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Value capture in hierarchically organized industries

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Abstract

Most goods today are designed and produced by value chains of firms. The value that a value chain as a whole captures is distributed among its members through bargaining. For complex products, such bargaining will consist of several individual negotiations, typically structured according to the hierarchical organization of the respective industry. We introduce the notion of "bargaining structure" to describe the sequence and participants of these individual negotiations. Using cooperative game theory, in particular the Shapley value and extensions of it, we show how bargaining structure affects the distribution of value among the constituent firms of the value chain. Positions in the bargaining structure most conducive to value capture are those where large complementarity gains are realized, and split among an ideally small number of negotiators. Since the bargaining structure of a value chain is to some extent malleable, firms have an incentive to shape it in such a way as to optimize their own value capture. We suggest that product architecture is a key lever to influence the architecture of the value chain, and as a consequence bargaining structure and value capture.

Value capture in hierarchically organized industries: The hierarchy strategy

Abstract: Most goods today are designed and produced by value chains of firms. The value that a value chain as a whole captures is distributed among its members through bargaining. For complex products, such bargaining will consist of several individual negotiations, typically structured according to the hierarchical organization of the respective industry. We introduce the notion of “bargaining structure” to describe the sequence and participants of these individual negotiations. Using cooperative game theory, in particular the Shapley value and extensions of it, we show how bargaining structure affects the distribution of value among the constituent firms of the value chain. Positions in the bargaining structure most conducive to value capture are those where large complementarity gains are realized, and split among an ideally small number of negotiators. Since the bargaining structure of a value chain is to some extent malleable, firms have an incentive to shape it in such a way as to optimize their own value capture. We suggest that product architecture is a key lever to influence the architecture of the value chain, and as a consequence bargaining structure and value capture.

Keywords: value capture, negotiations, Shapley value, industry architecture, modularity

1. Introduction

A firm may be an important player in its industry, yet fail to realize solid returns. In the classic PC industry, leading OEMs such as HP or Dell faced very small profit margins of about 3% for a long time (The Guardian 2014). Even IBM, despite being the innovator behind the PC platform, mostly realized only meager profits in this industry (Lohr 2004). In contrast, Intel and Microsoft were able to generate very attractive profits through strong positions in their respective segments (The Guardian 2014; Kunert 2013).

As the examples show, the value captured by an industry overall may be split highly unevenly among the members. In terms of the determinants of this value split, the resource-based view emphasizes ownership and control of critical resources (Daft 1983; Barney 1986), while the market-based view focuses on market structure, competition, and potential new entry in the focal industry as well as among suppliers and customers (Bain 1956; Porter 1980).

Against the background of resource ownership and market structure, value is split among firms in the value chain through bargaining (Brandenburger, Stuart 2007), where we define a value chain following Sturgeon (2001) as the collectivity of all firms that contribute to a particular instance of value creation through a specific division of labor. A given firm bargains upstream with its suppliers and downstream with its customers to determine its input and sales prices and thus the value it appropriates. A favorable position with respect to resources and market structure may put a firm in a “bottleneck” position in an industry, making it the least replaceable firm (Morris, Ferguson 1993; Iansiti, Levien 2004; Jacobides et al. 2006; Pisano, Teece 2007; Jacobides, MacDuffie 2013).

The literature discusses various approaches to attaining a bottleneck position. Some of these approaches imply changes to industry architecture through fostering competition, or mobility, in other segments of the value chain, e.g., through open interfaces, and reducing competition in the focal firm’s own segment, e.g., with the help of legal protection mechanisms such as patents (Jacobides et al. 2006; Eisenmann et al. 2009).

While existing studies have greatly enhanced our understanding of how industry architecture affects value capture, the changes to a value chain that have been considered are limited to fostering or decreasing competition in certain segments. Yet, more fundamental variations in the architecture of value chains are ubiquitous. For example, a microprocessor maker may supply its product directly to the manufacturer of the final good, or may alternatively sell it to an integrator that combines it with other components such as memory chips on a motherboard. In general, changes to a value chain that would rearrange its member firms are not considered in the existing literature. In fact, the meaning of “architecture” as describing the structure of the value chain and the linkages among its constituent firms is, so far, largely unexplored. The study by Erat et al. (2013) is a notable exception, though it focuses on competitive differentiation and the benefits of outsourcing the integration function rather than on effects of the bargaining structure itself.

The present study addresses this gap. Focusing on the value chain as the unit of analysis, we argue that the division of value between its member firms takes place in a hierarchy of negotiations. For example, the manufacturer of a final good will negotiate with its tier-one suppliers, which in turn will negotiate with their respective suppliers. We refer to the bargaining structure of a value chain to describe which of its members negotiate amongst each other in the various stages and branches of the value chain, and how these individual negotiation processes are linked hierarchically.

Using cooperative game theory, we analyze how the bargaining structure of the value chain for a specific product affects the distribution of value among the contributing firms. We generalize the Shapley value solution concept (Shapley 1953) by introducing the notion of the hierarchical Shapley value. We then use this concept to study the effects of bargaining structure, essentiality of firms, the role of integrators, and the availability of freely available building blocks (e.g., open source software) on the value split.

A simple example of three firms shows how bargaining structure affects value distribution. There are two possible bargaining structures. Either all three firms bargain jointly on the same level; or one firm splits the available value with a representative of the other two firms, which subsequently negotiate to split among each other the value captured by their representative. If all firms are essential (in the sense that each firm's absence would reduce the overall value to zero) they would, according to the Shapley value (and to intuition), split the value equally and obtain one third each if bargaining on one level. However, if the bargaining structure is hierarchical there are two equal players in the first negotiation sharing the available value equally. While this outcome may appear counter-intuitive at first consider that, in the top-level negotiation, the two firms together are just as essential as the single firm. In the second step, the two focal firms would again arrive at an equal split given that both are essential, each obtaining one quarter. In this case, thus, a hierarchical bargaining structure favors the single firm dramatically, which secures half of the overall value.

