

Global Sourcing of Complex Production Processes (revised version)

May 14, 2013

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Abstract

We develop a theory of a firm in an incomplete contracts environment which decides on the complexity, the organization, and the global scale of its production process. Specifically, the firm decides i) how many intermediate inputs are simultaneously combined to a final product, ii) if the supplier of each input is an external contractor or an integrated affiliate, and iii) if that input is offshored to a foreign country. Our model leads to a rich set of predictions on the internal structure of multinational firms. In particular, it provides an explanation why many firms choose *hybrid sourcing* and have both outsourced and integrated suppliers.

Keywords: Multinational firms, outsourcing, intra-firm trade, offshoring, vertical FDI
JEL-class.: F12, D23, L23

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We thank Pol Antrás (the editor), two anonymous referees, Bruce Blonigen, Gregory Corcos, Fabrice Defever, Giordano Mion, Peter Neary, Gianmarco Ottaviano, Uwe Stroinski, and participants at the 2011 CESifo Summer Institute in Venice and the 2010 European Trade Study Group (ETSG) in Lausanne for helpful comments and suggestions. All errors and shortcomings are solely our responsibility.

1 Introduction

Research in international trade has revealed the existence of substantial firm-level heterogeneity even within narrowly defined industries. The literature was first concerned with the comparison of firms that only sell locally with exporting firms which also serve foreign markets. More recent studies then emphasized that firms also differ markedly in their *importing* behaviors, and more generally, in their sourcing strategies for intermediate inputs.¹

In this paper, we highlight three important dimensions along which firms' sourcing strategies differ. Specifically, we develop a theory of a firm where the headquarter (the "producer") decides on i) *complexity*: the mass of intermediate inputs – each provided by a separate supplier – that are simultaneously combined in the production process for a final good, ii) *organization*: if the supplier of each component is an external subcontractor or an integrated subsidiary, and iii) *global scale*: if the supplier is domestic or foreign.

Our model builds on the seminal approaches by Antràs (2003), Antràs and Helpman (2004) and Acemoglu, Antràs and Helpman (2007). The former two papers were the first to study global sourcing in a property rights framework with incomplete contracts. These models are, however, restricted to a setting with a headquarter and *one single* supplier. The latter paper considers an endogenous mass of suppliers. The more inputs are combined in the production process, the more specialized is the task that each single supplier performs and the finer is the division of labor inside the firm. However, in Acemoglu et al. (2007) there are only symmetric firm structures where either all suppliers are integrated or all are outsourced. We extend their framework and allow for *hybrid sourcing*, that is, for a firm structure where *some* suppliers are vertically integrated while the others remain independent, and where *some* inputs are offshored while the others are produced domestically. This, in turn, endogenously generates asymmetries across suppliers in their bargaining powers and investment incentives. Thereby, our model leads to a rich set of predictions on the structure of multinational enterprises (MNEs) that are consistent with stylized facts from the recent empirical literature. It also leads to several novel testable predictions that may motivate future empirical research.

The recent empirical trade literature has shown that hybrid sourcing is a highly relevant phenomenon. For example, Defever and Toubal (2013) observe that in 1999 only about 8% of all French MNEs in the largely globalized motor vehicle industry (e.g., Iveco and Molsheim) have imported intermediates exclusively from related parties, 47% of them (e.g., Heuliez Bus and Smart Car) have imported exclusively from external foreign suppliers, while the remaining 45% have chosen some combination of outsourcing and vertical integration. When it comes to the important "make or buy" decision, we thus observe that there is often a co-existence of different sourcing modes for different inputs within the same firm. Such a pattern is also found, among others, by Costinot et al. (2013), Corcos et al. (2013), Kohler and Smolka (2012) and

¹See Bernard et al. (2010, 2012) for recent overviews how firms engaged in exporting and global sourcing differ from firms that only sell and source domestically.

Tomiura (2007) for US, French, Spanish, and Japanese firms, respectively. Hybrid sourcing also spans the *global scale* dimension. Baldwin (2009), for instance, discusses the case of the “Swedish” car *Volvo S40*. He illustrates that Volvo chooses to offshore only *some* intermediate inputs while relying on domestic manufacturing for others, and for the offshored components the firm relies on a mix of arm’s length outsourcing and intra-firm trade.²

With respect to the *complexity* dimension, evidence is more scarce since current data typically only allows to observe supplier relationships where the parent firm owns a majority share of the input provider, whereas the number of external supplier relationships is not observable. Given this caveat, the available recent evidence still suggests that firms differ vastly in their complexity. For example, Alfaro and Charlton (2009) report that the *General Motors Corporation* (GM) can be traced as the ultimate owner (“global ultimate parent”) of 2,248 firm entities, 455 of which are subsidiaries outside the USA and 123 are in manufacturing industries. Of those 123 affiliates, Alfaro and Charlton (2009) classify 43 to be input suppliers providing manufacturing components for GM’s final products. By comparison, using similar but more comprehensive data for roughly 300,000 business groups worldwide, Altomonte and Rungi (2013) report that the average US headquarter firm owns just 21 affiliates, only some of which can be classified as input suppliers.³ In addition, more than 50 % of those headquarters have less than four affiliates, and are thus far less “complex” than the GM business group.

Summing up, both within and across industries, there is substantial heterogeneity with respect to the *complexity*, *organization* and *global scale* of firms’ internal structures. Understanding those patterns in the data requires a theoretical model with multiple suppliers which can be asymmetric in their organizational mode and their country of origin. Our framework can address those facts. It provides an economic theory on the firm- and industry-level determinants of those firm structure decisions, and it provides an explanation why firms often choose different organizational and global scale modes for some inputs than for others.⁴

This paper is organized as follows. Section 2 presents our basic model structure. Section 3 focusses on the complexity and organizational decisions in a closed economy setup. Section 4 turns to the open economy and introduces the global scale decision. Section 5 concludes.

²Further examples for MNEs’ sourcing strategies are discussed in Antràs and Rossi-Hansberg (2009) and Antràs (2013). Partial offshoring can also arise in the model by Grossman and Rossi-Hansberg (2008). They do, however, not analyze different organizational modes for supplier relationships.

³Even if it is not directly observable in the data, big corporations like GM are likely to have not only more affiliates than the average US firm in the same sector, but also more unrelated suppliers with whom they contract via market transactions.

⁴A different extension of the Antràs and Helpman (2004) framework with more than one supplier is due to Du, Lu and Tao (2009). In their model, the *same* input can be provided by two suppliers, and “bi-sourcing” (one supplier integrated and the other outsourced) can arise out of a strategic motive, because it systematically improves the headquarter’s outside option. In our model there is an endogenous mass of suppliers who provide differentiated inputs, and our hybrid sourcing result relies on a different motive. Van Biesebroeck and Zhang (2011) also study an incomplete contracts model with a headquarter and multiple suppliers. However, they do not consider an endogenous complexity choice and focus on the organizational form of outsourcing. Last, Nowak et al. (2012) study a global sourcing model with *two* asymmetric, discrete suppliers and thus also disregard the endogenous complexity decision.

2 Model

2.1 Demand, technology and firm structure

We consider a firm that produces a final good q for which it faces the following iso-elastic demand function:

$$q = A \cdot p^{-1/(1-\beta)}. \quad (1)$$

Here, p denotes the price, and $A > 1$ is an exogenous term that captures the market size for this final product. The demand elasticity is $1/(1-\beta)$, which is increasing in $\beta \in [0, 1]$. Producing this good requires headquarter services and manufacturing components, which are combined according to the following Cobb-Douglas production function:

$$q = h^\eta \cdot \left(\int_{j=0}^N x(j)^\alpha dj \right)^{\frac{1-\eta}{\alpha}}. \quad (2)$$

Headquarter services are denoted by h and are provided by the “producer”. The parameter $\eta \in [0, 1]$ is the headquarter-intensity of final goods production.⁵ For the components, we assume that there is a continuum of inputs with measure $N \in \mathbb{R}_+$, where each component is provided by a separate supplier. The supplier $j \in [0, N]$ delivers $x(j)$ units of his particular input, and the components are aggregated according to a constant elasticity of substitution (CES) function where $\alpha \in [0, 1]$ measures the degree of component substitutability. We shall assume that $\alpha > \beta$, i.e., that the elasticity of substitution across components is sufficiently large. Using equations (1) and (2), total revenue can then be written as follows:

$$R = A^{1-\beta} \cdot h^{\beta\eta} \cdot \left(\int_{j=0}^N x(j)^\alpha dj \right)^\gamma \quad \text{where} \quad \gamma \equiv \frac{\beta(1-\eta)}{\alpha} < 1. \quad (3)$$

In our model, the producer decides on the structure of the firm, and this choice involves three aspects: *complexity*, *organization*, and *global scale* of production.

The *complexity* choice refers to the mass of components N . From (2) it is clear that the overall component-intensity of final goods production is exogenously given by $1-\eta$. This parameter reflects the technology of the sector in which the firm operates. When the producer chooses N , she thus essentially decides on the division of labor inside the firm.⁶ The larger N is, the narrower is the task that each single supplier performs, and the more complex is the firm’s production process.⁷ We assume that a greater mass of suppliers induces agency costs νN for managerial oversight, where $\nu > 0$ is the fixed cost per additional supplier.

⁵The headquarter services thus account for a fixed share η of total value added and necessarily have to be performed by the producer herself, i.e., they cannot be unbundled, outsourced or offshored.

⁶We should emphasize that we do not consider a sequential setup as in Antràs and Chor (2013) or Costinot et al. (2013), where inputs pass along various subsequent stages in a value chain. In our model, all components $x(j)$ are upstream inputs that enter simultaneously into the production process for the final good.

⁷This complexity choice is thus closely related to Acemoglu et al. (2007)’s notion of the firm’s *technology*.

Turning to the *organizational* decision, the producer decides separately for each of those components if the respective supplier is integrated as a subsidiary within the boundaries of the firm, or if that component is outsourced to an external supplier. Following the property rights approach of the firm à la Grossman and Hart (1986) and Hart and Moore (1990), we assume that input investments are not contractible as their precise characteristics are difficult to specify *ex ante* and also difficult to verify *ex post*.⁸ A hold-up problem thus arises, even for affiliated suppliers within the firm, and the producer and the suppliers end up bargaining at a time when their investment costs are already sunk. The bargaining power of the involved parties depends crucially on the firm structure as will be explained below.

Finally, the producer decides on the location where each component is manufactured (*global scale*). She is located in country 1 where final assembly is carried out. The respective input suppliers may either also come from country 1, or from a foreign low-wage country 2.

2.2 Structure of the game

We consider a game that consists of five stages. The timing of events is as follows:

1. The producer simultaneously makes the following decisions: i) She decides on the mass N of suppliers/manufacturing components. ii) For each $j \in [0, N]$ she chooses the organizational form $\{O, V\}$. Here, O denotes “outsourcing” and V denotes “vertical integration” of supplier j . We order the mass N such that each supplier $i \in [0, N^O]$ is outsourced, and each supplier $k \in (N^O, N]$ is vertically integrated. Then, $\xi = N^O/N$ (with $0 \leq \xi \leq 1$) denotes the outsourcing share, and $(1 - \xi) = N^V/N$ is the share of vertically integrated suppliers. Finally, iii) for each $j \in [0, N]$ the producer decides on the country $r = \{1, 2\}$ where that component is manufactured. We order the mass of outsourced suppliers N^O such that each supplier $i \in [0, N_2^O]$ is offshored to the low-wage country 2, and each supplier $k \in (N_2^O, N^O]$ is located in the high-wage country 1. Then, $\ell^O = N_2^O/N^O$ denotes the offshoring share among all outsourced suppliers (with $0 \leq \ell^O \leq 1$). Similarly, $\ell^V = N_2^V/N^V$ (with $0 \leq \ell^V \leq 1$) is the offshoring share among all integrated suppliers, and the total offshoring share is $\ell = \xi \cdot \ell^O + (1 - \xi) \cdot \ell^V$.

Given these firm structure decisions $\{N, \xi, \ell^O, \ell^V\}$, the producer offers a contract to potential input suppliers for every component $j \in [0, N]$. This contract includes an upfront payment $\tau(j)$ (positive or negative), an ex post payment $s(j)$, and stipulates an input quantity for the prospective supplier.

2. There exists a large pool of potential applicant suppliers for each manufacturing component in both countries. These suppliers have an outside opportunity equal to w_r^0 in

⁸Antràs and Helpman (2008) and Acemoglu et al. (2007) consider partial contractibility and cross-country differences in contracting institutions. We could introduce those features as well, but this would make the exposition considerably more complicated without adding many novel insights.

country $r = \{1, 2\}$. They are willing to accept the contract if their payoff is at least equal to w_r^0 . The payoff consists of the upfront payment $\tau(j)$, the ex post payment $s(j)$ that supplier j anticipates to receive, minus the investment costs for the input production (which may differ across applicants). Potential suppliers apply for the contract, and the producer chooses one supplier for each component $j \in [0, N]$.

3. The producer and the suppliers independently decide on their input levels for the head-quarter services h and the components $x(j)$, respectively. Due to non-contractibility, suppliers are not obliged to supply the quantity as stipulated in the first stage.
4. Since input investments are non-contractible, all parties threaten to withhold their inputs at this stage. The suppliers and the producer bargain over the division of the surplus value. Supplier j receives the ex post payment $s(j)$, and the producer receives s_0 .
5. Output is produced, revenue is realized, and the surplus value is divided according to the bargaining agreement.

We solve this game by backward induction, successively moving from simplified setups where single aspects or decisions are faded out, to the encompassing version of the model.

3 Closed economy

We start the analysis with a closed economy setting. That is, we abstract from the global scale decision for the moment, and impose that all suppliers are located in country 1. The firm structure decision then only consists of the complexity and the organizational choice.

3.1 Complete contracts

As a benchmark, we first consider a setup with complete contracts that leads to the first-best outcome from the viewpoint of the firm. In this scenario, the producer chooses the complexity level N and her own input investment h . Furthermore, she makes a contract offer $\{x(j), \tau(j), s(j)\}$ to each supplier $j \in [0, N]$ in the first stage of the game, and in stage 3 each supplier must supply (and cannot withhold) the input level $x(j)$ that is stipulated in the contract, in exchange for the agreed payment $\tau(j) + s(j)$ that is not re-negotiable.

