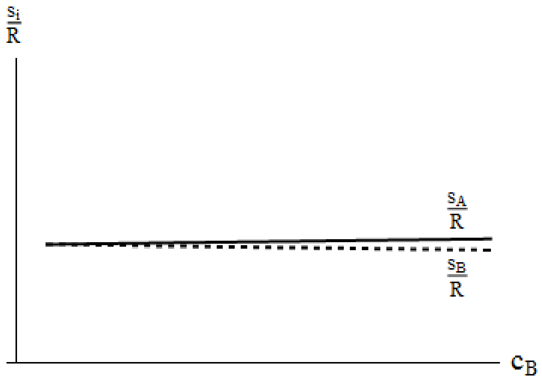


$\alpha = 0.5, \beta = 0.8$

***$\alpha > \beta$*, very high substitutability**



$\alpha = 0.9, \beta = 0.8$

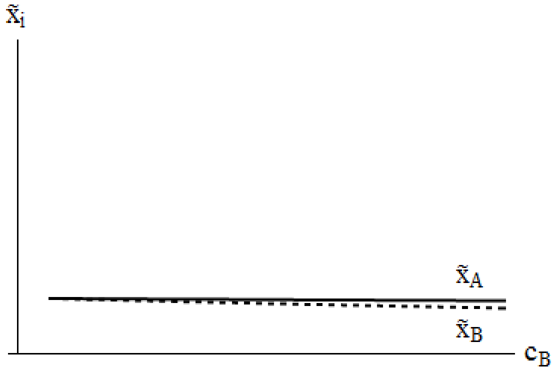


$\alpha = 0.7, \beta = 0.4$

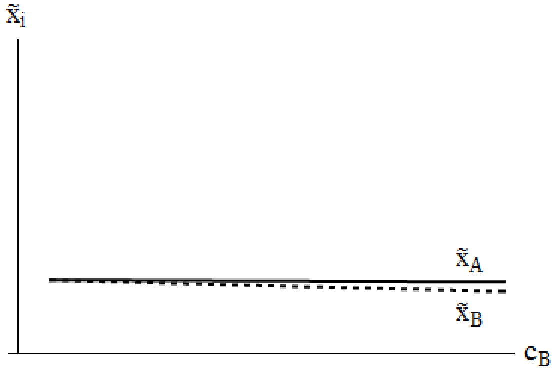
- If supplier A has lower unit costs than supplier B, supplier A makes a higher input contribution than supplier B.