Given that the bargaining structure affects the distribution of value, each firm has an incentive to shape the value chain architecture in such a way as to maximize its own value capture (though very few will be in a position to accomplish this). Since a bargaining structure defines a hierarchy of negotiations, we denote a firm's approach to optimizing its value capture through creating a favorable bargaining structure in its value chain as the hierarchy strategy. Following Henderson and Clark (1990), Baldwin and Clark (2000), and Cofler and Baldwin (2010), we suggest that firms can leverage the underlying modular product architecture to shape industry (or value chain) architecture and thus the bargaining structure.

2. Determinants of value capture

Since our analysis focuses on the distribution of value within the value chain, we take both the cost of producing a certain good or service and the price that buyers pay for it as given, and follow Bowman and Ambrosini (2000), Lepak et al. (2007), and Dedrick et al. (2010) in defining value (more

specifically, “value created”) as the difference between them. We now review the pertaining literature on bargaining, introduce the concept of bargaining structure, and discuss determinants of the latter.

2.1. Bargaining power and bottlenecks

Value is distributed among the firms that contribute to its creation through bargaining (Brandenburger, Stuart 1996), where the value share a given firm can appropriate depends on its bargaining power relative to its negotiation partners (Porter 1980). Bargaining power, in turn, is driven by the availability of alternative providers of the same good or substitutes, the replacement costs to be borne by the remaining firms if a firm withdraws from negotiations, the switching costs for the focal firm if it needs to deploy its resources for other purposes, time pressure, and access to relevant information (Porter 1980; Buvik, Reve 2002; Dedrick et al. 2010).

A favorable position for a firm in a value chain or a negotiation is to be the bottleneck, or least replaceable player (Jacobides, MacDuffie 2013) (Morris, Ferguson 1993; Iansiti, Levien 2004; Jacobides et al. 2006; Pisano, Teece 2007). A negotiation party is more likely to attain this position the more its resources, and as a consequence its contributions to the value creation process, are valuable, rare, inimitable and non-substitutable (Barney 1991). Inimitability may be due to various isolating mechanisms (Rumelt 1984), in particular causal ambiguity regarding the source of the respective resource and legal property rights. If the resource is knowledge, secrecy and intellectual property rights may constitute effective isolating mechanisms, depending on the strength of the appropriability regime (Teece 1986). We refer to the approach to optimizing a firm’s value capture by becoming the bottleneck in the value chain as the bottleneck strategy.

2.2. Hierarchy in negotiations: Bargaining structure

When several parties have to split a given value, one or more individual negotiations may take place. For example, the parties may be divided into two groups, and the distribution of value between the groups is negotiated by representatives from each group. In a second step, the value obtained by each group is split, in further negotiations, between the members of the respective group. In the present context, we thus define the bargaining structure of the overall value distribution process as a division of the set of players into disjoint subsets, each of which may in turn be divided into disjoint subsets, and so on until all lowest-level subsets contain only one party.¹

Such hierarchical negotiations will be present in most real-life value chains, except for very simple cases. In particular with large numbers of participating firms, bargaining will in general be a hierarchical, multi-stage process, for one thing to reduce transaction cost. The manufacturer of the final good will negotiate with its tier-one suppliers; these firms, in turn, will negotiate with their own

¹ Implicit in this definition is the assumption that each party participates only at one point in the bargaining structure. Relaxing this assumption is possible, but would make our model considerably more complicated.

suppliers. For complex products, this chain of negotiations may continue for several more stages. It will in general have no clearly defined end point, since even suppliers of raw materials have their own suppliers of machinery. For the purpose of our analysis, we thus define as the value chain those firms that provide inputs or production steps that are either close to the final product or specific to it. Since adding an additional tier does not affect the distribution of value in the tiers above, the choice of which tiers to include is not critical to our analysis.

Importantly in our context, a given set of parties may conduct negotiations under different bargaining structures. For example, a final good manufacturer may buy its inputs directly from a large number of suppliers, or may alternatively choose some of them as tier-one suppliers that provide entire subsystems and that are, in turn, each supplied by a subset of the other suppliers. Also, an individual firm may be positioned in the top tier, supplying directly to the manufacturer, or may deliver its goods to some intermediate integrator.

2.3. Determinants of bargaining structure

If bargaining structure matters for value capture we need to ask what, in turn, determines bargaining structure. We identify industry and value chain architecture and the participants' individual power as the key determinants, and address them in turn

Distinct product solutions satisfying the same customer need might have different value chain architectures. In particular, when a new market emerges each product design may come with its own organization of the value chain as firms approach market needs and process difficulties differently and there is no common understanding of key performance criteria (Clark 1985). However, with the emergence of a dominant product design (Abernathy, Utterback 1978), firms will mostly adopt or co-specialize around the corresponding organization of firms in order to reduce transaction costs. Thus, one or a small number of stable "industry architectures," consisting of several value chains for core and complementing products, emerge in the formative years of an industry, each with its own members (Gawer, Cusumano 2002; Iansiti, Levien 2004).

As the architecture of a value chain or industry circumscribes the division of labor and roles of firms that participate in producing the product (Jacobides et al. 2006), it outlines as well the transactions of goods and provision of services from upstream producers to downstream firms. Transactions are governed by contracts. The term "contract" is not necessarily to be understood in a legal sense but more generally as explicit or implicit agreements and understandings between firms². Hence, the value chain architecture serves as well as the basis for the transaction related contract structure, i.e., the network of contracts between firms governing the exchange of goods and provision

² The net of transaction related contracts is part of what Alchian and Demsetz (1972) and Baldwin and Clark (2000) call contract structure.

of services. A contract can cover more than one transaction and in rare cases involves more than two parties³. Thus, there might not be a one-to-one mapping between transaction and transaction related contract structure.

The terms of transaction related contracts include the price and thus determine directly the distribution of value. As they are commonly subject to negotiations (Nagarajan, Sošić 2008), the transaction related contract structure entails the bargaining structure. Consequently, the industry or value chain architecture does not only play a key role in implementing a bottleneck strategy, but can also be used to enhance value capture through the hierarchy strategy.