We assume that unit costs of input production are the same for all suppliers, and are given by $c_x > 0$. Moreover, the outside opportunity w^0 is also the same for all domestic suppliers. Since all component inputs enter symmetrically into the production function, the producer therefore chooses a common input level x and common payments $\tau + s$ for all suppliers, and the "make or buy" question (outsourcing or integration) is irrelevant in this scenario with complete contracts. The producer maximizes her payoff, which is given by

$$\Pi = R - c_h h - N(\tau + s) - \nu N,$$

where $c_h > 0$ denotes the unit costs of providing headquarter services, and where revenue is given by $R = A^{1-\beta} h^{\beta\eta} x^{\beta(1-\eta)} N^\gamma$ due to the symmetry of the component inputs. This payoff is maximized subject to the suppliers' participation constraint $\tau + s - c_x x \geq w^0$. Since the producer has no reason to leave rents to the suppliers, she will adjust the payment $\tau + s$ in such a way that the participation constraint is satisfied with equality. The firm's optimization problem can then be expressed in a simpler way as follows:

$$\max_{\{h,x,N\}} \Pi = A^{1-\beta} h^{\beta\eta} x^{\beta(1-\eta)} N^\gamma - c_h h - c_x x N - w^0 N - \nu N. \quad (4)$$

The first-order conditions for this problem are

$$\frac{\partial \Pi}{\partial h} = \beta\eta \cdot \frac{A^{1-\beta} (N^{\gamma/\beta} h^\eta x^{1-\eta})^\beta}{h} - c_h = 0 \quad (5)$$

$$\frac{\partial \Pi}{\partial x} = \beta(1-\eta) \cdot \frac{A^{1-\beta} (N^{\gamma/\beta} h^\eta x^{1-\eta})^\beta}{x} - c_x N = 0 \quad (6)$$

$$\frac{\partial \Pi}{\partial N} = \gamma \cdot \frac{A^{1-\beta} (N^{\gamma/\beta} h^\eta x^{1-\eta})^\beta}{N} - (w^0 + \nu) - c_x x = 0 \quad (7)$$

Manipulating (6) and (5) yields $h/(xN) = \eta/(1-\eta) \cdot (c_x/c_h)$. That is, the optimal headquarter contribution relative to the aggregate input contribution of all suppliers is higher, the higher is the technological parameter η (the sectoral headquarter-intensity) and the lower are the relative unit costs c_h/c_x . Furthermore, using (6) and (7) yields the optimal input level for every single supplier, which is given by

$$x^* = \frac{\alpha(w^0 + \nu)}{c_x(1-\alpha)}. \quad (8)$$

Plugging this and $h^* = \eta/(1-\eta) \cdot (c_x/c_h) \cdot x^*N$ into (7) then leads to

$$N^* = \left(\beta \cdot \frac{A^{1-\beta}}{c_x} \cdot (1-\eta) \cdot \left(\frac{c_x(1-\alpha)}{\alpha(w^0 + \nu)} \right)^{1-\beta} \cdot \left(\frac{\eta c_x}{(1-\eta)c_h} \right)^{\beta\eta} \right)^{\frac{\alpha}{\alpha-\beta+(1-\alpha)\beta\eta}}. \quad (9)$$

It immediately follows from (9) that the firm's (first-best) optimal complexity choice depends positively on the market size term A , and negatively on the different cost terms c_h , c_x , w^0 , and ν .⁹ Furthermore, it follows from (9) that N^* depends negatively on η .¹⁰ That is, the optimal

⁹Recall that $\alpha > \beta$ by assumption, which ensures that the exponent in (9) is positive. Further notice that, if headquarter-intensity η were zero, expression (9) would become analogous to the optimal technology level in Acemoglu et al. (2007). To see this, notice that we do not include a "Benassy term" $N^{\kappa+1-1/\alpha}$ in front of the integral in (2), and that we have set $C'(N) = \nu$ for the specification of agency costs.

¹⁰The derivative can be written as $\partial N^*/\partial \eta = g(\eta)^{h(\eta)} \left(\frac{h(\eta)g'(\eta)}{g(\eta)} + h'(\eta) \cdot \log[g(\eta)] \right)$ where $g(\eta)$ is the term within the big parentheses and $h(\eta)$ is the exponent term in (9). We have $h'(\eta) < 0$ while $g'(\eta)$ is clearly negative only for $c_h/c_x > \eta/(1-\eta)$. Overall, however, the negative second term always dominates provided the level of $g(\eta)$ is large enough, which can be ensured by norming A , ν and w^0 accordingly. Hence, $\partial N^*/\partial \eta < 0$.

complexity level is lower in more headquarter-intensive industries. Finally, it is straightforward to show that – given those first-best decisions N^* , x^* and h^* – the overall share of the surplus that goes to the mass of suppliers is given by $N^* (c_x x^* + w^0) / R^* = \beta(1 - \eta) \left[\frac{w^0 + \alpha\nu}{\alpha(w^0 + \nu)} \right]$, with the remaining share going to the producer. That is, the optimal revenue share for the suppliers is linearly decreasing in η , which implies that the producer should receive a larger share of the surplus in sectors where headquarter services are more intensively used in production.

3.2 Incomplete contracts: Preliminaries and symmetric case

From now on, we move to the incomplete contracts scenario in which suppliers need not provide inputs as stipulated in stage 1. Similarly, in stage 3, the producer also anticipates the hold-up when deciding on her investment in headquarter services.

To analyze the multilateral bargaining, we use the *Shapley value* concept due to Shapley (1953). In this subsection we first provide some preliminaries, and then solve a simplified case where it is imposed that all N suppliers are *symmetric* in their organizational form and, thus, their equilibrium input amounts.¹¹ In the next subsection we then consider the producer's decisions on complexity *and* the outsourcing share, which endogenously generates asymmetries across suppliers. There, we address the phenomenon of hybrid sourcing in the closed economy.

3.2.1 The Shapley value with a discrete number of players

In the bargaining stage, the mass (number) of players and their input amounts are given. To fix ideas, consider a setup with the producer and with $M \geq 2$ discrete suppliers. Those $(M + 1)$ players can be ordered in $(M + 1)!$ different ways. Here is an example with $M = 3$, so with 24 possible permutations, where player 0 is the producer and 1, 2, 3 are the suppliers:

$$\begin{array}{ccc} \begin{bmatrix} 0 \\ 1 \\ 2 \\ 3 \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 3 \\ 2 \end{bmatrix} \begin{bmatrix} 0 \\ 2 \\ 1 \\ 3 \end{bmatrix} \begin{bmatrix} 0 \\ 2 \\ 3 \\ 1 \end{bmatrix} \begin{bmatrix} 0 \\ 3 \\ 1 \\ 2 \end{bmatrix} \begin{bmatrix} 0 \\ 3 \\ 2 \\ 1 \end{bmatrix} & \begin{bmatrix} 1 \\ 0 \\ 2 \\ 3 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \\ 3 \\ 2 \end{bmatrix} \begin{bmatrix} 1 \\ 2 \\ 0 \\ 3 \end{bmatrix} \begin{bmatrix} 1 \\ 2 \\ 3 \\ 0 \end{bmatrix} \begin{bmatrix} 1 \\ 3 \\ 0 \\ 2 \end{bmatrix} \begin{bmatrix} 1 \\ 3 \\ 2 \\ 0 \end{bmatrix} & \begin{bmatrix} 2 \\ 1 \\ 0 \\ 3 \end{bmatrix} \begin{bmatrix} 2 \\ 1 \\ 3 \\ 0 \end{bmatrix} \begin{bmatrix} 2 \\ 0 \\ 1 \\ 3 \end{bmatrix} \begin{bmatrix} 2 \\ 0 \\ 3 \\ 1 \end{bmatrix} \begin{bmatrix} 2 \\ 3 \\ 1 \\ 0 \end{bmatrix} \begin{bmatrix} 2 \\ 3 \\ 0 \\ 1 \end{bmatrix} & \begin{bmatrix} 3 \\ 1 \\ 2 \\ 0 \end{bmatrix} \begin{bmatrix} 3 \\ 1 \\ 0 \\ 2 \end{bmatrix} \begin{bmatrix} 3 \\ 2 \\ 1 \\ 0 \end{bmatrix} \begin{bmatrix} 3 \\ 2 \\ 0 \\ 1 \end{bmatrix} \begin{bmatrix} 3 \\ 0 \\ 1 \\ 2 \end{bmatrix} \begin{bmatrix} 3 \\ 0 \\ 2 \\ 1 \end{bmatrix} \end{array}$$

Adopt the perspective of one single supplier, say $j = 1$. For the computation of his Shapley value (SV) we need to compute his marginal contribution to all relevant coalitions. A *coalition* is a subset of players from the above set of possible permutations.¹² As a convention, we consider the player ordered last in a coalition to be the one who is about to leave. The remaining coalition, after player 1 has left, must include the producer since she is essential in the production process; otherwise the remaining coalition earns zero revenue. In practise, we thus need to find those permutations where player 1 is ordered below the essential player 0, and the 12 relevant coalitions from those permutations are indicated in **red**. More generally, there are $(M + 1)!/2 = (M - 1)! \left[\sum_{i=1}^M i \right]$ permutations where 1 is ordered below 0, and thus

¹¹This part largely draws on Acemoglu et al. (2007), but our analysis still differs from theirs because in our model the firm contributes inputs (headquarter services h) to the production process.

¹²For example, $[0, 1, 2]$, $[1, 2, 3, 0]$, or $[3, 1]$ are coalitions involving player 1. Notice that the players within a coalition can be ordered in different ways (e.g., $[0, 1, 2]$ and $[2, 0, 1]$).

$i \cdot (M - 1)!$ relevant remaining coalitions of size $i \leq M$ that lead to non-zero revenue when player j has left. Many of them differ only with respect to the ordering, but not with respect to the set of players that are involved.¹³ The Shapley value of player j is defined as

$$s(j) = \frac{1}{(M + 1)!} \cdot \sum_{i=1}^M i(M - 1)! \cdot \Delta_R^j(i, M) = \frac{1}{M(M + 1)} \cdot \sum_{i=1}^M i \cdot \Delta_R^j(i, M) \quad (10)$$

Here, $\Delta_R^j(i, M)$ is the marginal contribution of player j , that is, the change in revenue when player j drops out of the coalition and leaves behind a remaining coalition of size $i \leq M$. In (10), we sum the marginal contribution of player j to all remaining coalitions that involve player 0 (recall that there are $(M - 1)! \sum_{i=1}^M i$ such cases), and then divide by the total number of possible permutations. In other words, we compute average marginal contribution of player j to all relevant coalitions.¹⁴

3.2.2 Asymptotic Shapley value with symmetric suppliers

This notation has assumed a discrete number of players, whereas for our model we need to compute the asymptotic SV assuming a very large (infinite) number of very small (infinitely small) players. For that purpose, recall that the total mass of intermediate inputs is given by N . Suppose that each supplier controls a range $\kappa = N/M$ of those inputs. Substituting $M = N/\kappa$ into (10), we can rewrite the SV as

$$s(j) = \frac{1}{N(N + \kappa)} \cdot \sum_{i=1}^{N/\kappa} i\kappa^2 \cdot \Delta_R^j(i, N, \kappa) = \frac{1}{N(N + \kappa)} \cdot \sum_{i=1}^{N/\kappa} i\kappa^2 \cdot \left[R_{IN}^j(i + 1, N, \kappa) - R_{OUT}^j(i, N, \kappa) \right],$$

where R_{IN}^j is the revenue level of the coalition of size $i + 1$ when player j is part of it, while R_{OUT}^j is the revenue of the remaining coalition of size i when player j is not part.

Since we focus on a symmetric case, we compute the asymptotic SV for supplier j , who contributes $x(j)$, assuming that all other suppliers, denoted $-j = \{1, 2, \dots, M\} \neq j$, contribute a common input level $x(-j)$. Using (3), we then have

$$\begin{aligned} R_{IN}^j(i + 1, N, \kappa) &= A^{1-\beta} h^{\beta\eta} \cdot (\kappa \cdot x(j)^\alpha + i\kappa \cdot x(-j)^\alpha)^\gamma \\ R_{OUT}^j(i, N, \kappa) &= A^{1-\beta} h^{\beta\eta} \cdot (\kappa \cdot (1 - \delta)x(j)^\alpha + i\kappa \cdot x(-j)^\alpha)^\gamma \end{aligned}$$

where $0 < (1 - \delta) < 1$ is the fraction of player j 's input contribution that remains with the

¹³If we only consider the substantially different remaining coalitions, irrespective of the ordering, we have $\frac{(M-1)!}{(i-1)!(M-i)!}$ remaining coalitions of size $i \leq M$, and $\sum_{i=1}^M \frac{(M-1)!}{(i-1)!(M-i)!} = 2^{(M-1)}$ remaining coalitions in total. In the above example, these are the remaining coalitions $[0]$, $[0, 2]$, $[0, 3]$ and $[0, 2, 3]$. Each of these substantially different remaining coalitions occurs $i!(M - i)!$ times in a different ordering.

¹⁴Alternatively, we can compute the Shapley value as $s(j) = \frac{1}{(M+1)!} \cdot \sum_{i=1}^M \frac{(M-1)!}{(i-1)!(M-i)!} \cdot i!(M - i)! \cdot \Delta_R^j(i, M)$, i.e., by summing across all substantially different feasible coalitions taking into account how often they occur.

firm, even if he has left the coalition.¹⁵ With those expressions, we show in Appendix A that the (asymptotic) SV of each symmetric supplier, \tilde{s} , and the share of the surplus \tilde{s}/R that he anticipates to realize in the bargaining stage, are given by:

$$\tilde{s} = \frac{\gamma \delta}{1 + \gamma} \cdot \frac{1}{N} \cdot \underbrace{A^{1-\beta} h^{\beta\eta} x^{\alpha\gamma} N^\gamma}_R \Rightarrow \tilde{s}/R = \frac{\gamma \delta}{1 + \gamma} \cdot \frac{1}{N}, \quad (11)$$

so that the group of suppliers as a whole realizes the revenue share $N \cdot (\tilde{s}/R) = \gamma\delta/(1 + \gamma)$. The producer as the essential player obtains the residual revenue share. From (11) it thus follows that her revenue share is given by $\tilde{s}_0/R = 1 - N \cdot (\tilde{s}/R) = (1 + \gamma(1 - \delta))/(1 + \gamma)$.

Notice that \tilde{s}/R is increasing in γ and in δ . That is, the suppliers have a higher bargaining power in more component-intensive industries (lower η), the lower is the elasticity of substitution across components (lower α), and the higher is the demand elasticity (higher β). Their bargaining power is also increasing in δ . For \tilde{s}_0/R , which is decreasing in γ and δ , the results are just opposite. In particular, if all suppliers maintain full ownership rights (if $\delta = 1$), the headquarter realizes the share $1/(1 + \gamma)$, and she realizes more the lower δ is.

3.2.3 Input investments and firm structure with symmetric suppliers

Having solved the bargaining problem in stage 4, we continue with the backward induction and now analyze the input investments (stage 3) and the firm structure decision (stage 1), which for now only involves the complexity choice since we impose that all suppliers have the same organizational form and are thus symmetric along all dimensions.