<u>Absolute input contributions</u>

***$\alpha < \beta$*, low substitutability**

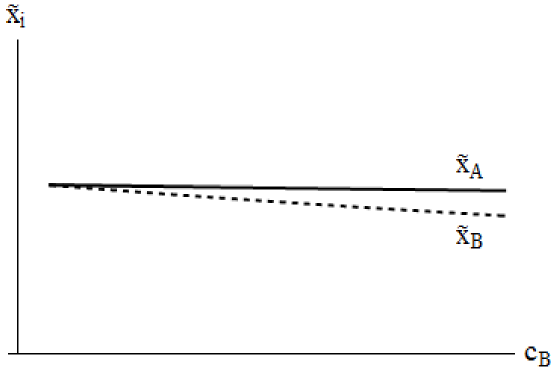


$\alpha = 0.1, \beta = 0.8$

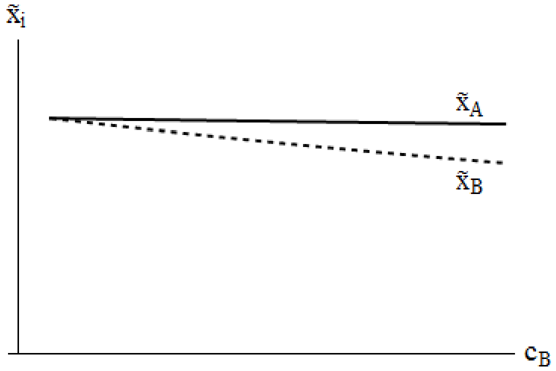


$\alpha = 0.05, \beta = 0.7$

***$\alpha < \beta$*, high substitutability**

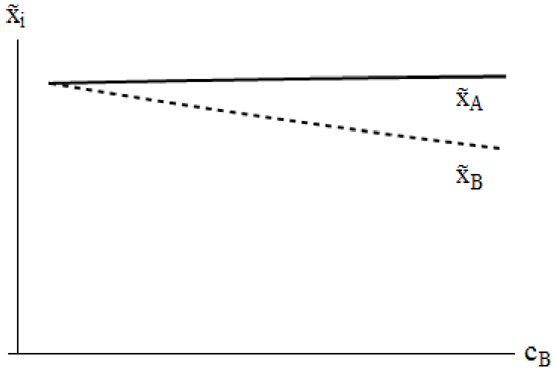


$\alpha = 0.35, \beta = 0.8$

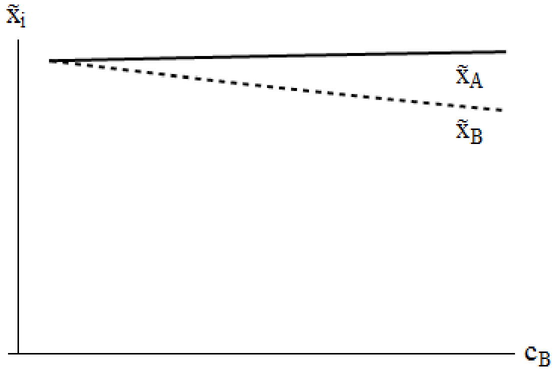


$\alpha = 0.5, \beta = 0.8$

***$\alpha > \beta$*, very high substitutability**



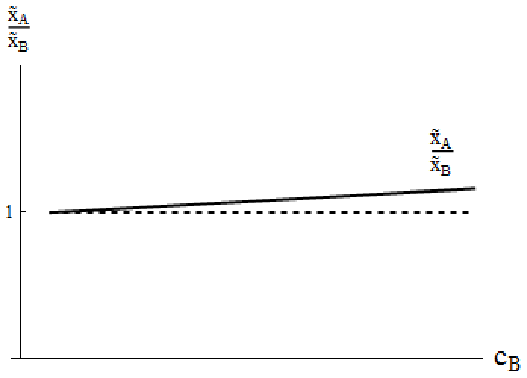
$\alpha = 0.9, \beta = 0.8$



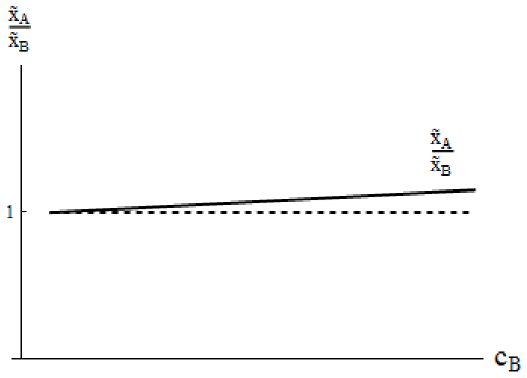
$\alpha = 0.7, \beta = 0.4$

Relative input contributions

***α < β*, low substitutability**

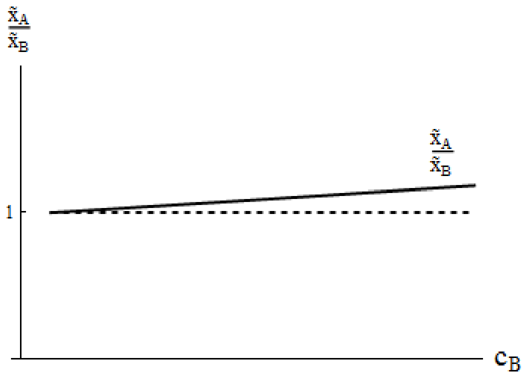


$\alpha = 0.1, \beta = 0.8$

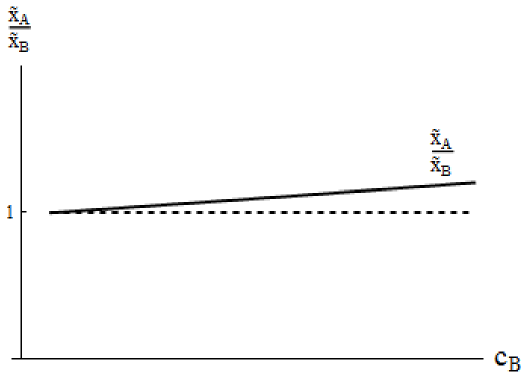


$\alpha = 0.05, \beta = 0.7$

***α < β*, high substitutability**

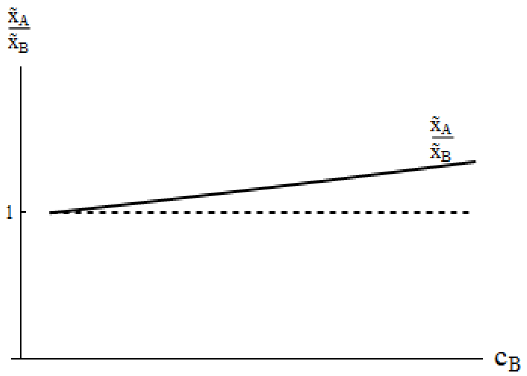


$\alpha = 0.35, \beta = 0.8$

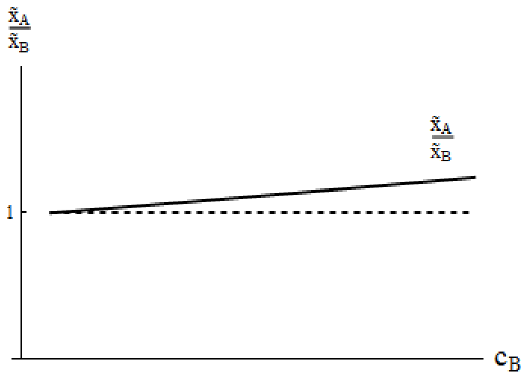


$\alpha = 0.5, \beta = 0.8$

***α > β*, very high substitutability**



$\alpha = 0.9, \beta = 0.8$



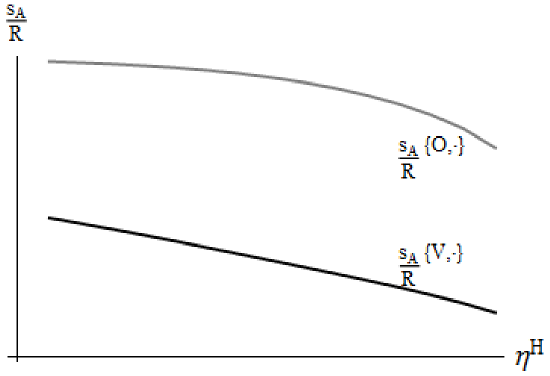
$\alpha = 0.7, \beta = 0.4$

v) outsourcing and integration: own organizational form

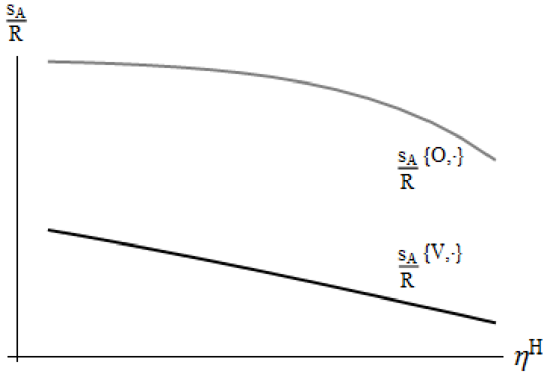
Common parameters: $c_A = c_B = 1$, $c^H = 1$, $\delta_A^O = \delta_B^O = 1$, $\delta_A^V = \delta_B^V = 0.85$, $\eta_A = 0.5$, $\theta = 1$, $Y = 1$, $w_A = w_B = 0$

- Supplier A's revenue share is higher if he is outsourced than if he is integrated. i.e. $s_A^{\{O,\cdot\}} > s_A^{\{V,\cdot\}}$.