On the other hand, besides value chain architecture, some firms might have the power to directly shape the bargaining structure through the use of their assets (e.g., resources, contacts) or their position in the industry. For example, automotive OEMs in some cases use their power and negotiate directly with tier-2 suppliers while leaving the respective tier-1 suppliers, despite their places in the industry architecture, aside (MacDuffie, Helper 2007).

2.4. Value chain and product architecture

Industry architectures can display significant inertia (Pisano, Teece 2007). In particular, when the industry becomes more mature and firms increasingly specialize, switching costs associated with changing the architecture increase. Nevertheless, they can change over time, triggered for example by significant technological and regulatory changes or demand shifts (Jacobides et al. 2006).

Scholars have studied how firms seek to influence the architecture of their value chain or industry for their own benefit, mostly with the goal of achieving a bottleneck position (Baldwin, Clark 2000; Chesbrough 2003; Iansiti, Levien 2004; Jacobides et al. 2006; Pisano, Teece 2007). Innovators (Jacobides et al. 2006), entrepreneurs (Santos, Eisenhardt 2009), or other key firms leveraging their position or assets (Iansiti, Levien 2004; Ferraro, Gurses 2009) may be in a position to shape the industry architecture to achieve a dominant position. However, while most scholars have focused on how to influence own and others' replaceability, i.e., the absolute bargaining power, bargaining structure as lever for enhancing relative bargaining power and value capture has passed unheeded.

Potential levers to shape industry architecture are the following. First, the distribution of knowledge and capabilities has a strong effect on value chain and industry architecture (Zirpoli, Camuffo 2009; Ferraro, Gurses 2009). Technical competences and capabilities can be developed over time, however, this process is slow, uncertain, and costly (Hoetker 2006). Although it is an important strategic activity for firms, the development of capabilities is a rather long-term oriented lever for firms trying to gain an advantage.

³ Alchian and Demsetz (1972) point out that for team development and production the creation of a central common party, a firm, in combination with bilateral contracts between the central party and the individual input owners more efficient than a multilateral contract.

Second, the norms-based and legal framework including reputation, regulation as well as technology and industry standards are factors that influence value chain and industry architectures (Jacobides, MacDuffie 2013) and therefore firms aim to influence them (Jacobides et al. 2006).

Third, product architecture and in particular modular product architecture affects value chain and industry architecture. Modular product architectures are characterized by a low level of interdependencies among sub-systems (Simon 1962; Baldwin, Clark 1997; Sanchez, Mahoney 1996) and therefore enable and shape the division of labor within an industry (Langlois, Robertson 1992; Baldwin, Clark 1997; Sturgeon 2002; Langlois 2003)⁴. As modules can be designed and produced independently of the rest of the system (Colfer, Baldwin 2010), modular product architectures speak in favor of specialization of firms (Langlois, Garzarelli 2008). Importantly in our context, the architecture of a newly introduced product is to a good extent under the control of the innovator, who may design it purposefully to affect value chain architecture and thus, through the hierarchy strategy, its value capture.

Based on the relation between industry architecture and bargaining structure discussed, we suggest that the modular product architecture does not only often mirror the architecture of the industry as suggested by Chesbrough and Teece (1996), Baldwin and Clark (2000) and Colfer and Baldwin (2010), but also shapes the bargaining structure of the industry. Thus, a shift in the modular product architecture is often followed by changes in the industry architecture (Colfer, Baldwin 2010) and the bargaining structure.

3. The basic model

In order to understand value appropriation in a value chain or industry we model the bargaining over value as a cooperative game among the participating firms. The following analysis is limited to value distribution under a given bargaining structure. We assume as given the selection of firms that contribute to value creation, the cost of production, and the value that the value chain as a whole captures on the market.

3.1. Non-hierarchical systems

Cooperative game theory has shown to be a useful tool in the area of business strategy to analyze value distribution (see for example Lippman and Rumelt (2003), MacDonald and Ryall (2004), Brandenburger and Stuart (2007), or Adegbesan (2009)).

Since the theory of cooperative games is well covered in literature we will build in the following on an existing concept, namely the Shapley value (Shapley 1953). The Shapley value (SV) provides an

⁴ Similarly, focusing on the transactional character of an industry, the coupling between product architecture and supply chain architecture has been noticed in the supply chain literature (Gan, Grunow 2013).

estimate for a player's value capture in a bargaining situation on the distribution of a fixed value. It is based on the player's average marginal contribution to all possible subsets or coalitions of players. In contrast to other solution concepts, such as the Core, the SV provides point estimates for the distribution, has a high predictive accuracy (Michener et al. 1983; Michener et al. 1987), and is the only solution concept for cooperative games that has a number of desirable and plausible properties⁵.

Formally, we consider a value chain with the set M of bargaining firms $M = \{m_j\}_{j:1:N}$, $N \in \mathbb{N}$. For the time being we introduce the simplifying assumption that every firm participates only once in the bargaining structure.

The characteristic function $v: 2^M \rightarrow \mathbb{R}$ with $v(\emptyset) = 0$ assigns every subset of firms $J \subseteq M$ its stand-alone value $v(J)$, i.e., the value that the focal group of firms could capture (more precisely, generate and capture) jointly without any other firm participating in the value chain (e.g., through selling an intermediate product to other firms or customers).

Further, we call a firm essential if it is indispensable in the bargaining structure in the sense that the other firms in the value chain would not obtain any value without it. Essentiality in the context of our model corresponds to a bottleneck position in the industry. Formally, the essential firms in the value chain constitute a set C_e such that $v(J) = 0$ if $C_e \not\subseteq J$.