Input investments. In the investment stage, each supplier j chooses his input contribution $x(j)$ so as to maximize his ex post payment minus the costs of input provision. We can therefore express the equilibrium input contribution as

$$\tilde{x}(j) = \operatorname{argmax}_{x(j)} \{s[x(j), x(-j), h, N] - c_x x(j)\}, \quad (12)$$

under the participation constraint $s[x(j), x(-j), h, N] + \tau(j) - c_x x(j) \geq w^0$ and taking $x(-j)$ as given. Using (11), supplier j thus chooses

$$\tilde{x}(j) = \operatorname{argmax}_{x(j)} \left\{ \frac{\gamma \delta}{1 + \gamma} \cdot \frac{A^{1-\beta} h^{\beta\eta} x(-j)^{\alpha\gamma} N^\gamma}{N} \cdot \left(\frac{x(j)}{x(-j)} \right)^\alpha - c_x x(j) \right\}. \quad (13)$$

Taking first-order conditions with respect to $x(j)$, and then imposing $x(j) = x(-j) = x$ due to symmetry, we obtain the following supplier input contribution:

¹⁵If $\delta = 1$, the supplier threatens to withhold the entire amount, which means that he has full ownership rights over his input. It is important to bear in mind that, for now, we assume that $\delta \in [0, 1]$ is common to *all* suppliers in order to focus on a fully symmetric case. Below we then consider an asymmetric firm structure where some suppliers are outsourced ($\delta = 1$) while others are vertically integrated ($\delta < 1$), which in turn leads to asymmetries across suppliers in their input amounts and their marginal contributions to a coalition.

$$\tilde{x} = \left(\frac{\alpha\beta(1-\eta)}{\alpha + \beta(1-\eta)} \cdot \frac{A^{1-\beta}}{c_x} \right)^{\frac{1}{1-\beta(1-\eta)}} \cdot \delta^{\frac{1}{1-\beta(1-\eta)}} \cdot h^{\frac{\beta\eta}{1-\beta(1-\eta)}} \cdot N^{\frac{\gamma-1}{1-\beta(1-\eta)}}. \quad (14)$$

Similarly, in the investment stage, the producer chooses h so as to maximize her payoff:

$$\tilde{h} = \operatorname{argmax}_h \{s_0 [h, x, N] - c_h \cdot h\} = \operatorname{argmax}_h \left\{ \frac{1 + \gamma(1 - \delta)}{1 + \gamma} \cdot A^{1-\beta} h^{\beta\eta} x^{\alpha\gamma} N^\gamma - c_h h \right\}.$$

The headquarter contribution is thus given by

$$\tilde{h} = \left(\frac{\alpha\beta\eta}{\alpha + \beta(1-\eta)} \cdot \frac{A^{1-\beta}}{c_h} \right)^{\frac{1}{1-\beta\eta}} \cdot (1 + \gamma(1 - \delta))^{\frac{1}{1-\beta\eta}} \cdot N^{\frac{\gamma}{1-\beta\eta}} \cdot x^{\frac{\beta(1-\eta)}{1-\beta\eta}}. \quad (15)$$

By using (14) in (15) we can express the input contributions $\tilde{x}(N)$ and $\tilde{h}(N)$ as functions of the complexity level N (which is given in stage 3) and of parameters only. We have

$$\tilde{x}(N) = \Psi_x \cdot \Delta_x \cdot N^{\frac{\beta(1-\eta)(1-\alpha)}{\alpha(1-\beta)} - 1} \quad \text{and} \quad \tilde{h}(N) = \Psi_h \cdot \Delta_h \cdot N^{\frac{\beta(1-\eta)(1-\alpha)}{\alpha(1-\beta)}}, \quad (16)$$

where the terms Ψ_x , Ψ_h , Δ_x , and Δ_h collect the parameters of the model, and are defined as:

$$\begin{aligned} \Psi_x &= A \cdot \left(\frac{1}{c_x} \right)^{\frac{1}{1-\beta}} \cdot \left(\frac{c_x}{c_h} \right)^{\frac{\beta\eta}{1-\beta}} \cdot \left(\frac{\alpha\beta(1-\eta)}{\alpha + \beta(1-\eta)} \right)^{\frac{1-\beta\eta}{1-\beta}} \cdot \left(\frac{\alpha\beta\eta}{\alpha + \beta(1-\eta)} \right)^{\frac{\beta\eta}{1-\beta}}, \\ \Psi_h &= A \cdot \left(\frac{1}{c_h} \right)^{\frac{1}{1-\beta}} \cdot \left(\frac{c_h}{c_x} \right)^{\frac{\beta(1-\eta)}{1-\beta}} \cdot \left(\frac{\alpha\beta(1-\eta)}{\alpha + \beta(1-\eta)} \right)^{\frac{\beta(1-\eta)}{1-\beta}} \cdot \left(\frac{\alpha\beta\eta}{\alpha + \beta(1-\eta)} \right)^{\frac{1-\beta(1-\eta)}{1-\beta}}, \\ \Delta_x &= \delta^{\frac{1-\beta\eta}{1-\beta}} \cdot (1 + \gamma(1 - \delta))^{\frac{\beta\eta}{1-\beta}}, \quad \Delta_h = \delta^{\frac{\beta(1-\eta)}{1-\beta}} \cdot (1 + \gamma(1 - \delta))^{\frac{1-\beta(1-\eta)}{1-\beta}}. \end{aligned}$$

It follows from (16) that, for a given N , the input contributions $\tilde{x}(N)$ and $\tilde{h}(N)$ depend negatively on c_x and c_h and positively on A and α . Furthermore, $\tilde{x}(N)$ depends positively on δ : the higher is the input fraction that each supplier threatens to withhold, the higher is the (symmetric) input amount as the suppliers' investment incentives are strengthened.

Firm structure. Finally, in the first stage of the game, the producer decides on the complexity level N . Given the freely adjustable participation fees $\tau(j)$, which dissipate all rents from the suppliers, the firm's problem can be expressed in the following way:

$$\max_{\{N\}} \Pi = A^{1-\beta} \tilde{h}(N)^{\beta\eta} \tilde{x}(N)^{\beta(1-\eta)} N^{\frac{\beta(1-\eta)}{\alpha}} - c_h \tilde{h}(N) - c_x \tilde{x}(N) N - (w^0 + \nu)N, \quad (17)$$

where $\tilde{x}(N)$ and $\tilde{h}(N)$ are the investment levels from (16). Substituting this into (17), and solving for N then yields the following complexity choice in the incomplete contracts scenario with symmetric suppliers (see Appendix B for details):

$$\tilde{N}_s = \left(\hat{\Gamma} \cdot \frac{A^{1-\beta}}{c_x} \cdot (1-\eta) \cdot \left(\frac{c_x(1-\alpha)}{\alpha(w^0 + \nu)} \right)^{1-\beta} \cdot \left(\frac{\eta c_x}{(1-\eta)c_h} \right)^{\beta\eta} \right)^{\frac{\alpha}{\alpha-\beta+(1-\alpha)\beta\eta}} \quad (18)$$

This complexity choice differs from its first-best counterpart given in (9) only with respect to the first term, which now reads as $\hat{\Gamma}$ instead of β . We show in Appendix B that $\hat{\Gamma} < \beta$ holds, which implies that $\tilde{N}_s < N^*$. In other words, the firm chooses a lower complexity level under incomplete contracts than in the first-best world. Furthermore, the comparative statics of \tilde{N}_s are analogous to those for N^* . That is, \tilde{N}_s is increasing in A and decreasing in c_x , c_h , ν and w^0 . Importantly, \tilde{N}_s is decreasing in η and increasing in δ . The intuition is that a higher headquarter-intensity η and a lower bargaining power δ both dilute the (symmetric) suppliers' investment incentives. To countervail this, the producer chooses a lower complexity level N , which per se raises the incentives for each single supplier whose individual input now accounts for a more important part of the final product. Notice that this implies that $\tilde{N}_O \equiv \tilde{N}_s(\delta = 1) > \tilde{N}_s(\delta < 1) \equiv \tilde{N}_V$, i.e., the producer chooses a higher complexity level in this symmetric setup if all suppliers maintain full ownership rights over their inputs than if all suppliers threaten to withhold only parts of their inputs.¹⁶

3.3 Asymmetric suppliers: Outsourcing versus vertical integration

After having analyzed the simplified case with an endogenous mass of symmetric suppliers, we now move to the asymmetric case and allow for differences across suppliers in terms of their organizational form. More specifically, suppliers are still assumed to be symmetric along all exogenous dimensions (unit costs, outside opportunities, and input intensity of the individual component for the final product). Yet, the producer now also decides on the outsourcing share ξ in the first stage of the game, which in turn endogenously generates asymmetries across suppliers in their ownership rights, bargaining powers, and investment incentives.

Still, we encounter a scenario where the suppliers of the *same* ownership form are symmetric and will, thus, contribute the same input amount in equilibrium. That is, assuming again a discrete number of suppliers for the moment, we have $x_O(i) = x_O \quad \forall i = 1, 2, \dots, M_O$ and $x_V(k) = x_V \quad \forall k = 1, 2, \dots, M_V$ where M_O and M_V are the (discrete) numbers of external and internal suppliers, respectively, with $M_O + M_V = M$. Revenue from (3) becomes

$$R = A^{1-\beta} h^{\beta\eta} \cdot (M_O \cdot (x_O)^\alpha + M_V \cdot (x_V)^\alpha)^\gamma = A^{1-\beta} h^{\beta\eta} M^\gamma \cdot (\xi (x_O)^\alpha + (1-\xi) (x_V)^\alpha)^\gamma$$

where $\xi = M_O/M$ is the outsourcing share. Letting $\hat{x}^\alpha \equiv \xi \cdot (x_O)^\alpha + (1-\xi) \cdot (x_V)^\alpha$, we may also write revenue as $R = A^{1-\beta} h^{\beta\eta} M^\gamma \cdot \hat{x}^{\alpha\gamma}$, where \hat{x} can be understood as the input contribution of the representative (average) supplier of the firm.

¹⁶Last, using (18) in (16), it can also be verified that $\tilde{x} < x^*$ and $\tilde{h} < h^*$ as given in (8). This illustrates the two-sided underinvestment problem resulting from contract incompleteness and the hold-up problem.

3.3.1 Bargaining and Shapley values with asymmetric suppliers

We start with the analysis of the multilateral bargaining in stage 4. There are two main issues compared to the symmetric case analyzed above. First, from the perspective of a single supplier j , his own organizational form $\{O, V\}$ will affect his marginal contribution to any coalition, as he may (under V) or may not (under O) leave behind parts of his input contribution when leaving the coalition. Second, more subtly, the ownership structure of the other suppliers also matter for the marginal contribution of player j to a specific coalition.

To see this, consider again the example with $M = 3$ from above. As stated there, four substantially different remaining coalitions can arise when player 1 leaves: $[0]$, $[0, 2]$, $[0, 3]$ and $[0, 2, 3]$. Suppose player 2 is outsourced while player 3 is integrated, so that they contribute different amounts, $x(2) \neq x(3)$. These organizational differences do *not* matter for player 1's marginal contribution to the remaining coalition of size 1, $R(i = 1) = R([0])$, which occurs twice in the set of relevant coalitions, nor for his contribution to $R(i = 3) = R([0, 2, 3])$ which occurs six times. This is so, because the ordering of agents within a remaining coalition does not matter for total revenue. However, the marginal contribution of 1 to the remaining coalition $[0, 2]$ is, in general, different from his marginal contribution to $[0, 3]$.

To compute his SV, we average over *all* feasible coalitions to which player 1 can belong:

$$s(1) = \frac{1}{24} \cdot [1!(3-1)!\Delta_R^1([0]) + 2!(3-2)!(\Delta_R^1([0, 2]) + \Delta_R^1([0, 3])) + 3!(3-3)!\Delta_R^1([0, 2, 3])]$$

The second term in squared parentheses captures the marginal contribution of player 1 to remaining coalitions of size 2. While his marginal contribution to the specific coalition $[0, 2]$ differs from his marginal contribution to $[0, 3]$, we eventually take the average across those two possible remaining coalitions.¹⁷ Hence, when averaging his marginal contribution to $[0, 2]$ and $[0, 3]$, we can as well consider the marginal contribution of player 1 to the *average* remaining coalition of size two: $4 \cdot (\frac{1}{2} \cdot \Delta_R^1([0, 2]) + \frac{1}{2} \cdot \Delta_R^1([0, 3])) = 4 \cdot \Delta_R^1(i = 2)$.¹⁸ The Shapley value then becomes $s(1) = \frac{1}{24} \cdot [2 \cdot \Delta_R^1(i = 1) + 4 \cdot \Delta_R^1(i = 2) + 6 \cdot \Delta_R^1(i = 3)]$.

Suppliers' Shapley values and revenue shares More generally, we can write the SV of supplier j as follows:

$$s(j) = \frac{A^{1-\beta} h^{\beta\eta}}{N(N+\kappa)} \cdot \sum_{i=1}^{N/\kappa} i\kappa^2 \cdot [R_{IN}^j(i+1, N, \kappa, \xi) - R_{OUT}^j(i, N, \kappa, \delta, \xi)], \quad (19)$$

where $R_{IN}^j(\cdot) = A^{1-\beta} h^{\beta\eta} \cdot (\kappa \cdot x(j)^\alpha + i\kappa \cdot (\xi(-j)x_O(-j)^\alpha + (1 - \xi(-j))x_V(-j)^\alpha))^\gamma$,
 $R_{OUT}^j(\cdot) = A^{1-\beta} h^{\beta\eta} \cdot (\kappa(1 - \delta(j)) \cdot x(j)^\alpha + i\kappa \cdot (\xi(-j)x_O(-j)^\alpha + (1 - \xi(-j))x_V(-j)^\alpha))^\gamma$.

¹⁷Notice that both $[0, 2]$ and $[0, 3]$ occur twice in the set of feasible permutations. That is, if player 1 faces a remaining coalition of size two, he faces the specific coalition $[0, 2]$ as often (with the same probability) as the remaining coalition $[0, 3]$, namely with probability $1/2$.

¹⁸This results from the fact that all component inputs enter symmetrically and additively into the production function (2), and it is straightforward to illustrate this property of the model with numerical examples.

Here, $\xi(-j)$ denotes the outsourcing share among the other suppliers $-j$, except player j . Notice that for *specific* remaining coalitions, there are of course different ownership structures that player j will face. But since we average over *all* feasible coalitions, he will on average face the ownership structure $\xi(-j)$. Finally, when M becomes large, the supplier-specific $\xi(-j)$ converges to the firm's overall outsourcing share ξ that is the same for all suppliers, $\lim_{M \rightarrow \infty} (\xi(-j)) = \xi \forall j$.¹⁹ We can then rewrite the SV of supplier j as follows:

$$s_j = \frac{A^{1-\beta} h^{\beta\eta}}{N(N+\kappa)} \cdot \sum_{i=1}^{N/\kappa} i\kappa^2 \cdot [(\kappa(z_1 + z_2))^\gamma - (\kappa((1-\delta(j))z_1 + z_2))^\gamma], \quad (20)$$

where $z_1 \equiv x(j)^\alpha$ and $z_2 \equiv i \cdot (\xi x_O(-j)^\alpha + (1-\xi) x_V(-j)^\alpha) = i \cdot \hat{x}(-j)^\alpha$. Using a similar approach as in Appendix A, we can then derive the asymptotic Shapley value for supplier j and his revenue share as follows

$$s(j) = \frac{\gamma \delta(j)}{(1+\gamma)N} \cdot \left(\frac{x(j)}{\hat{x}(-j)} \right)^\alpha \cdot R \quad \Rightarrow \quad \frac{s(j)}{R} = \frac{\gamma \delta(j)}{(1+\gamma)N} \cdot \left(\frac{x(j)}{\hat{x}(-j)} \right)^\alpha, \quad (21)$$

where $R = A^{1-\beta} h^{\beta\eta} \hat{x}(-j)^{\alpha\gamma} N^\gamma$. As can be seen from (21), the Shapley value of a single supplier j is higher if that supplier is outsourced than if he is vertically integrated. This is for two reasons: First, external suppliers have $\delta(j) = 1$ whereas internal suppliers have $\delta(j) = \delta < 1$. Second, the term $x(j)/\hat{x}(-j)$ captures the contribution of supplier j relative to the average supplier contribution $\hat{x}(-j)^\alpha = \xi x_O(-j)^\alpha + (1-\xi) x_V(-j)^\alpha$, which includes both the internal and the external suppliers' inputs. As is clear from above, $x_O(-j) > x_V(-j)$, and we therefore have $x(j) \geq \hat{x}(-j)$ if player j is outsourced, and $x(j) \leq \hat{x}(-j)$ if he is integrated. Finally, notice that if all suppliers were symmetric, so that $x(j) = \hat{x}(-j) = x$, the Shapley value from (21) boils down to the expression given in (11).

Headquarter revenue share Using (21), the Shapley value of the essential player 0 – the producer – is given by

$$s_0 = R - \int_{j=0}^N \frac{\gamma \delta(j)}{(1+\gamma)N} \cdot \left(\frac{x(j)}{\hat{x}(-j)} \right)^\alpha \cdot R \, dj = R \left(1 - \frac{\gamma}{(1+\gamma)N} \cdot \int_{j=0}^N \delta(j) \left(\frac{x(j)}{\hat{x}(-j)} \right)^\alpha \, dj \right)$$

Recalling that all outsourced suppliers are symmetric and contribute the same x_O , and that all integrated suppliers contribute the same x_V , we can rewrite this expression as

$$s_0 = R \left[1 - \frac{\gamma}{(1+\gamma)N} \cdot \left(\int_{j=0}^{\xi N} \frac{(x_O)^\alpha}{\xi \cdot (x_O)^\alpha + (1-\xi)(x_V)^\alpha} \, dj + \int_{k=\xi N}^N \frac{\delta \cdot (x_V)^\alpha}{\xi \cdot (x_O)^\alpha + (1-\xi)(x_V)^\alpha} \, dk \right) \right].$$

¹⁹Recall the example from above with $M = 3$, where supplier 2 was assumed to be outsourced while supplier 3 is integrated. If supplier 1 is also outsourced, the overall outsourcing share in the firm is $\xi = 2/3$ while from player 1's perspective we have $\xi(-j) = 1/2$. Yet, for a large number of suppliers M , there is no substantial difference between ξ and $\xi(-j)$.