α < β*, *low substitutability

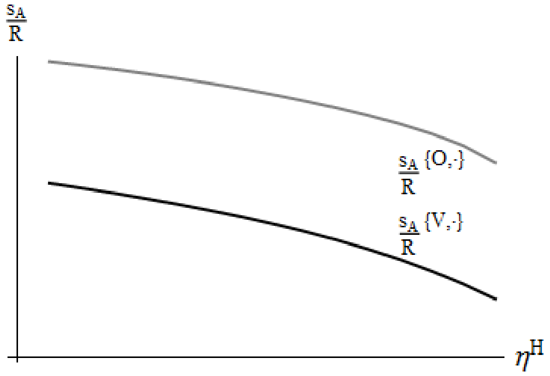


$\alpha = 0.1$, $\beta = 0.8$

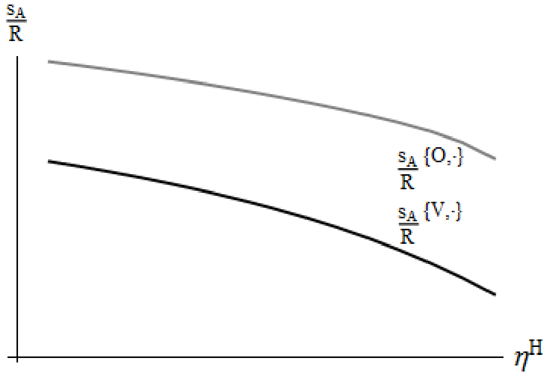


$\alpha = 0.05$, $\beta = 0.7$

α < β*, *high substitutability

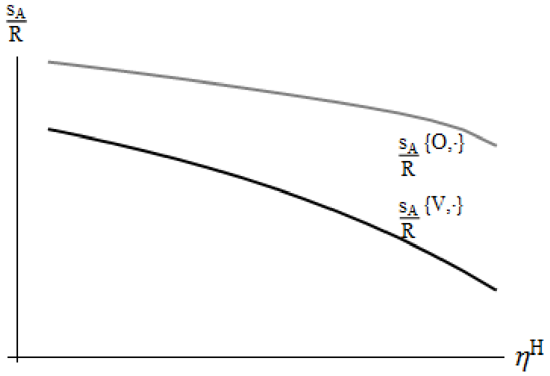


$\alpha = 0.35$, $\beta = 0.8$

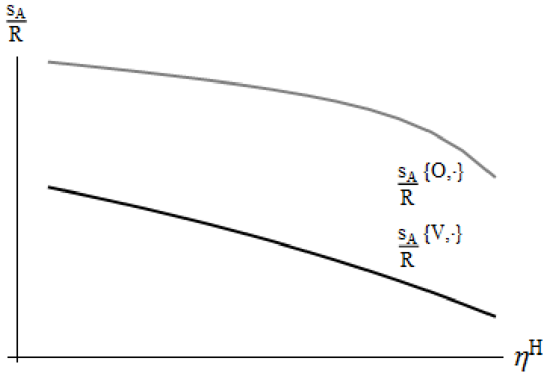


$\alpha = 0.5$, $\beta = 0.8$

α > β*, *very high substitutability



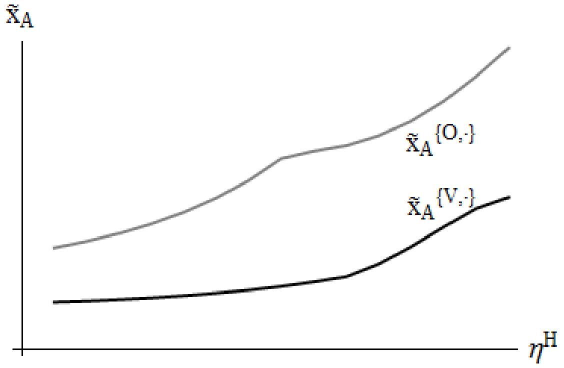
$\alpha = 0.9$, $\beta = 0.8$



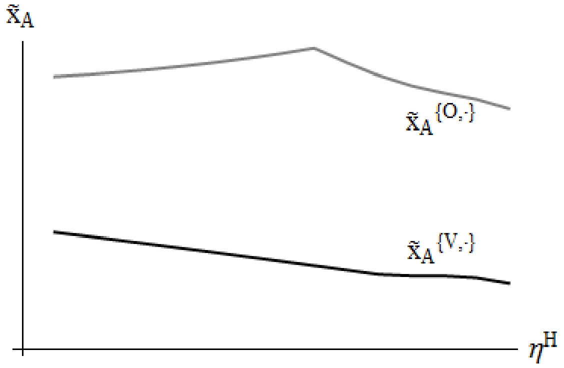
$\alpha = 0.7$, $\beta = 0.4$

- Supplier A's input contribution is higher if he is outsourced than if he is integrated, i.e. $\tilde{x}_A^{\{O,\cdot\}} > \tilde{x}_A^{\{V,\cdot\}}$.