If all firms are on the same hierarchical level in the bargaining structure, i.e., they bargain jointly (or, as tier-1 suppliers, in bilateral negotiations with the final product manufacturer), then the standard SV can be used to predict the value distribution. Hence, the estimated value appropriation of a player $m_j \in M$ is given by

$$\phi_{m_j}(v) := \sum_{S \subseteq M \setminus \{m_j\}} \frac{|S|!(n - |S| - 1)!}{n!} (v(S \cup \{m_j\}) - v(S)).$$

3.2. The hierarchical Shapley Value

We now consider a hierarchical bargaining structure, which for simplicity we restrict to two levels. The set of participating firms is divided into k subsets, the representatives of which bargain in a top-level (L1) negotiation. We denote these subsets as clusters. Subsequently, the members of each cluster bargain among each other in level-2 (L2) negotiations to split their respective group's bounty.

We propose a generalization of the SV to predict value distribution in such two-level bargaining structures. The Hierarchical Shapley value (HSV) describes a step-wise value distribution which, in both steps, follows the classical SV. For firms in a given L2 negotiation it assumes limited

⁵ These properties are (Shapley, 1953): efficiency (the full value is distributed among the participants), symmetry (players having the same value-add in a given negotiation receive the same value), additivity (combining two cooperative games yields a new game described by the sum of the two original characteristic functions), and invariance under dummy players (players without value-add do not capture any value).

transparency insofar as they only know each other's value-add and bargaining power, but not that of firms in other clusters. In an L2 negotiation, participants assume that all other clusters are complete and in place.⁶ In this respect, the HSV differs from the otherwise similar solution concept to hierarchical negotiations introduced by Owen (1977).

Formally, we build on the definition of coalition structures by Aumann and Drèze (1974) to model hierarchical bargaining structures. A hierarchical bargaining structure is a partition $\mathfrak{B} = \{M_i\}_{i \in 1:k}$ of the set M of firms into k clusters M_i such that $M = \bigcup_{i=1}^k M_i$ (the elements of \mathfrak{B} cover M), and $M_i \cap M_j = \emptyset \ \forall M_i, M_j \in \mathfrak{B}: i \neq j$ (the elements of \mathfrak{B} are pairwise disjoint).

To apply a SV distribution for L1 bargaining we define the induced characteristic function \hat{v} for a set of clusters $J \subseteq \mathfrak{B}$ as

$$\hat{v}: 2^{\mathfrak{B}} \rightarrow \mathbb{R}, \quad \hat{v}(J) := v\left(\bigcup_{M_i \in J} M_i\right).$$

Consequently, the L1-HSV of a cluster $M_i \in \mathfrak{B}$ is given by

$$\phi_{M_i}(\hat{v}) := \sum_{S \subseteq \mathfrak{B} \setminus \{M_i\}} \frac{|S|! (k - |S| - 1)!}{k!} (\hat{v}(S \cup M_i) - \hat{v}(S)).$$

For value distribution on L2, i.e., within a cluster M_i , we define for each $M_i \in \mathfrak{B}$ the induced characteristic function $\tilde{v}_{M_i}: 2^{M_i} \rightarrow \mathbb{R}$. For $J \subseteq M_i$, let

$$\tilde{v}_{M_i}(J) := \frac{(v(J \cup (M \setminus M_i)) - v(M \setminus M_i))}{v(M) - v(M \setminus M_i)} \phi_{M_i}(\hat{v}).$$

This definition ensures that the coalition consisting of all firms in M_i receives the value $\phi_{M_i}(\hat{v})$, while the empty set receives zero. The L2-HSV for a firm $m_j \in M_i$ is then given by

$$\phi_{m_j}^{HSV}(\tilde{v}_{M_i}) := \sum_{S \subseteq M_i \setminus \{m_j\}} \frac{|S|! (|M_i| - |S| - 1)!}{|M_i|!} (\tilde{v}_{M_i}(S \cup \{m_j\}) - \tilde{v}_{M_i}(S)).$$

4. Results

We start the model analysis with a basic model in which integration is not explicitly considered, that is, every firm can perform the integration or the integration service is in competitive supply. We further assume that none of the firms is in perfect competition, i.e., there are no easily available substitutes. We will relax these assumptions in Section 5.

⁶ This assumption is sensible, and even required, if the firms' contributions are characterized by complementarities. For example, the value of a laptop screen as a stand-alone product would be zero due to strong complementarities with the other parts of the computer. Thus, the firms that contribute to production of the screen (which form a cluster in our notation) would negotiate their value distribution assuming the rest of the computer to be complete.

4.1. Three-firm bargaining structures

We first analyze the general three-firm case with $M = \{m_1, m_2, m_3\}$. The hierarchical bargaining structure is given by $\mathfrak{B} = \{\{m_1, m_2\}, \{m_3\}\}$, that is, m_1 and m_2 form a cluster (see Figure 1). Using the definitions of the SV and the HSV introduced earlier it is straight-forward to calculate, for the single L1 firm (m_3), the difference between both as

$$\phi_{m_3}^{HSV}(v) - \phi_{m_3}(v) = \frac{1}{6}(v_{123} - v_{12} - v_{13} - v_{23} + v_1 + v_2 + v_3),$$

where we use $v_j \equiv v(m_j)$ etc. to simplify notation. Introducing the complementarity gains $\Delta_{jk} \equiv v_{jk} - v_j - v_k$ and $\Delta_{123} \equiv v_{123} - v_1 - v_2 - v_3$ we can rewrite the above result as follows:

$$\phi_{m_3}^{HSV}(v) - \phi_{m_3}(v) = \frac{1}{6}(\Delta_{123} - \Delta_{12} - \Delta_{13} - \Delta_{23}).$$

We thus obtain the result that being the single L1 firm in a hierarchical three-firm bargaining structure is superior to being in a non-hierarchical bargaining structure if and only if the system-level complementarity gains Δ_{123} exceed the sum of the three subsystem complementarity gains.⁷

To flesh out this result we analyze specific three-firm bargaining situations characterized by symmetry among the essential and among the non-essential firms. That is, the characteristic function only depends on the number non-essential firms in its argument: $|J| = |J'| \Rightarrow v(C_e \cup J) = v(C_e \cup J')$ for $J, J' \subseteq M \setminus C_e$. Let E denote an essential and N a non-essential firm. For abbreviation, we will denote $\{E, N, N\}$ by ENN . Further, let $0 < \alpha \leq \beta \leq 1$ and the characteristic function v be defined according to Table 1. Analyzing the hierarchical and non-hierarchical bargaining structures with different number of essential firms we can derive the following results (see Appendix for details).