Solving the integrals, and manipulating terms, yields

$$\frac{s_0}{R} = 1 - \frac{\gamma}{1 + \gamma} \left(\frac{\xi \cdot (x_O)^\alpha + \delta(1 - \xi) \cdot (x_V)^\alpha}{\xi \cdot (x_O)^\alpha + (1 - \xi) \cdot (x_V)^\alpha} \right), \quad (22)$$

and by using (22), we can establish our first main result:

Lemma 1: *The headquarter revenue share (s_0/R) is monotonically decreasing in ξ . It ranges between $(s_0/R)_{\max} = \frac{1+\gamma(1-\delta)}{1+\gamma}$ if $\xi = 0$ and $(s_0/R)_{\min} = \frac{1}{1+\gamma}$ if $\xi = 1$, with $\frac{d(s_0/R)}{d\xi} < 0$.*

For the polar cases of complete vertical integration ($\xi = 0$) and complete outsourcing ($\xi = 1$), the proof follows immediately from (22), and the respective headquarter revenue shares correspond to those from Section 3.2. For the intermediate cases, we need to differentiate (22) with respect to ξ . Importantly, when doing this, we have to take into account that the suppliers' input amounts $x_O(\xi)$ and $x_V(\xi)$ are also affected by ξ , since the organizational decision occurs before the investment decisions take place. Therefore, we have

$$\frac{d(s_0/R)}{d\xi} = - \frac{\gamma(1 - \delta) \cdot (x_O \cdot x_V)^{-(1-\alpha)}}{(1 + \gamma) \cdot (\xi \cdot (x_O)^\alpha + (1 - \xi)(x_V)^\alpha)^2} \cdot [\alpha\xi(1 - \xi)x_V x'_O + x_O(x_V - \alpha\xi(1 - \xi)x'_V)]$$

with $x'_O = \partial x_O / \partial \xi$ and $x'_V = \partial x_V / \partial \xi$. The term in front of the squared parentheses is negative and captures the direct effect of an increase in ξ on the headquarter revenue share for *given* supplier contributions. The term in squared parentheses captures the indirect effect of an increase in ξ on the supplier incentives. We show below that $x_V = \delta^{1/(1-\alpha)}x_O$, so that $x'_V = \delta^{1/(1-\alpha)}x'_O$. Using this, the term in squared parentheses becomes $\delta^{1/(1-\alpha)}x_O^2 > 0$, and hence we have $\frac{d(s_0/R^*)}{d\xi} < 0$. This completes the proof of Lemma 1.

Economically, Lemma 1 implies that the producer is able to continuously decrease her revenue share by increasing the outsourcing share. The logic behind this insight is similar as in Antràs and Helpman (2004): a transfer of ownership rights to the suppliers raises their investment incentives, but this comes at the expense that the producer has to suffice with a smaller share of the overall surplus. Yet, the important difference to their model is that the firm can *gradually* adjust the firm structure in our framework by using hybrid sourcing, and it is not bound to choosing only between extreme organizational structures. Hence, the producer can also gradually affect the share of the surplus that she leaves to the suppliers (in between an upper and a lower bound), by adjusting the outsourcing share accordingly.²⁰ Via the organizational decision ξ , she can therefore also gradually affect the suppliers' and her own incentives to invest into the relationship, as we show next.

²⁰Another difference to Antràs and Helpman (2004) is that we do not have to assume exogenously given bargaining powers (denoted β^O and β^V in their model) for the constellations of full outsourcing or integration, respectively. In our setup, the shares $(s_0/R)_{\min}$ and $(s_0/R)_{\max}$ are fully determined by the model parameters α , β , η and δ , and the producer can obtain any revenue share within those bounds via the choice variable ξ .

3.3.2 Input investments and firm structure with asymmetric suppliers

Input investments. We now move to the analysis of the input investment choices in stage 3. Using (21), an outsourced supplier j chooses his input contribution as

$$\tilde{x}_O(j) = \operatorname{argmax}_{x(j)} \left\{ \frac{\gamma}{1+\gamma} \cdot \frac{A^{1-\beta} h^{\beta\eta} \hat{x}(-j)^{\alpha\gamma} N^\gamma}{N} \cdot \left(\frac{x(j)}{\hat{x}(-j)} \right)^\alpha - c_x \cdot x(j) \right\}, \quad (23)$$

where $\hat{x}(-j)^\alpha = \xi x_O(-j)^\alpha + (1-\xi) x_V(-j)^\alpha$ is the average investment level of all other suppliers except j . Similarly, an integrated supplier k maximizes

$$\tilde{x}_V(k) = \operatorname{argmax}_{x(k)} \left\{ \frac{\gamma \delta}{1+\gamma} \cdot \frac{A^{1-\beta} h^{\beta\eta} \hat{x}(-k)^{\alpha\gamma} N^\gamma}{N} \cdot \left(\frac{x(k)}{\hat{x}(-k)} \right)^\alpha - c_x \cdot x(k) \right\}, \quad (24)$$

with $\hat{x}(-k)^\alpha = \hat{x}(-j)^\alpha = x^\alpha$ since there are many suppliers. Analogously, using (22), the producer chooses her contribution as

$$\tilde{h} = \operatorname{argmax}_h \left\{ A^{1-\beta} h^{\beta\eta} x^{\alpha\gamma} N^\gamma \cdot \left[1 - \frac{\gamma}{1+\gamma} \left(\frac{\xi(x_O)^\alpha + \delta(1-\xi)(x_V)^\alpha}{\xi(x_O)^\alpha + (1-\xi)(x_V)^\alpha} \right) \right] - c_h h \right\} \quad (25)$$

In Appendix C we derive the supplier investments $\tilde{x}_O(N, \xi)$ and $\tilde{x}_V(N, \xi)$ as functions of N and ξ only, which show that $\tilde{x}_V(N, \xi) = \delta^{1/(1-\alpha)} \cdot \tilde{x}_O(N, \xi)$. Integrated suppliers thus contribute less than outsourced ones, *ceteris paribus*, because of their inferior ownership rights. Those solutions, in turn, yield the average supplier investment $\tilde{x}(N, \xi)$ and the producer's investment choice $\tilde{h}(N, \xi)$ which are given by

$$\tilde{x}(N, \xi) = \Psi_x \cdot \Phi_x(\xi) \cdot N^{\frac{\beta(1-\eta)(1-\alpha)}{\alpha(1-\beta)} - 1} \quad \text{and} \quad \tilde{h}(N, \xi) = \Psi_h \cdot \Phi_h(\xi) \cdot N^{\frac{\beta(1-\eta)(1-\alpha)}{\alpha(1-\beta)}}. \quad (26)$$

The investment amounts for the asymmetric case in (26) are similar to their counterparts from (16) for the symmetric case. In fact, the exogenous terms Ψ_x and Ψ_h are those given above. Yet, the other exogenous terms Δ_x and Δ_h from above are now replaced by the endogenous terms $\Phi_x(\xi)$ and $\Phi_h(\xi)$ where the firm's organizational decision ξ enters. Those terms read as

$$\Phi_x(\xi) = \Xi_x^{\frac{(1-\alpha)(1-\beta\eta)}{\alpha(1-\beta)}} \cdot \Xi_h^{\frac{\beta\eta}{1-\beta}}, \quad \Phi_h(\xi) = \Xi_x^{\frac{(1-\alpha)\beta(1-\eta)}{\alpha(1-\beta)}} \cdot \Xi_h^{\frac{1-\beta(1-\eta)}{1-\beta}}, \quad (27)$$

with $\Xi_x = \xi + (1-\xi)\bar{\delta}$ and $\Xi_h = 1 + \gamma - \gamma \frac{\xi + (1-\xi)\bar{\delta}^{1/\alpha}}{\xi + (1-\xi)\bar{\delta}}$, where $\bar{\delta} \equiv \delta^{1/\alpha}$.

Notice that with $\xi = 1$ we have $\Xi_x = \Xi_h = 1$ and thus $\Phi_x = \Phi_h = 1$, while for $\xi = 0$ we have $\Xi_x = \Delta_x$ and $\Xi_h = \Delta_h$. That is, under full outsourcing or full integration – the only two firm structures where all suppliers are symmetric – the input amounts (26) are the same as in (16).

For the intermediate constellations of hybrid sourcing ($0 < \xi < 1$), the producer's input relative to the input of all suppliers is given by

$$\frac{\tilde{h}}{N \cdot \tilde{x}} = \frac{\eta c_x}{(1-\eta) c_h} \cdot \frac{\Xi_h(\xi)}{\Xi_x(\xi)^{\frac{1-\alpha}{\alpha}}}.$$

Since $\Xi_h(\xi) > 1$ and $0 < \Xi_x(\xi) < 1$, the second term on the RHS is larger than one if $0 < \xi < 1$. Moreover, that term is larger the smaller ξ is, as Ξ_x is increasing and Ξ_h is decreasing in ξ . Hence, when the producer chooses a higher share of vertically integrated suppliers (for a given mass N), she ends up contributing relatively more to the production process, because the underinvestment problems for the aggregate of suppliers is aggravated.

Firm structure. Finally, in stage 1, the producer now decides on the complexity and the organization of the production process. Formally, her decision problem is given by

$$\max_{\{N, \xi\}} \Pi = A^{1-\beta} \tilde{h}(N, \xi)^{\beta\eta} \tilde{x}(N, \xi)^{\beta(1-\eta)} N^{\frac{\beta(1-\eta)}{\alpha}} - c_h \tilde{h}(N, \xi) - c_x \tilde{x}(N, \xi) N - (w^0 + \nu)N,$$

where $\tilde{x}(N, \xi)$ and $\tilde{h}(N, \xi)$ are the investment levels from (26). In Appendix D we show that this maximization program is equivalent to the following simpler problem:

$$\max_{\{N, \xi\}} \Pi = \Theta(\xi) \cdot N^{\frac{\beta(1-\alpha)(1-\eta)}{\alpha(1-\beta)}} - (w^0 + \nu)N, \quad (28)$$

$$\text{subject to } \Theta(\xi) = A^{1-\beta} \cdot (\Psi_h \Phi_h(\xi))^{\beta\eta} \cdot (\Psi_x \Phi_x(\xi))^{\beta(1-\eta)} - c_h \Psi_h \Phi_h(\xi) - c_x \Psi_x \Phi_x(\xi). \quad (29)$$

The outsourcing share thus enters the payoff Π only via the term $\Theta(\xi)$, which does not depend on N . The first-order conditions (FOCs) for problem (28) can be expressed as follows:

$$\begin{aligned} \frac{d\Pi}{d\xi} &= \frac{\eta \Xi_x \Xi'_h}{\Xi_h} \left[\Xi_x (\alpha + \beta(1-\eta) - \alpha(1-\beta(1-\eta))\Xi_h) - \alpha\beta(1-\eta)\Xi_x^{1/\alpha} \right] + \\ &\quad \frac{(1-\alpha)(1-\eta)\Xi'_x}{\alpha} \left[\Xi_x (\alpha + \beta(1-\eta) - \alpha\beta\eta\Xi_h) - \alpha(1-\beta\eta)\Xi_x^{1/\alpha} \right] = 0, \end{aligned} \quad (30)$$

$$\frac{d\Pi}{dN} = \frac{\beta(1-\alpha)(1-\eta)}{\alpha(1-\beta)} \cdot \hat{\theta}(\xi) \cdot N^{\frac{\beta(1-\alpha)(1-\eta)}{\alpha(1-\beta)}-1} - (w^0 + \nu) = 0, \quad (31)$$

and we can proceed in two separate steps: First, the FOC (30) that does not depend on N is solved for the payoff-maximizing outsourcing share $\tilde{\xi}$. Second, using this solution in (31), we then solve the other FOC for the complexity level \tilde{N} .

As for the first step, we derive the second-order condition (SOC) in Appendix D and show that $\alpha + \beta < 1$ is sufficient (though not necessary) to ensure that $d^2\Pi(\xi)/d\xi^2 < 0$. We assume that this parameter restriction is satisfied, which rules out cases where demand is highly elastic and at the same time components are very close substitutes. The function $d^2\Pi(\xi)/d\xi^2$ is then monotonically decreasing in ξ , which implies that $\tilde{\xi}$ (with $0 \leq \tilde{\xi} \leq 1$) is uniquely determined. In the second step, \tilde{N} is also unique. In particular, plugging $\tilde{\xi}$ into $\Theta(\xi)$ from (29), and using this in (31) we obtain

$$\tilde{N} = \left(\left(\frac{\beta(1-\alpha)(1-\eta)}{\alpha(1-\beta)(w^0 + \nu)} \right)^{1-\beta} \cdot \Theta(\tilde{\xi})^{1-\beta} \right)^{\frac{\alpha}{\alpha-\beta+(1-\alpha)\beta\eta}}. \quad (32)$$

Notice that this \tilde{N} lies in between \tilde{N}_V and \tilde{N}_O as defined in (18), where it was imposed that all suppliers are symmetric. Put differently, the complexity choice corresponding to hybrid sourcing ranges between those for full vertical integration and full outsourcing, respectively.

3.3.3 Characterization and discussion of the firm structure decisions

We now characterize and illustrate the firm's complexity and organization decisions in more detail, and discuss the economic intuition. Proposition 1 summarizes the main insights

Proposition 1 – *In the closed economy, where the producer decides on the firm's complexity and organization, our model predicts that:*

1. *Firms from highly component-intensive industries ($\eta < \bar{\eta}_1$) choose full outsourcing of all suppliers. In more headquarter-intensive industries, $\eta > \bar{\eta}_1$, we have an optimal outsourcing share $0 \leq \tilde{\xi} < 1$. The threshold level $\bar{\eta}_1$ is given below in eq. (33).*
2. *Firms from more headquarter-intensive industries choose a lower complexity level \tilde{N} and a lower outsourcing share $\tilde{\xi}$.*
3. *Firms with a larger market size (higher A) choose a higher complexity \tilde{N} , whereas higher unit costs c_x and c_h , higher agency costs ν , and a higher outside opportunity w^0 lead to a lower complexity level \tilde{N} ; the outsourcing share $\tilde{\xi}$ is unaffected by those parameters.*

Result 1 shows that firms from highly component-intensive industries choose full outsourcing of *all* suppliers, and the corresponding complexity level follows directly as \tilde{N}_O by using $\tilde{\xi} = 1$ in (32). To derive the threshold level $\bar{\eta}_1$, notice that the FOC (30) implies that $d\Pi(\xi)/d\xi > 0$ for all values $\xi \in [0, 1]$ if η is below

$$\bar{\eta}_1 = \frac{1 - \alpha - \alpha^2(1 - \beta) \left[\frac{1 - \bar{\delta}^{1/\alpha}}{1 - \bar{\delta}} - 1 \right]}{1 - \alpha} \in [0, 1] \quad (33)$$

To see this, evaluate (30) at $\xi = 1$. This yields the following function that is decreasing in η :

$$\left. \frac{d\Pi(\xi)}{d\xi} \right|_{\xi=1} = \frac{\beta(1-\eta)}{\alpha} \left[1 - \eta - \alpha(1-\eta - \alpha\bar{\delta}^{1/\alpha}(1-\beta)) - \bar{\delta}(1 - \alpha - \alpha^2(1-\beta) - \eta(1-\alpha)) \right]$$

Setting this expression equal to zero, and solving for η , we obtain $\bar{\eta}_1$ as given in (33). The threshold level $\bar{\eta}_1$ is decreasing in α and increasing in β . In words, full outsourcing is less likely to occur the better the single components are substitutable (the higher α is) and the

less elastic final goods demand is (the lower β is). Importantly, if $\eta > \bar{\eta}_1$, full outsourcing is no longer the optimal organizational structure, and firms in those industries turn to a hybrid sourcing strategy ($0 \leq \tilde{\xi} < 1$) with some (or all) suppliers vertically integrated.