***$\alpha < \beta$*, low substitutability**

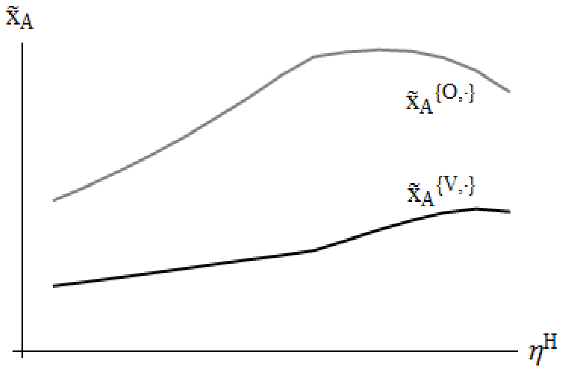


$\alpha = 0.1, \beta = 0.8$

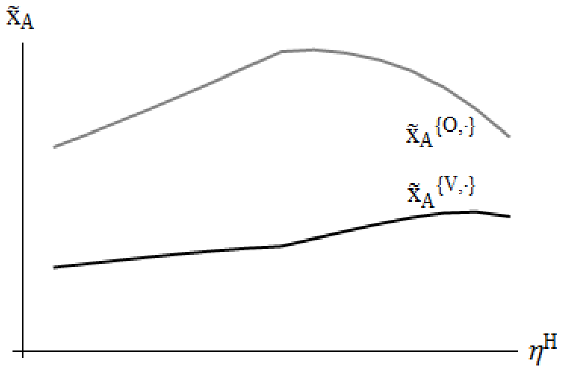


$\alpha = 0.05, \beta = 0.7$

***$\alpha < \beta$*, high substitutability**

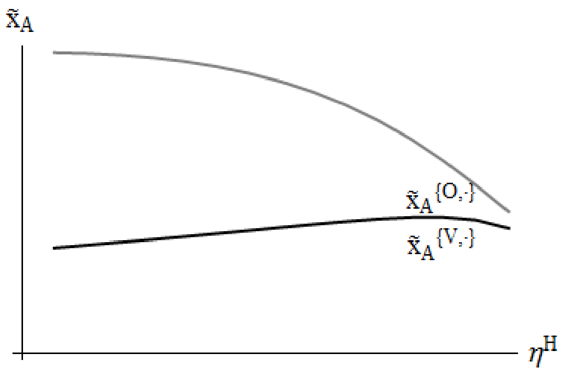


$\alpha = 0.35, \beta = 0.8$

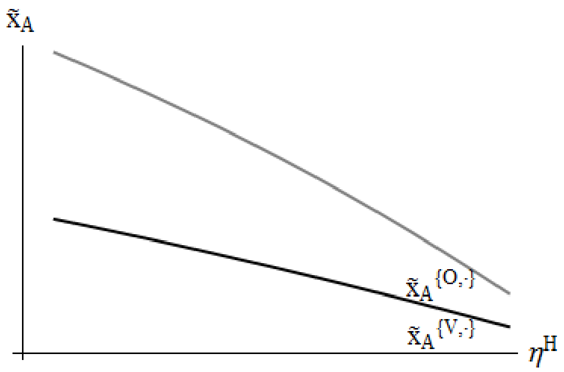


$\alpha = 0.5, \beta = 0.8$

***$\alpha > \beta$*, very high substitutability**



$\alpha = 0.9, \beta = 0.8$



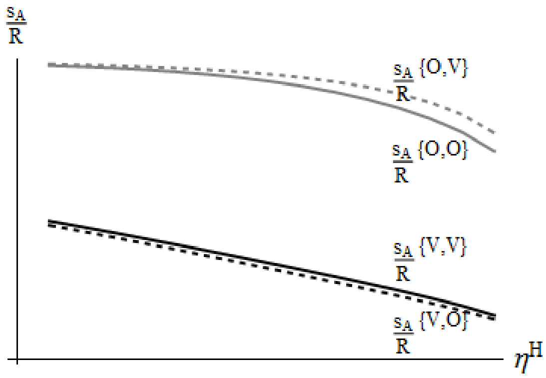
$\alpha = 0.7, \beta = 0.4$

vi) outsourcing and integration: organizational form of the other supplier

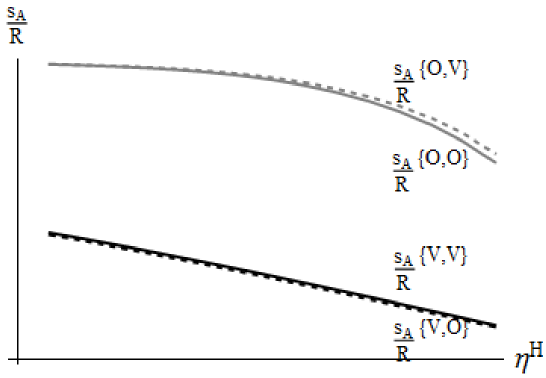
Common parameters: $c_A = c_B = 1$, $c^H = 1$, $\delta_A^O = \delta_B^O = 1$, $\delta_A^V = \delta_B^V = 0.85$, $\eta_A = 0.5$, $\theta = 1$, $Y = 1$, $w_A = w_B = 0$

- Supplier A's revenue share is higher if supplier B is integrated than if B is outsourced, i.e., $s_A^{\{O,V\}} > s_A^{\{O,O\}}$ and $s_A^{\{V,V\}} > s_A^{\{V,O\}}$.

***$\alpha < \beta$*, low substitutability**

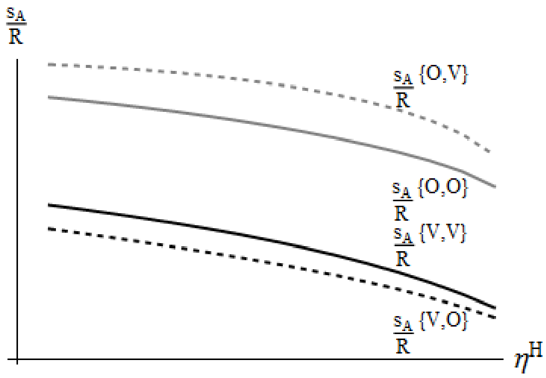


$\alpha = 0.1$, $\beta = 0.8$

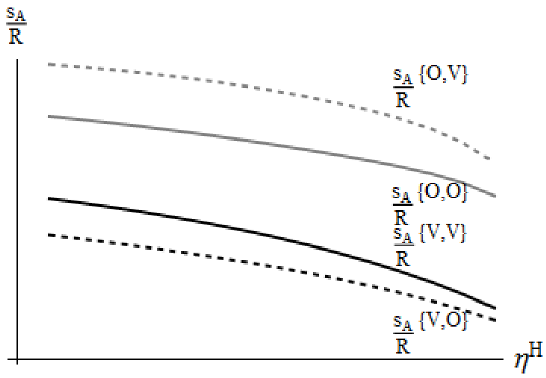


$\alpha = 0.05$, $\beta = 0.7$

***$\alpha < \beta$*, high substitutability**

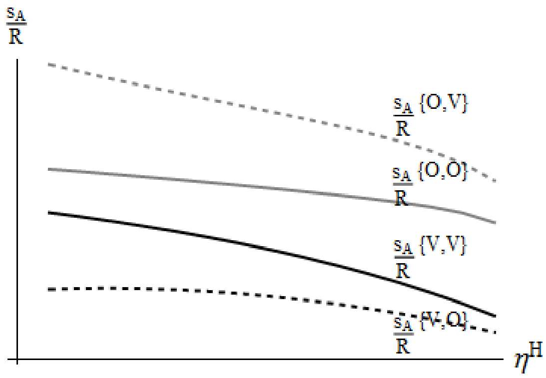


$\alpha = 0.35$, $\beta = 0.8$

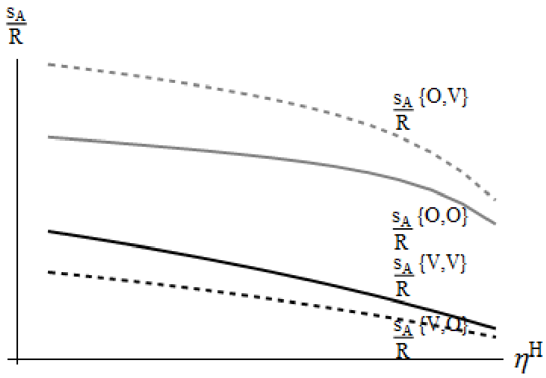


$\alpha = 0.5$, $\beta = 0.8$

***$\alpha > \beta$*, very high substitutability**



$\alpha = 0.9$, $\beta = 0.8$



$\alpha = 0.7$, $\beta = 0.4$

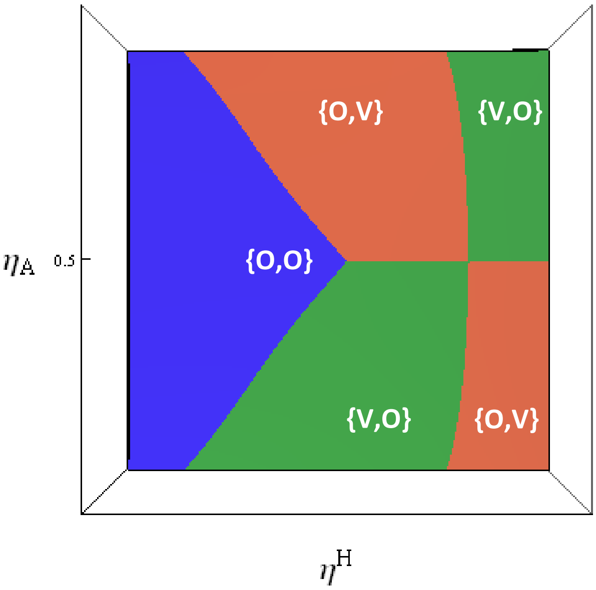
II. The producer's ownership choice

i) Ownership choice for varying headquarter-intensity and technological asymmetry