First, if there are no essential firms in the bargaining structure, then the single L1 firm (m_3) benefits from a hierarchical bargaining structure (compared to a non-hierarchical bargaining structure) if the value-add of m_2 to m_1 (and vice versa because of symmetry) is less than 1/3 of the overall value to be distributed.⁸ Thus, if there is sufficiently large complementarity between any two firms, they can increase value capture by joining forces in L1 negotiations and creating a joint cluster.

Second, if m_3 is the only essential firm, it benefits from hierarchy if the value-add of a second firm joining m_3 in the value chain is smaller than the value-add of a third firm joining m_3 and a non-essential firm—in other words, if the system-level complementarity gains exceed those on the subsystem level, or $1 - \beta > \beta - \alpha$.

⁷ The condition for m_1 (and similarly for m_2) to benefit from a hierarchical bargaining structure is more complicated and not particularly insightful.

⁸ This proposition can be generalized for the n-firm system: In a bargaining structure with only non-essential firms it is beneficial to be in a 2-firm cluster if and only if $\alpha_{n-1} - \alpha_1 > \frac{n-2}{n}$ with $\alpha_j := v(J)$ for $|J| = j$ given all other firms are not clustered.

Third, if m_1 is the only essential firm then a) m_1 gains through hierarchy if $\alpha < \frac{1}{4}(\beta + 1)(3\beta - 1)$, b) m_2 gains if $\alpha > \frac{3}{2}\beta^2 - \beta + \frac{1}{2}$, c) m_3 gains if $\alpha > 2\beta - 1$ (see Figure 2). Further, if the essential firm m_1 has a high stand-alone value (α large) it benefits from hierarchy if the value-add of a second firm ($\beta - \alpha$) is larger than half of the residual value to be distributed, i.e. if complementarity decreases. Otherwise both non-essential firms benefit from hierarchy.

Finally, if there are 2 or more essential firms, an essential firm loses from hierarchy if it is clustered with another firm on L1. Obviously, additional firms in a cluster with one essential firm do not improve the cluster's position in L1 negotiations. Thus, the preferred strategy for a firm being essential for value creation (and capture) is to position itself in top-level negotiations.

4.2. N-firm bargaining structures with one essential firm

We extend the basic 3-firm bargaining structure with exactly one essential firm to $n \in \mathbb{N}$ firms. We again denote the essential firm with E and the non-essential firms with N_1, \dots, N_{n-1} . In addition, let $\mathfrak{B} = \{M_i\}_{i \in \mathbb{N}}$ be the clusters of firms. We model complementarity among firms in the value chain through the characteristic function $v(J) = |J|^x$ for $J \subseteq M$ with $E \in J$ and $x > 1$, and $v(J) = 0$ for $J \subseteq M$ with $E \notin J$.

In addition to a non-hierarchical structure a multitude of alternative 2-level bargaining structures can be generated through varying the number of clusters as well as the number of firms within each cluster. In order to get a basic understanding we will focus on the extreme cases illustrated in Figure 3.

As the overall value generated increases with the number of firms in the value chain, we consider the difference between a firm's value appropriation in a given hierarchical and the non-hierarchical bargaining structure relative to the overall value $v(M)$. Therefore we introduce the measure $\Delta_m^{HSV} := \frac{(\Phi_m^{HSV} - \Phi_m)}{v(M)}$ for a firm $m \in M$. We analyze small to large bargaining structures ranging from 3 to 1 million firm while varying the level of complementarity on a realistic level ($1 < x \leq 3$) but showing as well differences for value chains with very high complementarity ($x = 20$). As design B coincides with the non-hierarchical architecture it always follows $\Delta_m^{HSV} = 0$. Very small values $0.05 > \Delta_m^{HSV} > 0$ or $0 > \Delta_m^{HSV/OV} > -0.05$ are denoted +0 and -0 respectively.

The results in Table 2 indicate that the less non-essential firms are clustered with E on L1 and the lower the overall number of clusters the more favorable is a hierarchical bargaining structure for the essential firm E with regard to value appropriation. In the ideal hierarchical bargaining structure for E , in which E bargains with a single firm representing all non-essential firms on top-level, E can appropriate a significantly larger share of the overall value (often more than 10%) than in a non-hierarchical setup.

Further, we can derive from the results in Table 3 for the non-essential firm which is in a cluster with E that in cases with reasonable complementarity a non-hierarchical bargaining structure would be

most beneficial. However, if the bargaining structure is hierarchical and the focal firm strongly tied to the essential firm in a cluster, value appropriation increases with the number of firms that are as well included in the cluster and with a lower number of participants in top-level negotiation (i.e., clusters).

Conversely, other non-essential firms (outside the cluster containing E) can appropriate more value the more firms are clustered with E (see Table 4). Further, a bargaining structure is most beneficial for a non-essential firm if it directly participates in top-level negotiations (without being part of a larger cluster).

In total, every firm, regardless of its essential or non-essential character, benefits from being directly involved in top-level negotiations. Being part of a cluster of firms has a negative effect on value capture.

4.3. Splitting bargaining positions

In the following section we release the assumption that a firm participates only once in the bargaining structure. That is, we analyze the options of a firm occupying several positions in the bargaining structure. A firm can have positions in different independent negotiations (for example being an upstream seller and a downstream buyer of the unfinished product), or several positions within a single negotiation (with different propositions⁹). Having connected positions provides the option to consolidate them and capture the value of the integrated position. In return, we assume that the firm has the option to capture the value of each position independently. If connected positions would directly result in a consolidated position, we assume the firm has the option to split them by selling one of them (with the corresponding assets) to a third party for a fair price.