Result 2 describes the comparative statics of the firm structure with respect to the sectoral headquarter-intensity. Starting with the complexity choice, \tilde{N} from (32) depends on η both directly and indirectly via the outsourcing share $\tilde{\xi}$. The direct effect is always negative, for essentially the same reason as explained for \tilde{N}_s above: Supplier incentives are weaker in more headquarter-intensive industries, and the producer countervails this by choosing fewer suppliers. As for the indirect effect, more outsourcing is per se endogenously associated with more complexity, since the producer countervails the adverse impact of vertical integration on the suppliers' incentives by having fewer suppliers. As $\tilde{\xi}$ depends negatively on η (as we show next), the indirect effect of η on \tilde{N} is thus also negative, hence $d\tilde{N}/d\eta < 0$.

Turning to the comparative statics of $\tilde{\xi}$ with respect to η , we can adopt an indirect approach to illustrate the economic intuition. First, recall our Lemma 1 which states that the producer is able to obtain every revenue share (Shapley value) in the range between $(s_0/R)_{\min} = \frac{1}{1+\gamma}$ and $(s_0/R)_{\max} = \frac{1+\gamma(1-\delta)}{1+\gamma}$ by adjusting the outsourcing share appropriately. This available range is illustrated in Figure 1, where the red curve depicts $(s_0/R)_{\min}$ and the green curve depicts $(s_0/R)_{\max}$, respectively. Notice that both curves are monotonically increasing in η , that is, the producer has higher bargaining power in more headquarter-intensive sectors under any organizational structure. Second, recall from the analysis in Section 3.1. that the *optimal* revenue share that the producer would obtain in a first-best world is given by $(s_0/R)^* = 1 - \beta(1 - \eta) \left[\frac{w^0 + \alpha\nu}{\alpha(w^0 + \nu)} \right]$. This share, which is linearly increasing in η , is depicted as the black curve in Figure 1. The left (right) panel in that figure assumes a high (low) value of δ , which shifts up the $(s_0/R)_{\max}$ -curve while the other curves are the same in both panels.

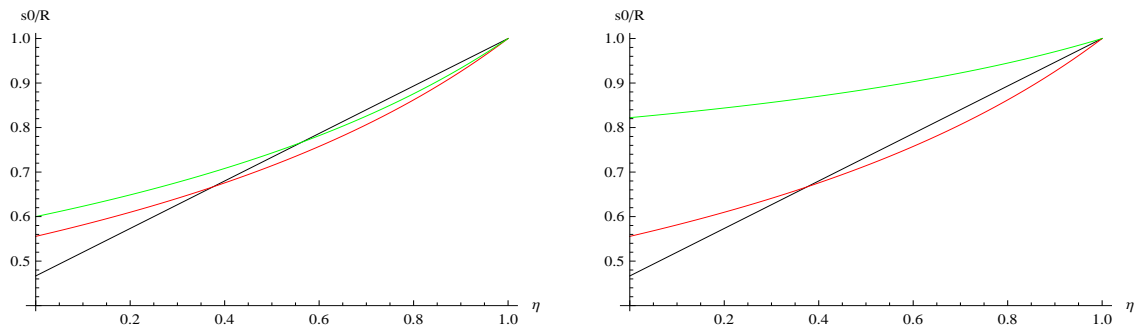


Figure 1: Organizational decision – optimal and realized headquarter revenue share

Black: optimal share $(s_0/R)^*$. **Red:** share under full outsourcing share, $(s_0/R)_{\min}$. **Green:** share under full integration, $(s_0/R)_{\max}$.

Parameters: $\alpha = 0.5$, $\beta = 0.4$, $\nu = 1$, $w^0 = 0.5$. Left panel: $\delta = 0.9$, right panel: $\delta = 0.4$.

Intuitively, the producer's organizational decision can be thought of as choosing ξ in such a way that her realized revenue share is realigned as closely as possible with the optimal one. For low headquarter-intensity, this means that the producer chooses full outsourcing since $(s_0/R)^* < (s_0/R)_{\min}$. Moreover, in the left panel, she chooses full vertical integration for high values of η since $(s_0/R)^* > (s_0/R)_{\max}$. Finally, in the range $(s_0/R)_{\min} < (s_0/R)^* < (s_0/R)_{\max}$ the producer can freely choose ξ so as to match $(s_0/R)^*$, and since that revenue share is increasing in η , this implies that she chooses a lower outsourcing share in more headquarter-intensive industries. In the left panel the organizational structure across industries thus changes from full outsourcing to hybrid sourcing to full vertical integration over the range of η . In the right panel, for low values of δ , integrated suppliers have too little investment incentives, and hence there is no fully integrated firm structure even in highly headquarter-intensive sectors.²¹

Finally, result 3 of Proposition 1 shows that \tilde{N} is affected by the other parameters similarly as \tilde{N}_s and N^* . For instance, the firm's complexity level is lower the higher the suppliers' unit costs c_x are. Yet, the organizational structure is unaffected since two effects exactly offset each other: Lower unit costs c_x raise the bargaining power of each single supplier, as he then tends to contribute more. Yet, since the firm also chooses *more* suppliers the lower c_x is, and since the revenue *level* increases, there is no need for the producer to adjust the distribution of revenue within the firm via a change in the organizational structure.

4 Global sourcing

We now incorporate the global scale dimension into the producer's problem. She may now also decide on the country $r \in \{1, 2\}$ where each component $i \in [0, N]$ is manufactured, and thus she can effectively choose from four different sourcing modes for each supplier: domestic integration, domestic outsourcing, foreign integration (intra-firm trade) or foreign outsourcing.

We assume that unit costs of foreign suppliers are lower than for domestic suppliers, $c_2 < c_1$, where we have dropped the subscript "x" for convenience. Those unit costs do, however, not depend on the ownership form of the foreign supplier.²² Furthermore, for the moment we abstract from any other cross-country differences, such as different fixed costs for domestic or foreign component manufacturing, but we will return to those issues below.

It is important to notice that, although suppliers can now be asymmetric along *two* dimensions, it is still the case that all suppliers who share the same organizational form *and* the same unit costs (country of origin) are symmetric in their investment incentives, and thus in their equilibrium input contributions. Revenue in the open economy can be written as $R = A^{1-\beta} h^{\beta\eta} x^{\alpha\gamma} N^\gamma$, where the average supplier contribution is now given by:

²¹The prediction that $\tilde{\xi}$ and η are negatively correlated is similar as in the seminal model by Antràs and Helpman (2004). Yet, since there are multiple suppliers in our framework, the firm can engage in hybrid sourcing and thereby adjust the firm structure gradually.

²²See Nowak et al. (2012) for a global sourcing model with two asymmetric suppliers and economies of scope, where it is assumed that external contractors have higher unit costs than integrated affiliates.

$$x^\alpha = \xi [(1 - \ell_O) (x_{O1})^\alpha + \ell_O (x_{O2})^\alpha] + (1 - \xi) [(1 - \ell_V) (x_{V1})^\alpha + \ell_V (x_{V2})^\alpha]. \quad (34)$$

Here, x_{kr} is the input contribution of a supplier from country $r \in \{1, 2\}$ with ownership form $k = \{O, V\}$, and $\ell_k \in [0, 1]$ is the offshoring share among the suppliers of ownership form k .

4.1 Bargaining and input investments

Starting with the multilateral bargaining in stage 4 of the game, to compute the asymptotic Shapley value for a single supplier j , notice that a relationship as in (21) still holds,

$$s_r(j) = \frac{\gamma \cdot \delta(j)}{(1 + \gamma)N} \cdot \left(\frac{x_r(j)}{x} \right)^\alpha \cdot R.$$

In other words, the revenue share realized by supplier j reflects his ownership rights via $\delta(j)$, and his own input contribution $x_r(j)$ relative to the average supplier contribution x , which is the same for all j since we have a continuum of suppliers.²³ Turning to the producer, she realizes the residual revenue share in the bargaining stage, that is

$$\frac{s_0}{R} = 1 - \frac{\gamma}{(1 + \gamma)N} \cdot \int_{j=0}^N \delta(j) \left(\frac{x_r(j)}{x} \right)^\alpha dj \quad (35)$$

In stage 3, the suppliers of the four sourcing modes choose their input amounts as follows

$$\begin{aligned} \tilde{x}_{O1}(j) &= \operatorname{argmax}_{x(j)} \left\{ \frac{\gamma}{1 + \gamma} \cdot \frac{A^{1-\beta} h^{\beta\eta} x^{\alpha\gamma} N^\gamma}{N} \cdot \left(\frac{x(j)}{x} \right)^\alpha - c_1 \cdot x(j) \right\}, \\ \tilde{x}_{V1}(k) &= \operatorname{argmax}_{x(k)} \left\{ \frac{\gamma \delta}{1 + \gamma} \cdot \frac{A^{1-\beta} h^{\beta\eta} x^{\alpha\gamma} N^\gamma}{N} \cdot \left(\frac{x(k)}{x} \right)^\alpha - c_1 \cdot x(k) \right\}, \\ \tilde{x}_{O2}(i) &= \operatorname{argmax}_{x(i)} \left\{ \frac{\gamma}{1 + \gamma} \cdot \frac{A^{1-\beta} h^{\beta\eta} x^{\alpha\gamma} N^\gamma}{N} \cdot \left(\frac{x(i)}{x} \right)^\alpha - c_2 \cdot x(i) \right\}, \\ \tilde{x}_{V2}(\ell) &= \operatorname{argmax}_{x(\ell)} \left\{ \frac{\gamma \delta}{1 + \gamma} \cdot \frac{A^{1-\beta} h^{\beta\eta} x^{\alpha\gamma} N^\gamma}{N} \cdot \left(\frac{x(\ell)}{x} \right)^\alpha - c_2 \cdot x(\ell) \right\}, \end{aligned}$$

with the average input contribution x given in (34). Solving for the respective input contributions, it is straightforward to see that $\tilde{x}_{k2} = (c_1/c_2)^{1/(1-\alpha)} \tilde{x}_{k1}$ and $\tilde{x}_{Vr} = \delta^{1/(1-\alpha)} \tilde{x}_{Or}$. That is, foreign suppliers contribute more than domestic suppliers of the same ownership form, because of their effective cost advantage ($c_1/c_2 > 1$). Furthermore, internal suppliers contribute less than external suppliers from the same country, because of their inferior ownership rights.

As for the producer, we show in Appendix E that her realized revenue share (35) can be rewritten as

²³Recall that, when computing the marginal contribution of supplier j , he will on average encounter remaining coalitions that reflect the overall structure (ownership and global scale composition) of the firm.

$$\frac{s_0}{R} = 1 - \frac{\gamma}{1+\gamma} \cdot \frac{\xi(1+\phi \ell_O) + (1-\xi)\bar{\delta}^{1/\alpha}(1+\phi \ell_V)}{\xi(1+\phi \ell_O) + (1-\xi)\bar{\delta}(1+\phi \ell_V)}, \quad (36)$$

where $\phi = [(c_1/c_2)^{\alpha/(1-\alpha)} - 1] > 0$ captures the unit cost advantage of foreign suppliers. It follows from (36) that the producer realizes a lower revenue share the higher is the share of external suppliers ξ , analogously as in the closed economy. As for the global scale decision, it turns out that there is no impact on the producers's revenue share as long as she sets the *same* offshoring share for external and for internal suppliers, i.e., if $\ell_O = \ell_V = \ell$. The intuition is that two effects then exactly offset each other: On the one hand, foreign suppliers have a higher bargaining power since they contribute more. On the other hand, these higher input contributions also raise the revenue level, so that s_0/R can effectively remain unchanged. The producer's revenue share is affected by the global scale decision, however, when ℓ_O and ℓ_V are not uniform. In particular, if the producer raises ℓ_O while keeping ℓ_V fixed, she ends up with a *lower* revenue share s_0/R , because this boosts the incentives of already powerful (external) suppliers. Vice versa, increasing ℓ_V while keeping ℓ_O fixed, leads to a higher s_0/R .

Finally, using (36), the producer's input choice for \tilde{h} in stage 3 can be expressed as

$$\tilde{h} = \operatorname{argmax}_h \left\{ A^{1-\beta} h^{\beta\eta} x^{\alpha\gamma} N^\gamma \left(1 - \frac{\gamma}{1+\gamma} \cdot \frac{\xi(1+\phi \ell_O) + (1-\xi)\bar{\delta}^{1/\alpha}(1+\phi \ell_V)}{\xi(1+\phi \ell_O) + (1-\xi)\bar{\delta}(1+\phi \ell_V)} \right) - c_h \cdot h \right\}.$$

The input investment choices have an analogous form as in the closed economy, see eqs. (23)–(25). The solutions for the optimal headquarter contribution $\tilde{h}(N, \xi, \ell_O, \ell_V)$ and for the average supplier contribution $\tilde{x}(N, \xi, \ell_O, \ell_V)$ in the open economy therefore resemble their closed economy counterparts given in (26). In particular, the optimal contributions by the average supplier and by the headquarter can be written as (see Appendix E):

$$\begin{aligned} \tilde{x}(N, \xi, \ell_O, \ell_V) &= \Psi_x \cdot \Phi_x^{open}(\xi, \ell_O, \ell_V) \cdot N^{\frac{\beta(1-\eta)(1-\alpha)}{\alpha(1-\beta)} - 1} \\ \tilde{h}(N, \xi, \ell_O, \ell_V) &= \Psi_h \cdot \Phi_h^{open}(\xi, \ell_O, \ell_V) \cdot N^{\frac{\beta(1-\eta)(1-\alpha)}{\alpha(1-\beta)}}, \end{aligned} \quad (37)$$

where the terms Ψ_x and Ψ_h are still the same as in (16), except that c_x is replaced by the domestic c_1 , and where $\Phi_x^{open}(\xi, \ell_O, \ell_V)$ and $\Phi_h^{open}(\xi, \ell_O, \ell_V)$ are now defined as:

$$\begin{aligned} \Phi_x^{open}(\xi, \ell_O, \ell_V) &= (\Xi_x^{open})^{\frac{(1-\alpha)(1-\beta\eta)}{\alpha(1-\beta)}} \cdot (\Xi_h^{open})^{\frac{\beta\eta}{1-\beta}}, \\ \Phi_h^{open}(\xi, \ell_O, \ell_V) &= (\Xi_x^{open})^{\frac{(1-\alpha)\beta(1-\eta)}{\alpha(1-\beta)}} \cdot (\Xi_h^{open})^{\frac{1-\beta(1-\eta)}{1-\beta}}, \end{aligned} \quad (38)$$

with

$$\begin{aligned} \Xi_x^{open} &= \xi(1+\phi \ell_O) + (1-\xi)\bar{\delta}(1+\phi \ell_V) \\ \Xi_h^{open} &= 1 + \gamma - \gamma \cdot \frac{\xi(1+\phi \ell_O) + (1-\xi)\bar{\delta}^{1/\alpha}(1+\phi \ell_V)}{\xi(1+\phi \ell_O) + (1-\xi)\bar{\delta}(1+\phi \ell_V)} \end{aligned}$$

Note that the offshoring shares ℓ_O and ℓ_V enter the equilibrium input contributions only via the terms Ξ_x^{open} and Ξ_h^{open} , where the former term is increasing in both offshoring shares while the latter is increasing in ℓ_V but decreasing in ℓ_O . For the case of a common offshoring share $\ell_O = \ell_V = \ell$, these terms simplify and become, respectively, $\Xi_x^{open} = (1 + \phi \ell) [\xi + (1 - \xi)\bar{\delta}]$ and $\Xi_h^{open} = 1 + \gamma - \gamma \cdot \frac{\xi + (1 - \xi)\bar{\delta}^{1/\alpha}}{\xi + (1 - \xi)\bar{\delta}}$. That is, Ξ_h^{open} is then the same as in the closed economy, while Ξ_x^{open} is larger than Ξ_x and is increasing in ℓ .