Common parameters: $c_A = c_B = 1,\ c^H = 1,\ \delta_A^O = \delta_B^O = 1,\ \delta_A^V = \delta_B^V = 0.85,\ \theta = 1,\ Y = 1,\ w_A = w_B = 0$

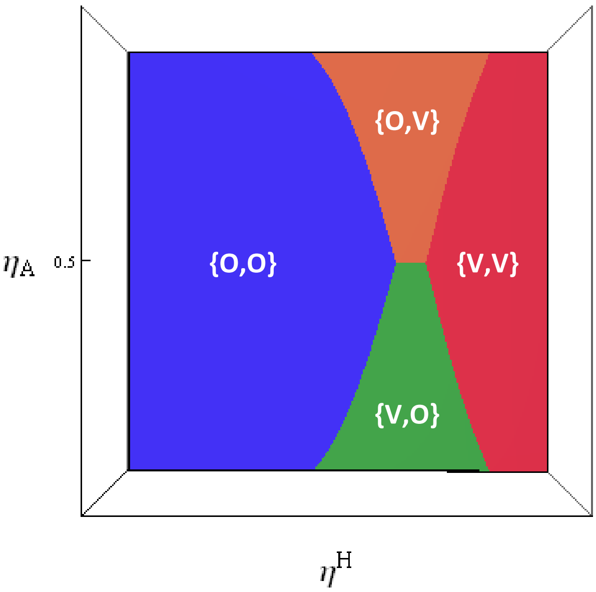
Figures are analogous to Figure 1 in the main text, but for different parameter constellations.

***α < β*, low substitutability**



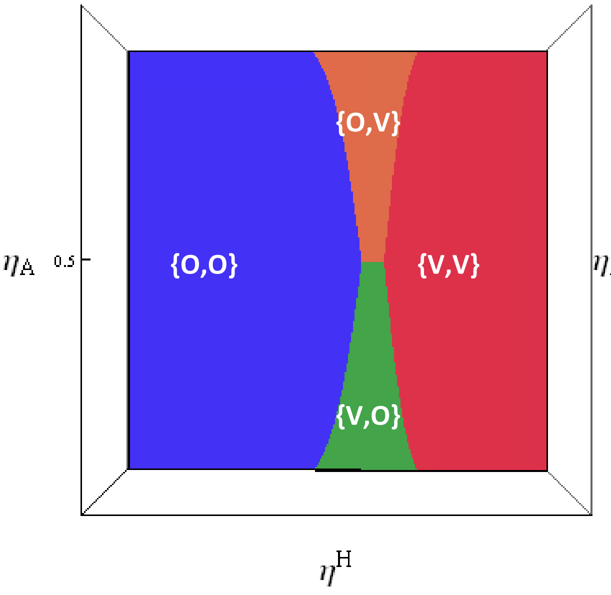
$\alpha = 0.05, \beta = 0.7$

***α < β*, high substitutability**

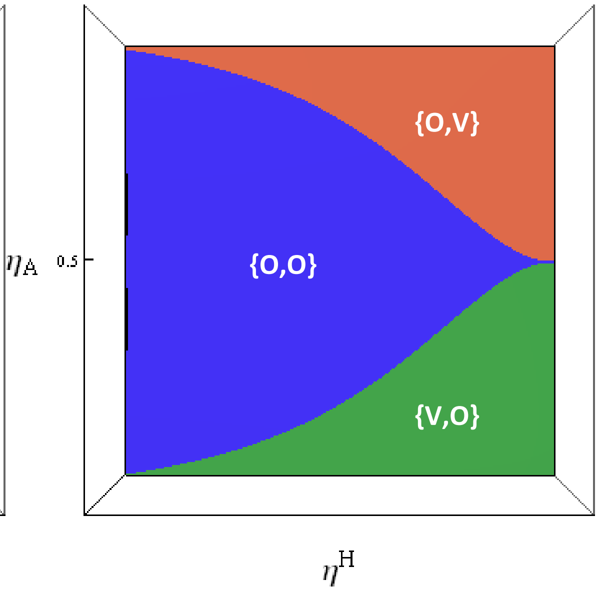


$\alpha = 0.5, \beta = 0.8$

α > β, very high substitutability



$\alpha = 0.9, \beta = 0.8$

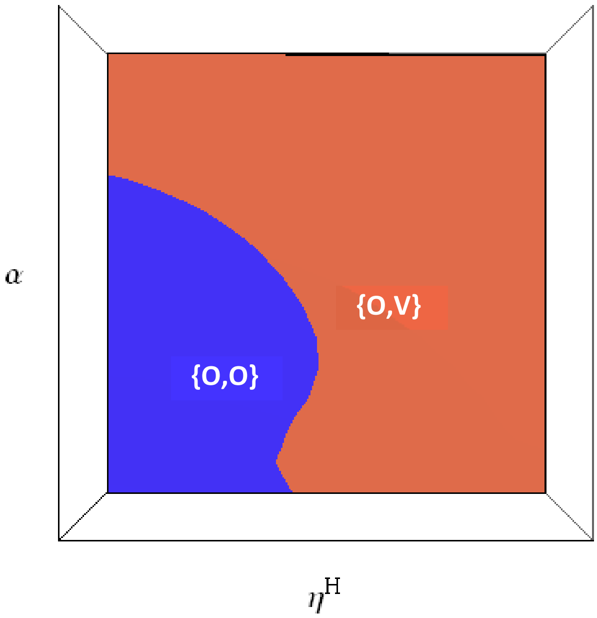


$\alpha = 0.7, \beta = 0.4$

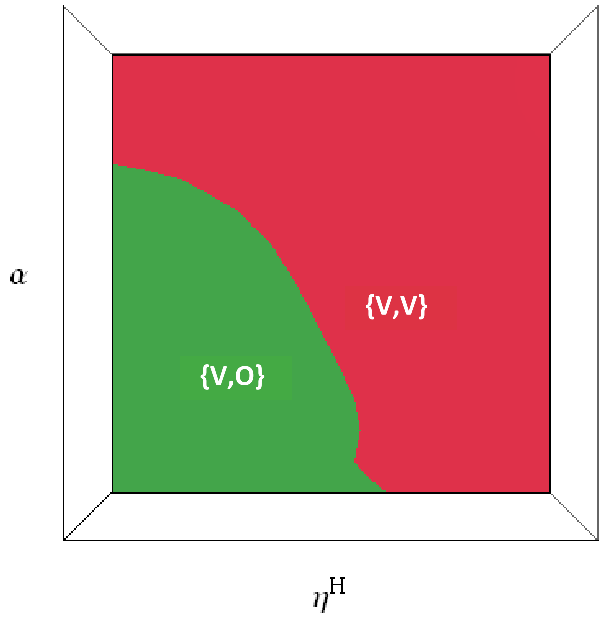
ii) Absolute input provisions of the two suppliers