We will derive insights from the case of a single firm in the value chain having two positions in the bargaining structure.

Formally, we reduce the basic non-hierarchical 3-firm bargaining structure $M = \{m_1, m_2, m_3\}$ to a 2-firm bargaining structure $M^* = \{m_{1,2}, m_3\}$ with one firm having a consolidated position $m_{1,2}$ (which is based on the positions m_1 and m_2). Using the characteristic function $v: 2^M \rightarrow \mathbb{R}$ on M defined according to

Table 1 with $0 < \alpha \leq \beta \leq 1$, we derive a characteristic function $v^*: 2^{M^*} \rightarrow \mathbb{R}$ on M^* by $v^*(m_{1,2} \cup J) := v(m_1 \cup m_2 \cup J)$ and $v^*(J) := v(J)$ for $J \subseteq M^* \setminus \{m_{1,2}\}$.

Based on the results in Table 5, we see in the non-hierarchical case that splitting positions is beneficial if both positions are essential. In other cases, splitting is beneficial if the value-add of a second position (or firm in the 3-firm case) is relatively low, in concrete terms if it is smaller than a third of the overall value in the case of no essential positions and if it is smaller than the value-add of a

⁹ Business units with own profit and loss responsibility (providing different value-adding activities) sometimes act independently in negotiations.

third position (i.e., if the system is complementary for the step from 2 to 3 firms) in the case of one essential position (m_1 or m_2). Hence, strong complementarity (which is not always the case¹⁰) with a high value-add of any second position (larger than a third of the overall value) leads to advantageousness of splitting.

In hierarchical bargaining structures, we analyze the option to merge a position within a cluster with another position the focal firm has in top-level bargaining. As a 3-position hierarchical bargaining structure with one firm occupying two positions does not provide meaningful results, we will now consider a 5-position structure $\mathfrak{B} = \{\{m_1, m_2, m_3\}, m_4, m_5\}$ (see Figure 4).

A firm having positions m_1 and m_4 has the option to keep the bargaining structure as is, or consolidate its positions to a single position $m_{1,4}$ in the top-level negotiation. This would change the bargaining structure to $\mathfrak{B}^* = \{\{m_2, m_3\}, m_{1,4}, m_5\}$. Similarly to the non-hierarchical case, we see that having two separate positions is more beneficial than one integrated position if there is a significant difference in value between the complete and incomplete value chain, i.e., there is high complementarity in adding the last firm/position to the value chain. In detail, for non-essential positions with a characteristic function $v: 2^M \rightarrow \mathbb{R}$ with $v(J) = \alpha$ for $|J| = 1$, $v(J) = \beta$ for $|J| = 2$, $v(J) = \gamma$ for $|J| = 3$, $v(J) = \delta$ for $|J| = 4$, $v(M) = 1$ and $0 < \alpha \leq \beta \leq \gamma \leq \delta \leq 1$, separated positions are beneficial compared to a single integrated one if $(\delta - \gamma) + (\beta - \alpha) < (1 - \delta) + \alpha$.

As we have seen, in particular in fully complementary value chains firms can benefit from splitting their positions in the bargaining structure (if possible). However, too many bargaining positions can lead to an underuse of the production capability of the value chain especially if too many positions have the potential for hold-up – a situation known as the tragedy of anti-commons (Heller, Eisenberg 1998).

5. Extensions and further results

In the following section we will extend the basic model by two important aspects to better represent realistic bargaining structures and value chains. We will closely analyze the effects of system integrators and firms that face (nearly) perfect competition on value distribution.

5.1. System integrators

System integrators put together components from suppliers to form a coherent product. If integration is complex integrators have a powerful role in the value chain as they are often difficult to replace (Jacobides, MacDuffie 2013) and essential to realize complementarity among firms. There are different roles system integrators can take on. For example, many automotive OEMs and tier-1

¹⁰ For example, the wireless technologies for smartphones NFC and Bluetooth are not complementary as they have overlapping use cases. However, both can be found in smartphones at the same time.

suppliers are component/subsystem suppliers as well system integrators and play central roles in the industry and bargaining structure as they deliver the integrated product to the next upstream level (customer or OEM respectively). On the contrary, the electronics device manufacturer Foxconn can be considered as a pure integration service provider with a similar role as a non-central component supplier in the bargaining structure. If system integration is critical it is likely that the system integrator is as well the central firm in negotiations.

Integrators can be found on top-level as well as within every cluster of a hierarchical bargaining structure¹¹. Let $M_{int} := \{m_{int(L1)}, \{m_{int(M_i)}\}_{i=1:k}\} \subseteq M$ be the set of integrators on top-level and within every cluster of firms M_i . The integrators enable complementarity among the firms in the value chain. Without them, the value of the value chain would be only the sum of values obtained by individual component suppliers.

Starting from a value chain M without the need for integration services with the relevant characteristic function $v: 2^M \rightarrow \mathbb{R}^{12}$, we define an induced function v^{int} on M with

$$v^{int}(J) := \begin{cases} v\left(\bigcup_{i: m_{int(M_i)} \in J} \bigcup_{m_j \in J \cap M_i} m_j\right) + \sum_{i: m_{int(M_i)} \notin J} \left(\sum_{m_j \in J \cap M_i} v(m_j)\right) & \text{if } m_{int(L1)} \in J \\ \sum_{i: m_{int(M_i)} \in J} v\left(\bigcup_{m_j \in J \cap M_i} m_j\right) + \sum_{i: m_{int(M_i)} \notin J} \left(\sum_{m_j \in J \cap M_i} v(m_j)\right) & \text{if } m_{int(L1)} \notin J \end{cases}$$

The definition coincides with a special case of the Myerson Value (Myerson 1977) which applies the SV concept to a non-hierarchical bargaining structure with a preset cooperation structure. Besides the integrator, the architect of the value chain (or parts thereof) has a similar role, given it is a separate firm like in house construction projects. Although the modeling of an architect would be analogous, we will not explicitly include it in the further model.