Importantly, it follows from (38) that both Φ_x^{open} and Φ_h^{open} are increasing in ℓ_O and in ℓ_V . Since the input amounts from (37) depend positively on these terms, we can therefore state the following result:

Lemma 2: *An increase of either offshoring share (ℓ_O or ℓ_V) raises the average supplier input \tilde{x} and the input amount of headquarter services \tilde{h} .*

The positive effect of offshoring on \tilde{x} is straightforward, as foreign suppliers contribute more than domestic ones, *ceteris paribus*. More surprisingly, offshoring also raises the amount of headquarter services \tilde{h} , even though it may reduce the producer's revenue *share* as shown above. Again, this is because the absolute value of the relationship – the revenue *level* – increases due to the unit cost reduction, which in turn incentivizes the producer to contribute.²⁴

4.2 Firm structure

Moving to the firm structure decision in the first stage of the game, the producer now decides on the complexity, the organization, and the global scale of the production process. Using the input contributions from (37), the firm's problem is

$$\max_{\{N, \xi, \ell_O, \ell_V\}} \Pi = A^{1-\beta} \tilde{h}^{\beta\eta} \tilde{x}^{\beta(1-\eta)} N^{\frac{\beta(1-\eta)}{\alpha}} - c_h \tilde{h} - \hat{c}_x \tilde{x} N - (w^0 + \nu)N, \quad (39)$$

where it is understood that \tilde{h} and \tilde{x} depend on N , ξ , ℓ_O , and ℓ_V . The term \hat{c}_x in (39) captures the unit cost level of the average supplier, which in the open economy is given by $c_x = (1 - \ell)c_1 + \ell c_2$, where $\ell = \xi \cdot \ell_O + (1 - \xi) \cdot \ell_V$. Notice that, since $c_1 > c_2$, this average unit cost level is decreasing in the offshoring shares ℓ_O and ℓ_V .

Since an increase in either offshoring share lowers the unit costs \hat{c}_x but raises the input contributions \tilde{h} and \tilde{x} (see Lemma 2) and, hence, the revenue level, it is easy to see that the producer decides to fully offshore all components, $\tilde{\ell}_O = \tilde{\ell}_V = \tilde{\ell} = 1$. The intuition is simple: In this scenario, where fixed costs or other types of offshoring costs are still absent, offshoring only has advantages (lower unit costs) but no disadvantages for the firm. To analyze the other two dimensions of the firm structure for this scenario, recall that we can rewrite the firm's problem in a simpler way as follows (see eq. (28)):

²⁴For the case of a common offshoring share, it follows immediately that \tilde{x} and \tilde{h} are increasing in ℓ , since $\Xi_x^{open} = (1 + \phi\ell)\Xi_x$ and $\Xi_h^{open} = \Xi_h$, so that $\Phi_x^{open} > \Phi_x$ and $\Phi_h^{open} > \Phi_h$.

$$\max_{\{N, \xi, \ell_O, \ell_V\}} \Pi = \Theta^{open}(\xi, \ell_O, \ell_V) \cdot N^{\frac{\beta(1-\alpha)(1-\eta)}{\alpha(1-\beta)}} - (w^0 + \nu)N, \quad (40)$$

where the term $\Theta^{open}(\xi, \ell_O, \ell_V)$ in the open economy reads as

$$\Theta^{open}(\cdot) = A^{1-\beta} \cdot (\Psi_h \cdot \Phi_h^{open}(\cdot))^{\beta\eta} \cdot (\Psi_x \cdot \Phi_x^{open}(\cdot))^{\beta(1-\eta)} - c_h \Psi_h \Phi_h^{open}(\cdot) - \hat{c}_x \Psi_x \Phi_x^{open}(\cdot),$$

with $\Phi_x^{open}(\xi, \ell_O, \ell_V)$ and $\Phi_h^{open}(\xi, \ell_O, \ell_V)$ as defined in (38). Under complete offshoring, the suppliers' unit costs become $\hat{c}_x = c_2$, and furthermore we have $\Xi_x^{open} = (1 + \phi)\Xi_x$ and $\Xi_h^{open} = \Xi_h$. Substituting those terms into (40), and deriving first-order conditions analogous as in the closed economy case, we can state the following results:

Proposition 2 – *In the open economy, where foreign suppliers have lower unit costs than domestic suppliers ($c_2 < c_1$), our model predicts that:*

1. *Firms offshore all components ($\ell_O = \ell_V = \ell = 1$)*
2. *Firms choose the same outsourcing share as in the closed economy setting ($\tilde{\xi}^{open} = \tilde{\xi}$).*
3. *Firms choose a higher complexity level than in the closed economy setting ($\tilde{N}^{open} > \tilde{N}$).*

The results 2 and 3 refer to a comparison of the *same* firm (with given headquarter-intensity, market size, and so on) in an open economy setting where component offshoring is possible, vis-a-vis a closed economy setting where all suppliers have to be domestic.²⁵ Proving these results is simple, as the essence can already be seen in Proposition 1. There we have shown that the optimal outsourcing share is unaffected by the suppliers' unit costs, while the complexity level is higher the lower the unit costs are. In the present context, complete offshoring is tantamount to fully replacing high-cost domestic suppliers (with $c_x = c_1$) by low-cost foreign suppliers (with $c_x = c_2 < c_1$) which according to our previous results has a positive effect on \tilde{N} but no effect on $\tilde{\xi}$.

Economically, Proposition 2 implies that *globalization boosts the division of labor within firms*. In the open economy, firms choose a setting with more suppliers and more narrowly defined tasks than under autarky. Globalization does, however, not affect the overall organizational structure as captured by the outsourcing share. Put differently, also in the open economy, ownership structures differ across firms with different characteristics (α , β , δ and η), and our comparative static results still hold. In particular, firms from sectors with intermediate headquarter-intensity rely on a hybrid global sourcing mode, where the share $\tilde{\xi}$ of the components is obtained via arm's length outsourcing, and the remaining share $(1 - \tilde{\xi})$ via intra-firm trade. Furthermore, there is still a negative correlation between headquarter-intensity

²⁵This corresponds to the standard thought experiment where an economy opens up to trade, which in our context means that we move from an autarky scenario to a setting where component offshoring is feasible.

and the outsourcing share. Yet, Proposition 2 shows that the move from autarky to trade does not induce any particular firm (with given η) to change its share of internal/external suppliers, at least not when offshoring only brings about unit cost reductions.

4.3 Organization-specific fixed costs and offshoring costs

Finally, in this last step of the analysis, we introduce fixed costs which may differ according to the firm's organizational structure and the global scale of the production process. Starting from the total payoff as given in (40), fixed costs are introduced via the last term in the following expression which depends on ξ , ℓ_O and ℓ_V :

$$\max_{\{N, \xi, \ell_O, \ell_V\}} \Pi = \Theta^{open}(\cdot) N^{\frac{\beta(1-\alpha)(1-\eta)}{\alpha(1-\beta)}} - (w^0 + \nu)N - [\xi f_O + (1 - \xi)f_V + (\ell_O + \ell_V)f_X]$$

Several aspects are noteworthy about this fixed cost specification. First, f_O and f_V are organization-specific fixed cost terms. Since the agency costs ν capture the additional fixed costs *per supplier*, f_O and f_V thus measure the differential increase when an external/internal supplier is added to the production process. If $f_O < f_V$, as we shall assume below, adding an outsourced supplier induces lower fixed costs, for example because internal organization requires more supervision and oversight. Second, the organization-specific fixed costs f_O and f_V do not depend on whether the external/internal suppliers are domestic or foreign. Those offshoring costs are explicitly introduced via the term f_X , which may capture higher communication or transportation costs for foreign component manufacturers.²⁶ Analogously, the offshoring costs f_X do not differ according to the ownership form of the foreign suppliers, but those organizational differences are captured by the terms f_O and f_V , since ξ is the firm's overall outsourcing share across all (domestic and foreign) suppliers.²⁷

What are the implications of these fixed costs for the firm structure decisions? To start our analysis, we first assume that fixed costs differ according to the organizational form, but we still impose no offshoring fixed costs ($f_X = 0$). Foreign component manufacturing then still has no disadvantages for the firm, and the producer thus still chooses foreign suppliers for all components. Figure 2 illustrates how the outsourcing decision is affected by organization-specific fixed costs. The left/middle/right panel depicts the case of an industry with low/medium/high headquarter-intensity. The dashed lines refer to the benchmark case where $f_O = f_V$, while the solid lines are for the case where $f_V > f_O$.

²⁶The term f_X again captures the differential increase in fixed costs when a foreign supplier is added, while the general increase in fixed costs per supplier are captured by ν . Notice further that different fixed costs for domestic/foreign suppliers could also be introduced by assuming that the outside opportunity w_r^0 differs across countries. Since the foreign country is a low-wage country, it seems reasonable to assume that $w_1^0 > w_2^0$. This, however, would mean that the offshoring gains of lower unit costs are even reinforced by lower fixed costs per foreign supplier. To keep things simple, we assume that w^0 is the same across countries.

²⁷Put differently, our specification is compatible with the reasonable fixed cost ranking assumed in Antràs and Helpman (2004), where foreign vertical integration is associated with the highest fixed costs, followed by foreign outsourcing, domestic integration, and domestic outsourcing.

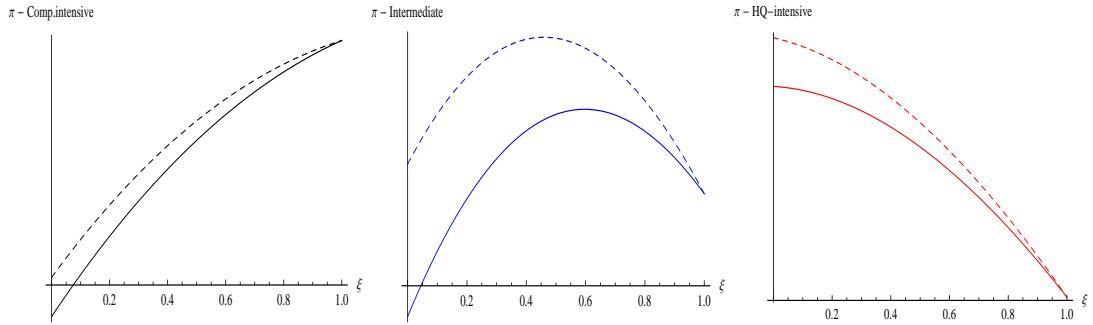


Figure 2: Optimal outsourcing share – with / without higher fixed costs of vertical integration

Parameters: $\alpha = 0.5$, $\beta = 0.4$, $\delta = 0.9$, $A = 4$, $c_h = 4$, $c_1 = 1$, $c_2 = 0.99$, $w^0 = 1$, $\nu = 1$, $f_X = 0$.

Left panel: $\Pi(\xi)$ for $\eta = 0.7$. Medium panel: $\Pi(\xi)$ for $\eta = 0.78$. Right panel: $\Pi(\xi)$ for $\eta = 0.88$.

Dashed lines: $f_O = f_V = 0.2$, solid lines: $0.2 = f_O < f_V = 0.2005$. Full offshoring ($\ell_O = \ell_V = 1$) in all cases.

In the benchmark (dashed lines), the total payoff is increasing/hump-shaped/decreasing in ξ if headquarter-intensity is on a low/intermediate/high level. Hence, the firm chooses, respectively, full outsourcing in the first, hybrid sourcing in the second, and full vertical integration in the third case. When integration now causes higher fixed costs, there are two changes (see the solid lines). First, the total payoff level decreases as fixed costs have risen. Second and more importantly, the organizational decision tilts towards more outsourcing. This can be seen most clearly in the medium panel for the case of intermediate headquarter-intensity. With equal fixed costs ($f_V = f_O$), the firm would choose an outsourcing share of $\tilde{\xi} \approx 0.46$ in this example, while with $f_V > f_O$ this share increases to $\tilde{\xi} \approx 0.51$.

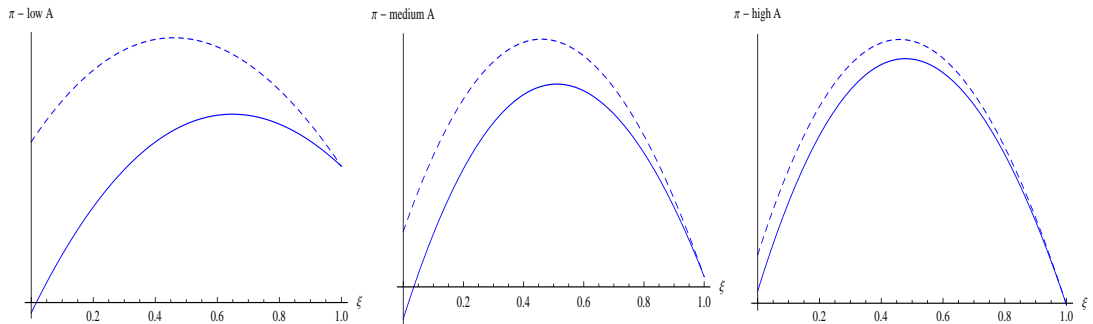


Figure 3: Tilt towards outsourcing – firms with different market sizes

Parameters: $\alpha = 0.5$, $\beta = 0.4$, $\delta = 0.9$, $c_h = 4$, $c_1 = 1$, $c_2 = 0.99$, $w^0 = 1$, $\nu = 1$, $f_X = 0$, $\eta = 0.78$.

Left panel: $A = 10$; Medium panel: $A = 30$; Right panel: $A = 70$.

Dashed lines: $f_O = f_V = 0.2$, solid lines: $0.2 = f_O < f_V = 0.2005$. Full offshoring ($\ell_O = \ell_V = 1$) in all cases.

How far the organizational decision is tilted depends, in particular, on the firm's exogenous market size. Notice that the fixed cost term is independent of A , while the (net-of-fixed-cost) payoff is monotonically increasing in A . The higher fixed costs of vertical integration therefore matter relatively little for firms with large market size, while low- A firms are affected more strongly. This is shown in Figure 3, which focuses on the case of intermediate headquarter-intensity, and depicts the organizational decision of a firm in this sector with low/medium/high market size, respectively.²⁸ As can be seen, the tilt is strongest in the left panel (for low A).

Finally, we move to the global scale decision with positive offshoring costs. Foreign component manufacturing now has an advantage (lower unit costs $c_2 < c_1$), but also a disadvantage: higher fixed costs $f_X > 0$. Figure 4 focuses again on an industry with medium headquarter-intensity, and depicts the total payoff Π as a function of the endogenously chosen offshoring shares ℓ_O and ℓ_V .²⁹ Again, we assume that vertical integration causes higher fixed costs ($f_V > f_O$), and the left/medium/right panel of Figure 4 is for the case of low/medium/high offshoring costs f_X , respectively (the other parameters are as before).