Common parameters: $c_A = c_B = 1$, $c^H = 1$, $\delta_A^O = \delta_B^O = 1$, $\delta_A^V = \delta_B^V = 0.85$, $\eta_A = 0.8$, $\theta = 1$, $Y = 1$, $w_A = w_B = 0$

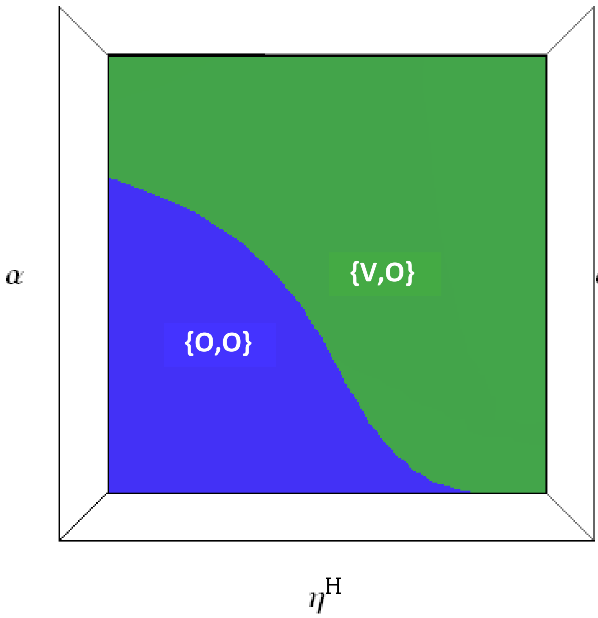
Figures are analogous to Figure 3 in the main text, but for different parameter constellations.