From the definition of the induced characteristic function v^{int} it follows directly that the top-level integrator appropriates a positive value if it enables complementarity among the clusters.

To understand value capture of system integrators and the effect on other firms in the bargaining structure we analyze the basic example of 3 non-essential firms extended by pure system integrators.

First, the new non-hierarchical bargaining structure consists besides m_1, m_2, m_3 of an integrator firm m_{int} (see Figure 5). Based on the characteristic function v for the hypothetical case that integration is not required (see Table 6) we can derive the induced characteristic function v^{int} and value capture of each firm in the bargaining structure with integrator.

11 In case of an easily replaceable integration process the integrator might not be part of the bargaining structure although being part of the value chain. We will discuss this case in more detail in section 5.2.

12 Pure integrators are in the case of a system without the need for integration services dummy players neither having a stand-alone value nor adding value to any coalition of firms.

In the non-hierarchical bargaining structure the integrator can capture $\frac{1}{4}(1 - 5\alpha + \beta)$ of the overall value. Consequently, if the value chain is fully complementary ($1 > 3\alpha$, $\beta > 2\alpha$) the integrator is going to capture a positive value.

In case of a hierarchical bargaining structure we introduce integrators on both levels. Let $m_{int(L1)}$ be the integrator on top-level and $m_{int(m_1m_2)}$ the integrator of the cluster m_1m_2 ¹³. Thus, using the induced characteristic with firms $m_{int(L1)}$ and $m_{int(m_1m_2)}$, the top-level integrator $m_{int(L1)}$ captures $\frac{1}{3}(1 - \alpha - \beta)$ value. This is, $m_{int(L1)}$ appropriates a third of the value it brings to the value chain which is the complementarity between the integrated cluster (stand-alone value of β) and m_3 (stand-alone value of α). As $m_{int(m_1m_2)}$ captures $(1 + 2\beta - \alpha)(1 + \beta - 5\alpha)/9(1 - \alpha)$ the sum of value appropriated by the integrators can exceed the value appropriated in the non-hierarchical bargaining structure (for $\alpha < 5/35$ there is β with $(5 - 5\alpha)/8 < \beta < 1 - 5\alpha$). This means that a system integrator having sufficient capabilities is better off in a hierarchical bargaining structure being involved twice on different levels if there is strong complementarity involved.

Although m_3 captures less value than in a case without required system integrators (just as m_1 and m_2), hierarchy remains beneficial for m_3 if the value add of a second firm $\beta - \alpha < 1/3$. However, for m_1 and m_2 there are no general criteria for when hierarchy is beneficial in a scenario with system integrators.

In addition, we take a quick look on the options of a firm that is integrator and supplier at the same time and can either consolidate or split its positions in the bargaining structure. Based on the hierarchical bargaining structure $\mathfrak{B} = \{\{m_1, m_2, m_{int(m_1, m_2)}, m_3, m_{int(L1)}\}$ (see Figure 5) we observe the following: First, if the top-level integrator m_{int} holds as well the positions as top-level supplier m_3 , the firm can increase its value capture through splitting if the value chain is complementary, i.e., if $\alpha < 1 - \beta$. Second, if the integrator of the cluster $m_{int(m_1, m_2)}$ is a supplier within the cluster as well (e.g., occupying position m_1), the firm is better off through selling one of the positions in case of high complementarity, i.e., $\beta + \alpha < \frac{1}{2}$.

5.2. Free value

In the last sections we developed a model that shows how value is split among the participants of the bargaining structure. However, there might be firms which are part of the value chain but not part of the bargaining structure – providing value to the system but not appropriating any. We call these firms in the following non-value-appropriating (NVA) firms. There are two aspects a NVA character can originate from: perfect competition and open source components. First, firms facing perfect

13 There is no need to introduce an integrator for the second cluster consisting only of m_3 . As no integration is required for the trivial m_3 cluster, the integrator would be a dummy player and not appropriate any value.

competition can be replaced easily, e.g., suppliers of commodities such as standardized screws or simple and commonly known integration processes. They have no bargaining power and therefore the transfer of goods will most likely not be subject to negotiations. However, they increase the overall value available to the value chain. Similarly, developers of open source software freely provide all relevant product-related information (i.e., the software source code) and a license free of charge that allows others to copy, modify, or further develop the product (Open Source Initiative 2014). Thus, an open source component adds value without the respective developer appropriating any. The question arises which firms can appropriate the free value contributed by NVA firms.

Firms in the bargaining structure that are aware of the presence of an NVA firm will try to take benefit and incorporate the offering of the NVA firm in their propositions. However, only if the required integration capabilities are available they can in fact leverage the value of the NVA firm.

In a non-hierarchical bargaining structure M we assume that all firms have transparency about other firms in the value chain. Hence, they are aware of the NVA firm m_{NVA} and take benefit. Formally, if m_{NVA} was not NVA, then let v'' be the relevant characteristic function on the set $M \cup m_{NVA}$. As a consequence, the NVA firm m_{NVA} induces a characteristic function v' on M with $v'(J) := v''(J \cup m_{NVA})$ for $J \subseteq M$.

Building on the assumption of limited transparency in hierarchical bargaining structures, we argue that only firms that would be in the same cluster with m_{NVA} in the bargaining structure if m_{NVA} was not NVA (i.e., their supplies or services are closely connected to the supply of the NVA firm) are aware of it and take benefit. We denote the cluster that would include m_{NVA} by M_{NVA} . Similarly, starting again from the characteristic function v'' on the set $M \cup m_{NVA}$ in the (hypothetical) situation that m_{NVA} is not NVA, we define for the HSV the induced characteristic function on L1 in the obvious fashion that $\hat{v}'(J) := v''(\cup_{M_i \in J} M_i \cup m_{NVA})$ if $J \cap M_{NVA} \neq \emptyset$ and $\hat{v}'(J) := \hat{v}(J)$ if $J \cap M_{NVA} = \emptyset$ for $J \subseteq \mathfrak{B}$. Accordingly, on L2 using \tilde{v}''_{M_i} as the underlying function on the set $M \cup m_{NVA}$ if m_{NVA} was not NVA, we define the induced characteristic function \tilde{v}'_{M_i} on M in the fashion that $\tilde{v}'_{M_i}(J) := \tilde{v}''_{M_i}(J \cup m_{NVA})$ if $J \cap M_i \neq \emptyset$. This is, a firm that is part of the cluster M_i will incorporate m_{NVA} into its bargaining position and include it into any coalition of firms $J \subseteq M$.