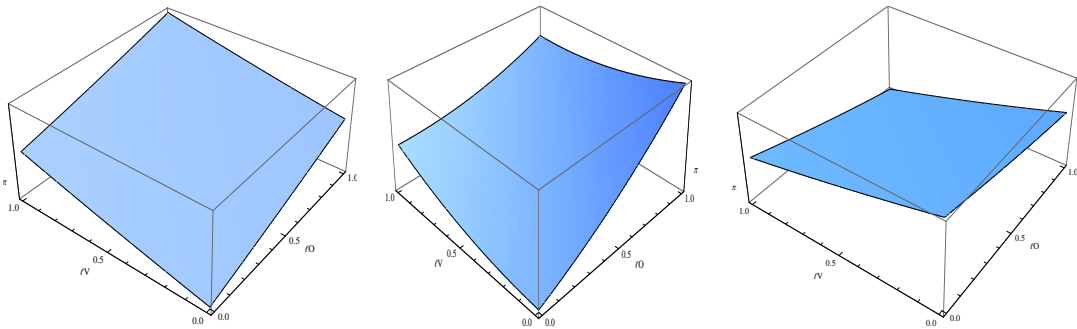


Figure 4: Optimal offshoring shares for different offshoring costs f_X

Parameters: $\alpha = 0.5$, $\beta = 0.4$, $\delta = 0.9$, $A = 4$, $c_h = 4$, $c_1 = 1$, $c_2 = 0.99$, $w^0 = 1$, $\nu = 1$, $f_O = 0.2$, $f_V = 0.2005$, $\eta = 0.78$. Left panel: $\Pi(\ell_O, \ell_V, \xi(\ell_O, \ell_V))$ for $f_X = 0.001$ (low offshoring costs). Medium panel: $\Pi(\ell_O, \ell_V, \xi(\ell_O, \ell_V))$ for $f_X = 0.0016$ (intermediate offshoring costs). Right panel: $\Pi(\ell_O, \ell_V, \xi(\ell_O, \ell_V))$ for $f_X = 0.003$ (high offshoring costs).

For low offshoring costs the producer only has foreign suppliers, see the left panel where the maximum payoff is achieved at $\tilde{\ell}_O = \tilde{\ell}_V = 1$. Analogously, for high offshoring costs the producer only has domestic suppliers, as can be seen in the right panel where the maximum is now at $\tilde{\ell}_O = \tilde{\ell}_V = 0$. The most interesting case is the one in the middle, where offshoring costs

²⁸Reminiscent of the large literature on firm-level heterogeneity, we could introduce an exogenous productivity shifter à la Melitz (2003) in the production function. Firm-level differences in this productivity shifter then would have analogous effects on the organizational decision as differences in market size A .

²⁹We simulate for each combination of ℓ_O and ℓ_V the corresponding outsourcing share $\xi(\ell_O, \ell_V)$ that maximizes the firm's payoff, given the respective global scale structure. In Figure 4 the optimal global scale decision $\{\tilde{\ell}_O, \tilde{\ell}_V\}$ is, therefore, at the point where the respective three-dimensional plane Π achieves a global maximum, and the outsourcing share is given by the corresponding value of $\xi(\tilde{\ell}_O, \tilde{\ell}_V)$. Notice that this outsourcing share cannot be directly read in Figure 4.

are on an intermediate level. Here we find that the maximum payoff is achieved at $\tilde{\ell}_O = 1$ and $\tilde{\ell}_V = 0$, that is, the firm offshores all external suppliers but keeps all integrated suppliers domestic. The rationale is that intra-firm trade (vertical integration of foreign suppliers) is associated with the highest overall fixed costs, and the lower foreign unit costs do not compensate this offshoring disadvantage. For the external suppliers, however, the unit cost gains are substantial enough to render offshoring profitable.

The firm structure in this final scenario is, therefore, characterized by a *partial* offshoring, where *some* suppliers (the internal ones) are domestic, while others (the external ones) are foreign. Under the standard assumption that $f_V > f_O$, our model therefore predicts a positive correlation of outsourcing and offshoring: The external suppliers are offshored first, while intra-firm trade is chosen only at lower levels of f_X . Another related observation is that the optimal $\tilde{\xi}$ in case with intermediate offshoring costs is higher than in the scenario with high offshoring costs.³⁰ That is, when f_X gradually falls and the firm starts to collaborate with foreign external suppliers, it inter alia raises the firm's overall outsourcing share.

5 Conclusions

An abundant empirical literature has recently established various stylized facts about the internal structure of firms, in particular:

1. Firms differ vastly in the number of suppliers they contract with, and thus in the complexity of their production processes.
2. Firms often have both internal and external suppliers, that is, they do not outsource or vertically integrate *all* intermediate inputs, but the two organizational modes co-exist.
3. Firms that collaborate with foreign suppliers typically engage in partial offshoring, that is, they import only some inputs but choose domestic suppliers for others.

Fact 1 has been shown by Alfaro and Charlton (2009) or Altomonte and Rungi (2013), who compare the sizes of business groups both within and across industries. Facts 2 and 3 indicate that many (if not most) firms choose a *hybrid sourcing* strategy for the organizational and the global scale dimension of their production processes. Those facts are established in, or can be deduced from, various recent contributions including Costinot et al. (2013), Corcos et al. (2013), Defever and Toubal (2013), Kohler and Smolka (2012), Jabbour (2012), Jabbour and Kneller (2010), Bernard et al. (2010), Farinas and Marcos (2010), Federico (2010), Nunn and Treffer (2008), Tomiura (2007), Yeaple (2006), Marin (2006), Feenstra and Hanson (2005), and others.

³⁰In the medium panel with intermediate f_X we have $\tilde{\xi}(\tilde{\ell}_O = 1, \tilde{\ell}_V = 0) \approx 0.614$ while in the right panel with high f_X we have $\tilde{\xi}(\tilde{\ell}_O = 0, \tilde{\ell}_V = 0) \approx 0.512$.

The global sourcing models by Antràs (2003) and Antràs and Helpman (2004) cannot accommodate those facts, because these frameworks assume a single supplier so that hybrid sourcing or differences in the complexity level can – by construction – not arise. The incomplete contracts model by Acemoglu, Antràs and Helpman (2007) is consistent with fact 1, but not with facts 2 and 3, because they focus on entirely symmetric firm structures with full outsourcing or full vertical integration of *all* suppliers.

In this paper, we have developed an extension of the latter framework. In particular, in our model the producer not only chooses the total mass of suppliers, but she is also able to choose the outsourcing and the offshoring share among them, which endogenously generates asymmetries across suppliers. We have shown that firms actually use this hybrid sourcing in equilibrium, as it gives them leeway to gradually affect the revenue distribution inside the firm, the bargaining powers of the involved agents, and their incentives to invest into the relationship. Our model is therefore consistent with all facts 1–3 mentioned above, and may thus be useful to make sense of those observed patterns in the data.

Our model may also motivate future empirical research, as it leads to several novel predictions that have – to the best of our knowledge – not been tested yet. For example, our model predicts that the *same* firm would choose a deeper division of labor in an open economy context than under autarky. In the public press, there seems to be the widespread conception that globalization has indeed led to a stronger unbundling (or slicing) of production processes. However, we are unaware of serious econometric work on this relationship for which our model provides a theoretical foundation. Similarly, our model predicts a positive correlation of offshoring and outsourcing. That is, as firms go “more global” in their sourcing strategies, they tend to engage more in outsourcing than in a pure closed economy setting. Importantly, this “time series” correlation is still consistent with a “cross sectional” pattern where many firms choose vertical integration, particularly in headquarter-intensive industries. Again, it would be interesting to confront these theoretical predictions with longitudinal firm-level data.

The model in this paper is about single firms. It can potentially be embedded into a general equilibrium framework where firm interactions within and across industries are taken into account. Such a framework would be useful to explore more fully the repercussions of trade integration with cross-country differences in market conditions, factor prices and incomes, as well as their implications for global sourcing decisions. Furthermore, our model is based on a static bargaining scenario. In practice, suppliers may care about long-term relationships, or may try to collude with other suppliers in order to induce pressure on the headquarter. Exploring those and other extensions is left for future research.

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Appendix

A) Shapley value with symmetric suppliers

Using the expressions for $R_{IN}^j(i+1, N, \kappa)$ and $R_{OUT}^j(i, N, \kappa)$ we obtain the following marginal contribution of player j to a remaining coalition of size i :

$$\Delta_R^j(i, N, \kappa) = A^{1-\beta} h^{\beta\eta} \cdot [(\kappa x(j)^\alpha + i\kappa \cdot x(-j)^\alpha)^\gamma - (\kappa \cdot (1-\delta)x(j)^\alpha + i\kappa \cdot x(-j)^\alpha)^\gamma]. \quad (41)$$

Let $z_1 \equiv x(j)^\alpha$ and $z_2 \equiv i \cdot x(-j)^\alpha$. Using (41) in the definition of the SV, we have

$$s_j = \frac{A^{1-\beta} h^{\beta\eta}}{N(N+\kappa)} \cdot \sum_{i=1}^{M=N/\kappa} i\kappa^2 \cdot [(\kappa(z_1 + z_2))^\gamma - (\kappa((1-\delta)z_1 + z_2))^\gamma]. \quad (42)$$

A first-order Taylor expansion of the term in squared parentheses with respect to z_1 , evaluated at $z_1 = 0$, yields $\gamma\delta\kappa^\gamma \cdot z_2^{\gamma-1} \cdot z_1 + o(z_1)$. Hence, we can approximate (42) as

$$s_j = \gamma \cdot \delta \cdot \frac{A^{1-\beta} h^{\beta\eta} \cdot x(-j)^{\alpha\gamma} \cdot N^\gamma}{N^{1+\gamma}(N+\kappa)} \cdot \left(\frac{x(j)}{x(-j)}\right)^\alpha \cdot \sum_{i=1}^{N/\kappa} \kappa \cdot (\kappa i)^\gamma \cdot \kappa \quad (43)$$

Now we consider the range κ to be infinitely small, i.e., we let the number of suppliers become infinitely large. The above sum then becomes a Riemann integral, and we have

$$\lim_{\kappa \rightarrow 0} \left(\frac{s_j}{\kappa}\right) = \gamma \cdot \delta \cdot \frac{A^{1-\beta} h^{\beta\eta} \cdot x(-j)^{\alpha\gamma} \cdot N^\gamma}{N^{2+\gamma}} \cdot \left(\frac{x(j)}{x(-j)}\right)^\alpha \cdot \int_{z=0}^N (z)^\gamma dz \quad (44)$$

Since $\int_{z=0}^N (z)^\gamma dz = N^{(1+\gamma)}/(1+\gamma)$, and since $x(j) = x(-j)$ due to symmetry across suppliers, we then immediately obtain the asymptotic SV as given in (11).

B) Complexity choice under incomplete contracts w. symmetric suppliers

Substituting (16) into (17), we can rewrite the firm's overall payoff Π as follows:

$$\left(A^{1-\beta} (\Psi_h \Delta_h)^{\beta\eta} (\Psi_x \Delta_x)^{\beta(1-\eta)}\right) N^{\frac{\beta(1-\eta)}{\alpha} + \beta\eta \frac{\beta(1-\alpha)(1-\eta)}{\alpha(1-\beta)} + \beta(1-\eta) \left(\frac{\beta(1-\alpha)(1-\eta)}{\alpha(1-\beta)} - 1\right)} - (c_h \Psi_h \Delta_h + c_x \Psi_x \Delta_x) N^{\frac{\beta(1-\alpha)(1-\eta)}{\alpha(1-\beta)}} - (w^0 + \nu)N$$

This can be simplified as $\Pi = \Theta_s \cdot N^{\frac{\beta(1-\alpha)(1-\eta)}{\alpha(1-\beta)}} - (w^0 + \nu)N$, where the term Θ_s read as

$$\begin{aligned} \Theta_s &= A^{1-\beta} \cdot (\Psi_h \Delta_h)^{\beta\eta} \cdot (\Psi_x \Delta_x)^{\beta(1-\eta)} - c_h \Psi_h \Delta_h - c_x \Psi_x \Delta_x \\ &= A^{1-\beta} \cdot (\Psi_h \Delta_h)^{\beta\eta} \cdot (\Psi_x \Delta_x)^{\beta(1-\eta)} \left(1 - \frac{c_h \Psi_h \Delta_h}{A^{1-\beta} (\Psi_h \Delta_h)^{\beta\eta} (\Psi_x \Delta_x)^{\beta(1-\eta)}} - \frac{c_x \Psi_x \Delta_x}{A^{1-\beta} (\Psi_h \Delta_h)^{\beta\eta} (\Psi_x \Delta_x)^{\beta(1-\eta)}}\right) \\ &= A^{1-\beta} \cdot \left[\Psi_h^{\beta\eta} \cdot \Psi_x^{\beta(1-\eta)}\right] \cdot \left[\Delta_h^{\beta\eta} \cdot \Delta_x^{\beta(1-\eta)}\right] \left(1 - \frac{\alpha\beta\eta}{\alpha + \beta(1-\eta)} \cdot (1 + \gamma(1-\delta)) - \frac{\alpha\beta(1-\eta)}{\alpha + \beta(1-\eta)} \cdot \delta\right) \\ &= A \left[\left(\frac{\eta}{c_h}\right)^{\frac{\beta\eta}{1-\beta}} \left(\frac{1-\eta}{c_x}\right)^{\frac{\beta(1-\eta)}{1-\beta}} \left(\frac{\alpha\beta}{\alpha + \beta(1-\eta)}\right)^{\frac{\beta}{1-\beta}} \left[\delta^{\frac{\beta(1-\eta)}{1-\beta}} (1 + \gamma(1-\delta))^{\frac{\beta\eta}{1-\beta}} \right] \left(1 - \frac{\alpha\beta(\delta + (1-\delta)\eta(1+\gamma))}{\alpha + \beta(1-\eta)}\right) \right] \end{aligned}$$

Maximizing $\Pi = \Theta_s \cdot N^{\frac{\beta(1-\alpha)(1-\eta)}{\alpha(1-\beta)}} - (w^0 + \nu)N$ with respect to N yields the following complexity choice in the incomplete contracts scenario with symmetric suppliers:

$$\tilde{N}_s = \left(\left(\frac{\beta}{1-\beta} \right)^{1-\beta} \cdot (1-\eta)^{1-\beta} \cdot \left(\frac{1-\alpha}{\alpha(w^0 + \nu)} \right)^{1-\beta} \cdot \Theta_s^{1-\beta} \right)^{\frac{\alpha}{\alpha - \beta + (1-\alpha)\beta\eta}} \quad (45)$$

Noting that

$$\Theta_s^{1-\beta} = A^{1-\beta} \cdot c_x^{-\beta} \cdot (1-\eta)^\beta \cdot \left(\frac{\eta c_x}{(1-\eta)c_h} \right)^{\beta\eta} \cdot \Gamma,$$

where

$$\Gamma = \left(\frac{\alpha\beta}{\alpha + \beta(1-\eta)} \right)^\beta \cdot \left[\delta^{\frac{\beta(1-\eta)}{1-\beta}} (1 + \gamma(1-\delta))^{\frac{\beta\eta}{1-\beta}} \right]^{1-\beta} \left(1 - \frac{\alpha\beta(\delta + (1-\delta)\eta(1+\gamma))}{\alpha + \beta(1-\eta)} \right)^{1-\beta},$$

we can express the complexity choice as in (18), with $\hat{\Gamma} = \left(\frac{\beta}{1-\beta} \right)^{1-\beta} \Gamma$. It is straightforward to show that $\hat{\Gamma}$ is increasing in δ . Since δ enters in (18) only via the term $\hat{\Gamma}$, we can thus be sure that $\partial\tilde{N}_s/\partial\delta > 0$. For $\delta = 1$, the term $\hat{\Gamma}$ becomes

$$\hat{\Gamma}(\delta = 1) = \left(\frac{\beta}{1-\beta} \right)^{1-\beta} \left(\frac{\alpha\beta}{\alpha + \beta(1-\eta)} \right)^\beta \left(1 - \frac{\alpha\beta}{\alpha + \beta(1-\eta)} \right)^{1-\beta},$$

which is unambiguously smaller than β . Hence, $\tilde{N}_s < N^*$ if $\delta = 1$, and since \tilde{N}_s is increasing in δ , we thus have $\tilde{N}_s < N^*$ in general.