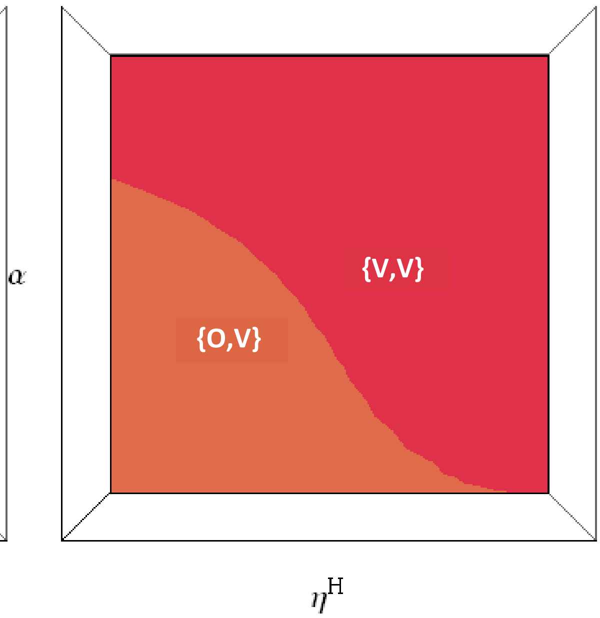
1: Supplier A – {O,O} vs. {O,V}



2: Supplier A – {V,O} vs. {V,V}

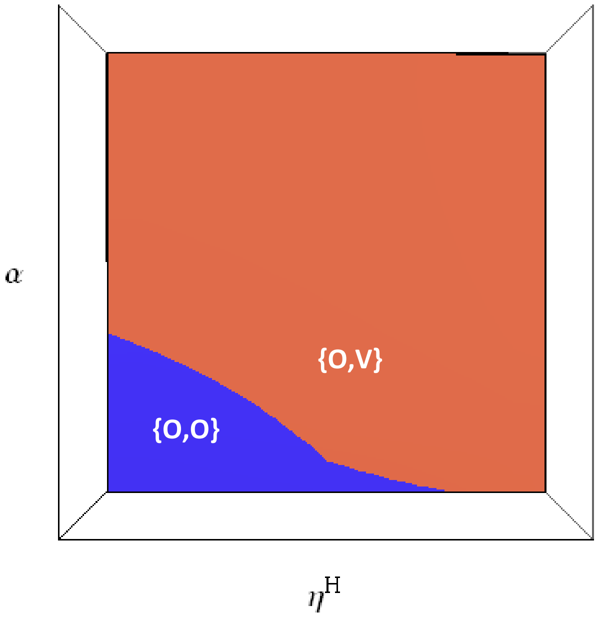


3: Supplier B – {O,O} vs. {V,O}

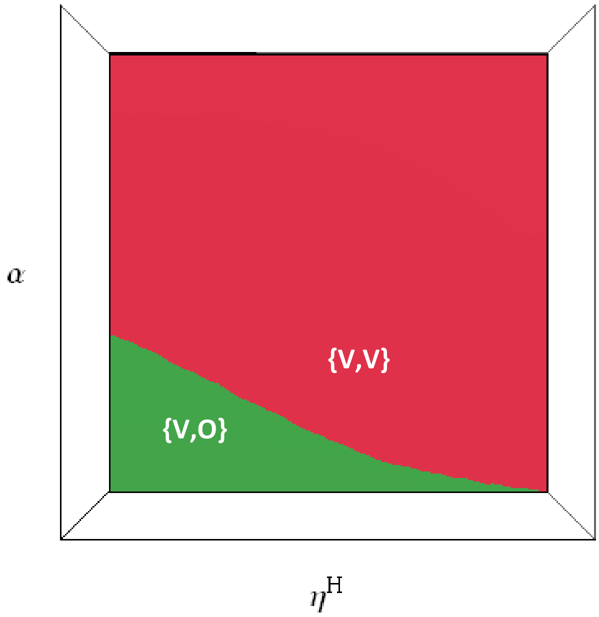


4: Supplier B – {O,V} vs. {V,V}

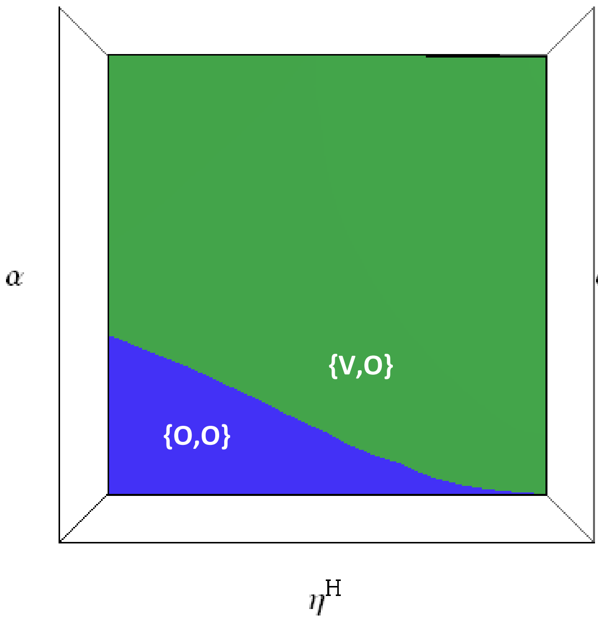
$\beta = 0.7$



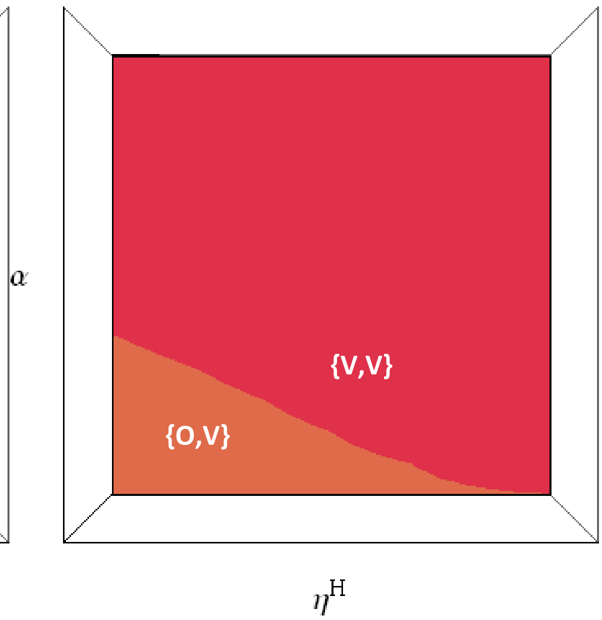
1: Supplier A – {O,O} vs. {O,V}



2: Supplier A – {V,O} vs. {V,V}



3: Supplier B – {O,O} vs. {V,O}



4: Supplier B – {O,V} vs. {V,V}

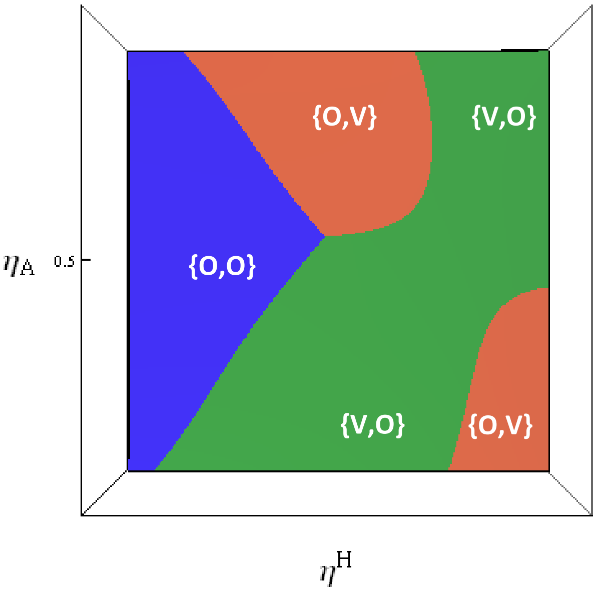
$\beta = 0.4$

iii) Asymmetries in the degree of sophistication

Common parameters: $c_A = c_B = 1$, $c^H = 1$, $\delta_A^O = \delta_B^O = 1$, $\delta_A^V = 0.9$, $\delta_B^V = 0.85$, $\theta = 1$, $Y = 1$, $w_A = w_B = 0$

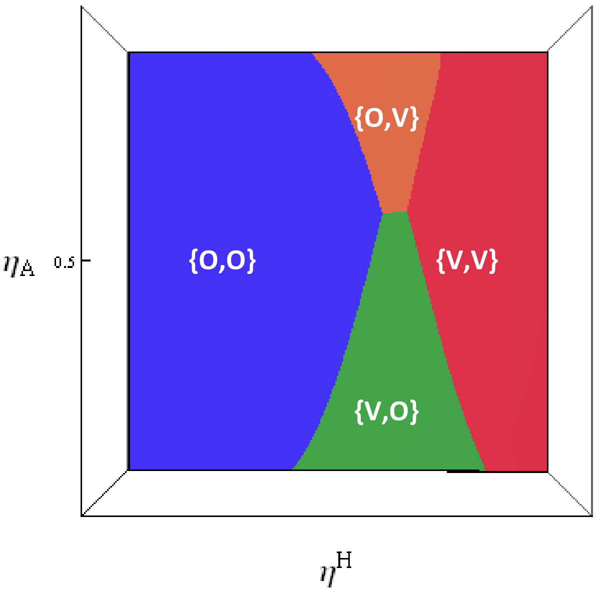
Figures are analogous to Figure 4 in the main text, but for different parameter constellations.

***α* < *β*, low substitutability**



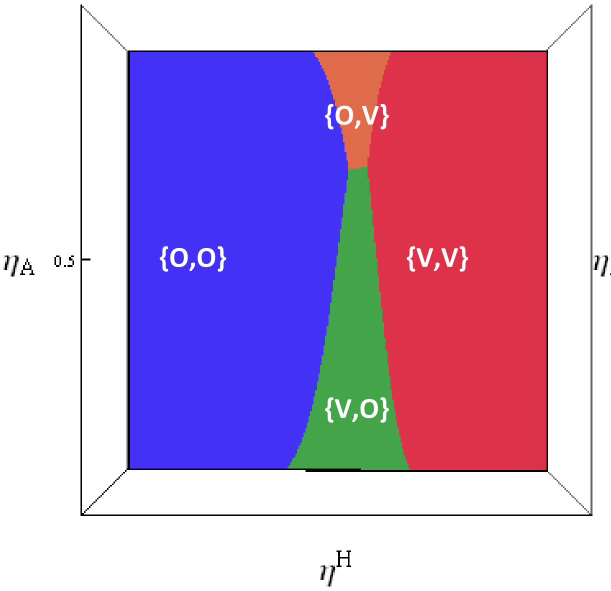
$\alpha = 0.05$, $\beta = 0.7$

***α* < *β*, high substitutability**

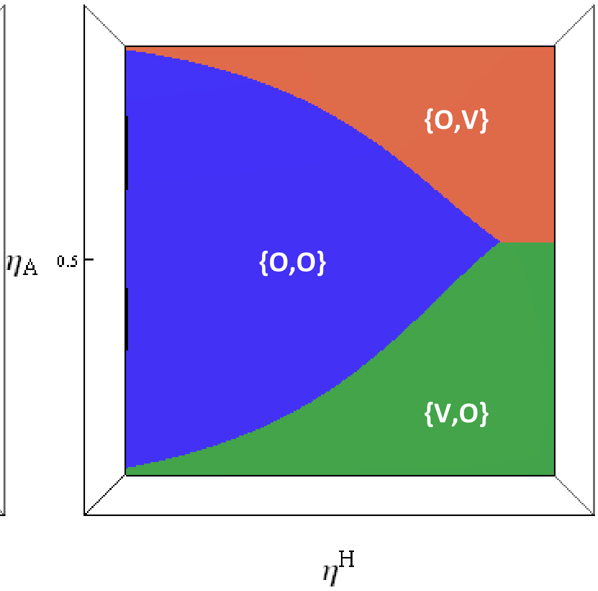


$\alpha = 0.5$, $\beta = 0.8$

α > β*, *very high substitutability



$\alpha = 0.9$, $\beta = 0.8$



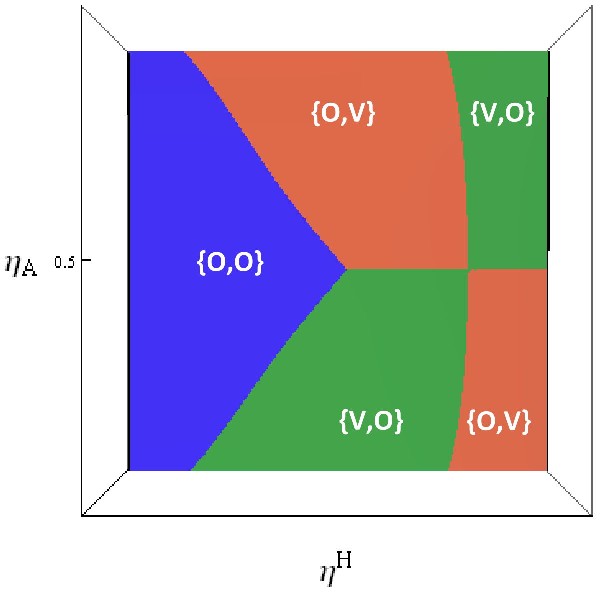
$\alpha = 0.7$, $\beta = 0.4$

iv) Asymmetries in the suppliers' unit costs

Common parameters: $c_A = 1$, $c_B = 3$, $c^H = 1$, $\delta_A^O = \delta_B^O = 1$, $\delta_A^V = \delta_B^V = 0.85$, $\theta = 1$, $Y = 1$, $w_A = w_B = 0$

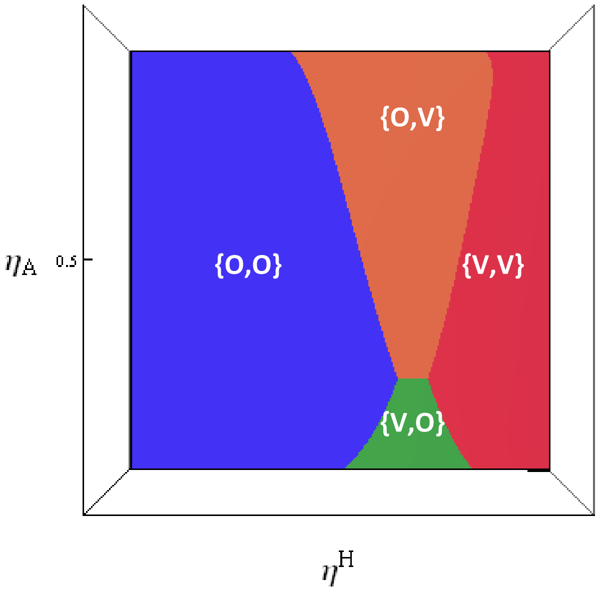
Figures are analogous to Figure 5 in the main text, but for different parameter constellations.

α < β*, *low substitutability



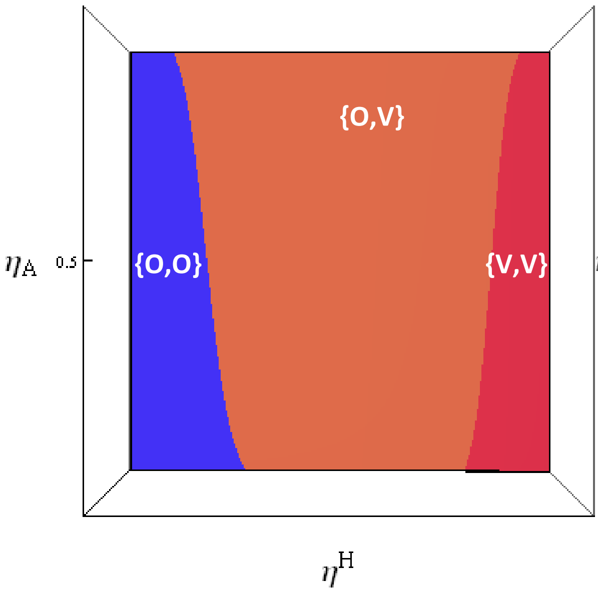
$\alpha = 0.05$, $\beta = 0.7$

α < β*, *high substitutability

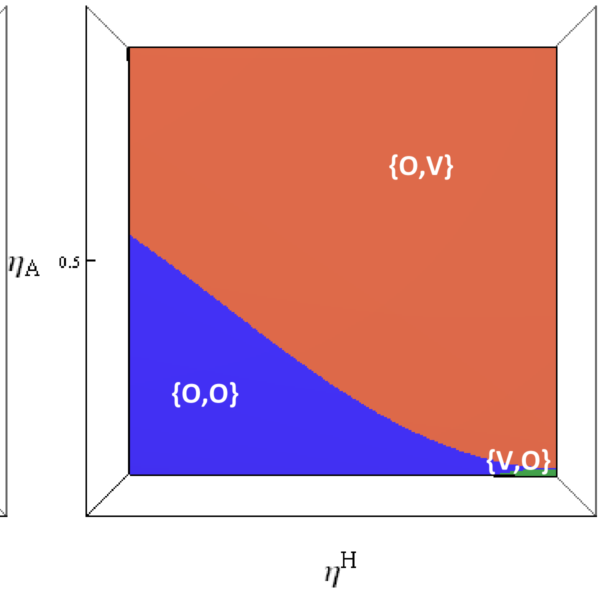


$\alpha = 0.5, \beta = 0.8$

α > β*, *very high substitutability



$\alpha = 0.9, \beta = 0.8$



$\alpha = 0.7, \beta = 0.4$

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