Finally, the comparative statics of \tilde{N}_s with respect to η can be derived similarly as for N^* above. Let \tilde{N}_s be written in the form $\tilde{N}_s = \left(\hat{\Gamma}(\eta)g(\eta) \right)^{h(\eta)}$. Then we have

$$\partial\tilde{N}_s/\partial\eta = \left(\hat{\Gamma}(\eta) \cdot g(\eta) \right)^{h(\eta)} \left(\frac{h(\eta)[g'(\eta)\hat{\Gamma}(\eta) + g(\eta)\hat{\Gamma}'(\eta)]}{\hat{\Gamma}(\eta)g(\eta)} + h'(\eta) \log[\hat{\Gamma}(\eta) \cdot g(\eta)] \right),$$

with $h'(\eta) < 0$, $\hat{\Gamma}'(\eta) > 0$ and $g'(\eta) < 0$ for $c_h/c_x > \eta/(1-\eta)$. Again, by normalizing A , ν or w^0 appropriately, it is ensured that $g(\eta)$ becomes large enough so that the first term in parentheses becomes small, and the overall expression $\partial\tilde{N}_s/\partial\eta$ is negative.

C) Input investments with asymmetric suppliers

Maximizing (23) with respect to $x_O(j)$, taking the average $\hat{x}(-j)$ as given, yields

$$\tilde{x}_O = \left(\frac{\alpha\beta(1-\eta)}{\alpha + \beta(1-\eta)} \cdot \frac{A^{1-\beta}}{c_x} \right)^{\frac{1}{1-\alpha}} \cdot h^{\frac{\beta\eta}{1-\alpha}} \cdot N^{\frac{\gamma-1}{1-\alpha}} \cdot \hat{x}(-j)^{\frac{\alpha(\gamma-1)}{1-\alpha}}. \quad (46)$$

Similarly, maximizing (24) with respect to $x_V(k)$, and bearing in mind that $\hat{x}(-k) = \hat{x}(-j) = x$ since there is a continuum of suppliers, gives $\tilde{x}_V = \delta^{1/(1-\alpha)} \cdot \tilde{x}_O$, with \tilde{x}_O as in (46). Substi-

tuting $x^\alpha = x_O^\alpha[\xi + (1 - \xi)\bar{\delta}]$ into (46), where $\bar{\delta} = \delta^{\alpha/(1-\alpha)}$, then leads to

$$\tilde{x}_O = \left(\frac{\alpha\beta(1-\eta)}{\alpha + \beta(1-\eta)} \cdot \frac{A^{1-\beta}}{c_x} \right)^{\frac{1}{1-\beta(1-\eta)}} \cdot h^{\frac{\beta\eta}{1-\beta(1-\eta)}} \cdot N^{\frac{\gamma-1}{1-\beta(1-\eta)}} \cdot \Xi_x^{\frac{\gamma-1}{1-\beta(1-\eta)}},$$

where $\Xi_x = \xi + (1 - \xi) \cdot \bar{\delta}$. Hence, the average supplier investment is

$$\tilde{x} = \tilde{x}_O \cdot \Xi_x^{(1/\alpha)} = \left(\frac{\alpha\beta(1-\eta)}{\alpha + \beta(1-\eta)} \cdot \frac{A^{1-\beta}}{c_x} \right)^{\frac{1}{1-\beta(1-\eta)}} \cdot h^{\frac{\beta\eta}{1-\beta(1-\eta)}} \cdot N^{\frac{\gamma-1}{1-\beta(1-\eta)}} \cdot \Xi_x^{\frac{1-\alpha}{\alpha(1-\beta(1-\eta))}} \quad (47)$$

Turning to the producer, bearing in mind that $x_V^\alpha = \bar{\delta} \cdot x_O^\alpha = \frac{\bar{\delta}}{\xi + (1-\xi)\bar{\delta}} \cdot x^\alpha$ we can rewrite the maximization problem (25) as

$$\tilde{h} = \operatorname{argmax}_h \left\{ \frac{A^{1-\beta} h^{\beta\eta} x^{\alpha\gamma} N^\gamma}{1 + \gamma} \cdot \left(1 + \frac{\gamma(1-\delta)(1-\xi)\bar{\delta}}{\xi + (1-\xi)\bar{\delta}} \right) - c_h \cdot h \right\},$$

Maximizing this with respect to h , and manipulating terms, yields:

$$\tilde{h} = \left(\frac{\alpha\beta\eta}{\alpha + \beta(1-\eta)} \cdot \frac{A^{1-\beta}}{c_h} \right)^{\frac{1}{1-\beta\eta}} \cdot N^{\frac{\gamma}{1-\beta\eta}} \cdot x^{\frac{\alpha\gamma}{1-\beta\eta}} \cdot \Xi_h^{\frac{1}{1-\beta\eta}} \quad (48)$$

where $\Xi_h = 1 + \gamma - \gamma \cdot \frac{\xi + (1-\xi)\bar{\delta}^{1/\alpha}}{\xi + (1-\xi)\bar{\delta}}$. Next, we substitute (48) into (46) and solve for \tilde{h} and for \tilde{x} (and thereby for \tilde{x}_O and \tilde{x}_V) as functions of N and ξ only. Straightforward algebra then leads to the solutions given in (26).

D) Firm structure decision with asymmetric suppliers: Organization

i) The Θ -term: Substituting $\tilde{h}(N, \xi)$ and $\tilde{x}(N, \xi)$ from (26) into

$$\Pi = A^{1-\beta} \tilde{h}(N, \xi)^{\beta\eta} \tilde{x}(N, \xi)^{\beta(1-\eta)} N^{\frac{\beta(1-\eta)}{\alpha}} - c_h \tilde{h}(N, \xi) - c_x \tilde{x}(N, \xi) N - (w^0 + \nu)N,$$

we obtain the expression $\Pi = \Theta(\xi) \cdot N^{\frac{\beta(1-\alpha)(1-\eta)}{\alpha(1-\beta)}} - (w^0 + \nu)N$ by using the same approach as in Appendix B, since the exponents on N are identical, so that N can be factorized as is shown there. The only difference to the approach from Appendix B is that the terms Δ_x and Δ_h are now replaced by $\Phi_x(\xi)$ and $\Phi_h(\xi)$, respectively. The term

$$\Theta(\xi) = A^{1-\beta} \cdot (\Psi_h \cdot \Phi_h(\xi))^{\beta\eta} \cdot (\Psi_x \cdot \Phi_x(\xi))^{\beta(1-\eta)} - c_h \Psi_h \Phi_h(\xi) - c_x \Psi_x \Phi_x(\xi),$$

can then be rewritten in a similar way as above:

$$\begin{aligned}
\Theta(\xi) &= A^{1-\beta} \cdot (\Psi_h \Phi_h)^{\beta\eta} \cdot (\Psi_x \Phi_x)^{\beta(1-\eta)} \left(1 - \frac{c_h \Psi_h \Phi_h}{A^{1-\beta} \cdot (\Psi_h \Phi_h)^{\beta\eta} \cdot (\Psi_x \Phi_x)^{\beta(1-\eta)}} - \frac{c_x \Psi_x \Phi_x}{A^{1-\beta} \cdot (\Psi_h \Phi_h)^{\beta\eta} \cdot (\Psi_x \Phi_x)^{\beta(1-\eta)}} \right) \\
&= A \left[\left(\frac{\eta}{c_h} \right)^{\frac{\beta\eta}{1-\beta}} \left(\frac{1-\eta}{c_x} \right)^{\frac{\beta(1-\eta)}{1-\beta}} \left(\frac{\alpha\beta}{\alpha+\beta(1-\eta)} \right)^{\frac{\beta}{1-\beta}} \right] \cdot \left[\Phi_h^{\beta\eta} \Phi_x^{\beta(1-\eta)} \right] \cdot \left(1 - \frac{\alpha\beta\eta}{\alpha+\beta(1-\eta)} \cdot \Xi_h - \frac{\alpha\beta(1-\eta)}{\alpha+\beta(1-\eta)} \cdot \Xi_x^{\frac{1-\alpha}{\alpha}} \right) \\
&= A \left[\left(\frac{\eta}{c_h} \right)^{\frac{\beta\eta}{1-\beta}} \left(\frac{1-\eta}{c_x} \right)^{\frac{\beta(1-\eta)}{1-\beta}} \left(\frac{\alpha\beta}{\alpha+\beta(1-\eta)} \right)^{\frac{\beta}{1-\beta}} \right] \cdot \left\{ \Xi_x^{\frac{\beta(1-\alpha)(1-\eta)}{\alpha(1-\beta)}} \Xi_h^{\frac{\beta\eta}{1-\beta}} \left(1 - \frac{\alpha\beta \left[\eta \Xi_h + (1-\eta) \Xi_x^{\frac{1-\alpha}{\alpha}} \right]}{\alpha+\beta(1-\eta)} \right) \right\}
\end{aligned}$$

ii) *First- and second-order conditions:* Using this expression, the first-order condition $d\Pi/d\xi$ boils down to differentiating the (multiplicative) term in curly brackets in $\Theta(\xi)$, since ξ enters only there via $\Xi_h(\xi)$ and $\Xi_x(\xi)$. After some simplification, this first-order condition (FOC) can be written as in (30). Deriving the FOC with respect to N is straightforward from (28).

Furthermore, noting that $\Xi_x'' = 0$, the second-order condition (SOC) can be written as

$$\begin{aligned}
\frac{d^2\Pi}{d\xi^2} &= (\eta \Xi_x (\Xi_h')^2 / (\Xi_h)^2) \left[-(\alpha + \beta - \beta\eta)\Xi_x + \alpha\beta(1-\eta)\Xi_x^{1/\alpha} \right] \\
&\quad - \beta\eta(1 + \alpha\eta - \alpha - \eta) \Xi_h (\Xi_x')^2 \\
&\quad - \frac{(1-\alpha)(1-\eta)(1-\beta\eta)}{\alpha} (\Xi_x)^{(1-\alpha)/\alpha} (\Xi_x')^2 - \alpha\eta(1-\beta+\beta\eta) (\Xi_x)^2 \Xi_h'' \\
&\quad + \frac{\eta(\alpha+\beta-\beta\eta)\Xi_x}{\Xi_h} [2\Xi_h' \Xi_x' + \Xi_x \Xi_h''] \\
&\quad + (\Xi_x'/\alpha) [(1-\alpha)(1-\eta)(\alpha+\beta-\beta\eta)\Xi_x' - \Xi_x \Xi_h'(\alpha\eta(\beta+\alpha(2-3\beta(1-\eta))+\beta\eta))] \\
&\quad - \left(\beta\eta(1-\eta) (\Xi_x)^{1/\alpha} / \Xi_h \right) [\alpha \Xi_x \Xi_h'' + (1+\alpha) \Xi_x' \Xi_h']
\end{aligned}$$

Bearing in mind that $\Xi_h > 1$, $0 < \Xi_x < 1$, $\Xi_h' < 0$, $\Xi_x' > 0$, and $\Xi_h'' > 0$, it follows that the first four terms are unambiguously negative for any ξ , the fifth term is positive but is dominated by the four negative terms, and the sign of the sixth term is ambiguous. A sufficient condition to ensure that the sixth term, and hence the overall expression, is negative is to assume that $\alpha + \beta < 1$. Provided this parameter restriction is satisfied, the $d\Pi/d\xi$ -curve is thus generally downward-sloping in ξ , and the optimal $\tilde{\xi}$ must be unique.

E) Bargaining and input investments in the open economy

Since there are four types of suppliers, and since the suppliers of each type are symmetric, we can write out the integral in (35) as follows:

$$\int_{j=0}^{\xi(1-\ell_O)N} \frac{(x_{O1})^\alpha}{x^\alpha} dj + \int_{i=\xi(1-\ell_O)N}^{\xi N} \frac{(x_{O2})^\alpha}{x^\alpha} di + \int_{k=\xi N}^{\xi N+(1-\xi)(1-\ell_V)N} \frac{\delta \cdot (x_{V1})^\alpha}{x^\alpha} dk + \int_{\iota=\xi N+(1-\xi)(1-\ell_V)N}^N \frac{\delta \cdot (x_{V2})^\alpha}{x^\alpha} d\iota.$$

where the integration bounds add up to the total mass of suppliers. Solving the integrals,

and using the average input contribution x from (34), the producer's revenue share can be computed as

$$\frac{s_0^*}{R^*} = 1 - \frac{\gamma}{1 + \gamma} \left(\frac{\xi [(1 - \ell_O)(\tilde{x}_{O1})^\alpha + \ell_O(\tilde{x}_{O2})^\alpha] + \delta (1 - \xi) [(1 - \ell_V)(\tilde{x}_{V1})^\alpha + \ell_V(\tilde{x}_{V2})^\alpha]}{\xi [(1 - \ell_O)(\tilde{x}_{O1})^\alpha + \ell_O(\tilde{x}_{O2})^\alpha] + (1 - \xi) [(1 - \ell_V)(\tilde{x}_{V1})^\alpha + \ell_V(\tilde{x}_{V2})^\alpha]} \right). \quad (49)$$

Using $\tilde{x}_{k2} = (c_1/c_2)^{1/(1-\alpha)}\tilde{x}_{k1}$ and $\tilde{x}_{Vr} = \delta^{1/(1-\alpha)}\tilde{x}_{Or}$ in (49), it can be immediately seen that \tilde{x}_{O1} cancels from this expression, so that we can write the producer's revenue share as in (36).

Finally, we solve for the equilibrium input contributions as given in (37) and (38). To do so, notice that the payoff maximization of an outsourced domestic supplier yields

$$\tilde{x}_{O1} = \left(\frac{\alpha\beta(1-\eta)}{\alpha + \beta(1-\eta)} \frac{A^{1-\beta}}{c_1} \right)^{\frac{1}{1-\alpha}} h^{\frac{\beta\eta}{1-\alpha}} N^{\frac{\gamma-1}{1-\alpha}} x^{\frac{\alpha(\gamma-1)}{1-\alpha}},$$

with \tilde{x}_{V1} , \tilde{x}_{O2} and \tilde{x}_{V2} defined accordingly using $\tilde{x}_{k2} = (c_1/c_2)^{1/(1-\alpha)}\tilde{x}_{k1}$ and $\tilde{x}_{Vr} = \delta^{1/(1-\alpha)}\tilde{x}_{Or}$. Substituting those expressions into (34) we thus have $x^\alpha = (\tilde{x}_{O1})^\alpha \cdot \Xi_x^{open}$, with

$$\Xi_x^{open} = \xi \left(1 + \ell_O \underbrace{[(c_1/c_2)^{\alpha/(1-\alpha)} - 1]}_{=\phi>0} \right) + (1-\xi)\bar{\delta} \left(1 + \ell_V \underbrace{[(c_1/c_2)^{\alpha/(1-\alpha)} - 1]}_{=\phi>0} \right) = \xi(1 + \ell_O\phi) + (1-\xi)\bar{\delta}(1 + \ell_V\phi)$$

The average supplier contribution in equilibrium can therefore be written as

$$\tilde{x} = \left(\frac{\alpha\beta(1-\eta)}{\alpha + \beta(1-\eta)} \frac{A^{1-\beta}}{c_1} \right)^{\frac{1}{1-\beta(1-\eta)}} h^{\frac{\beta\eta}{1-\beta(1-\eta)}} N^{\frac{\gamma-1}{1-\beta(1-\eta)}} (\Xi_x^{open})^{\frac{1-\alpha}{\alpha(1-\beta(1-\eta))}}.$$

The producer's maximization problem for the provision of headquarter services yields

$$\tilde{h} = \left(\frac{\alpha\beta\eta}{\alpha + \beta(1-\eta)} \frac{A^{1-\beta}}{c_h} \right)^{\frac{1}{1-\beta\eta}} x^{\frac{\alpha\gamma}{1-\beta\eta}} N^{\frac{\gamma}{1-\beta\eta}} (\Xi_h^{open})^{\frac{1}{1-\beta\eta}},$$

with Ξ_h^{open} as defined in the main text. Solving those two expressions for \tilde{x} and \tilde{h} then yields the solution given in (37).