If m_{NVA} does not belong to any cluster, it would be participating hypothetically in top-level negotiations. Similarly to the non-hierarchical case we assume that all firms and representatives of clusters participating in L1 negotiations are aware of and split the free value and further share it with the firms in the respective cluster.

In the following, we analyze how a given firm should seek to influence the bargaining structure to benefit most from free value provided by a non-vale-appropriating firm (NVA; for example a firm in perfect competition or a provider of open source code). Starting from the basic bargaining structure with 3 non-essential firms (in case of hierarchy $\mathfrak{B} = \{\{m_1, m_2\}, m_3\}$), we extend the value chain

through a NVA firm m_{NVA} . Let the characteristic function $v'': 2^{M \cup \{OS\}} \rightarrow \mathbb{R}$ for the hypothetical case of m_{NVA} not being NVA be defined according to Table 7 with $0 < \alpha \leq \beta \leq \gamma \leq 1$.

In case of a non-hierarchical bargaining structure the symmetric non-essential firms share the overall value of the value chain and consequently the additional value provided by m_{NVA} . Each firm appropriates $\Phi_{m_1}(v') = \Phi_{m_2}(v') = \Phi_{m_3}(v') = 1/3$ (with $v'(J) := v''(J \cup m_{NVA})$ on M).

We distinguish among three different value chain setups in the hierarchical case driven by the position of m_{NVA} in the hypothetical case of being value-appropriating (see Figure 6).

In the first case m_{NVA} is not adapted to any cluster but added to the overall product in the final integration step. Thus, every participant in top negotiation incorporates m_{NVA} into its own position. For the firms in the cluster as well as for m_3 it holds that they can appropriate a share of the free value (and thus benefit in absolute terms) if their value-add to the remaining system is not significantly lower through the presence of m_{NVA} than in a value chain without m_{NVA} . In detail, m_3 benefits if $1 - \gamma + \beta - \alpha > \gamma - \beta$, and the firms in the cluster, m_1 and m_2 , benefit if $1 - \beta > \beta - \alpha$. In relative terms, it is likely that the firms in the cluster can benefit disproportionately from m_{NVA} . If $\gamma - \beta > (\beta - \alpha)/\gamma$ holds, which is in particular true for fully complementary value chains, m_1 and m_2 can increase their relative value capture in the value chain.

Second, if m_3 includes m_{NVA} in an own cluster, we assume that the other firms are not aware of m_{NVA} and only m_3 includes m_{NVA} in its proposition. Thus, m_3 could increase its value capture share from $1/2 * (\alpha + \gamma - \beta)$ (in the case without NVA) to $1/2$. However, if m_{NVA} sufficiently increases the value to be distributed, m_1 and m_2 may benefit as well from m_{NVA} in absolute terms (although having a smaller share of the overall value). This is the case if $1 - \beta > \gamma - \alpha$, i.e., if the value add of the m_1 - m_2 -cluster to the m_3 - m_{NVA} -cluster is higher than to the stand-alone firm m_3 .

Similarly, if m_1 and m_2 form a joint cluster with m_{NVA} , they both disproportionately benefit from the free value and increase their share of value capture. Analogue to the last case, m_3 benefits if the presence of m_{NVA} in the value chain increases its value-add to the remaining system, that is if $1 - \gamma > \gamma - \beta$.

As expected, we see that it is beneficial to be directly clustered with the NVA firm. The higher the complementarity between m_{NVA} and focal firm or cluster, the more beneficial it is to incorporate (and integrate) the NVA firm's proposition. Moreover, we see that other firms may benefit as well from the presence of the NVA firm, if it increases their marginal contribution to the value chain. These results can be generalized for larger technical bargaining structures.

We complement existing literature on how commercial firms can benefit from open source developments. Providing complementary products and services in addition to an open source product or enhancing the own product through open source complements are ways to monetize open source developments (Lerner, Tirole 2002; West, Gallagher 2006). In addition, we see that that firms share

the benefits from the open source development with other companies in the value chain and benefit most if they directly build on the open source product.

6. Applications

6.1. Embedded connected systems

A fire alarm control panel is the control system of a fire alarm system. It receives and processes information from the environmental sensors, e.g., heat or smoke detectors and transmits information in the case of fire to notification devices. A fire alarm control panel is a modular system consisting in most cases of housing, a panel controller, different functional modules, power supply and cabling. The panel controller is the operating and display unit of the system. Besides the display it consists of a motherboard, which is again modular. Modules are among others a microcontroller, memory, interfaces for external communication (e.g., USB or Ethernet), and interfaces for internal communication.

A large producer of fire alarm control panels, called Firm A, has two options for the motherboard in the panel controller: First, the firm can buy the components of the motherboard from specialized firms and directly integrate it as it has the required capabilities. The alternative is to source a fully integrated motherboard complying with the requirements from a main producer of motherboards, Firm B. The key decision criteria for Firm A are design flexibility, complexity, and costs.

Apart from bottleneck aspects and value appropriation through the integration service (which is either with Firm A or Firm B) the two options differ from a value appropriation perspective as their bargaining structures do not coincide (see Figure 9). Direct sourcing of modules and integration by Firm A creates a non-hierarchical bargaining structure (with respect to the motherboard). Depending on the market competition and technical value-add of all modules of the panel controller, one bargaining structure is more beneficial than the other for Firm A with regard to value appropriation according to the hierarchy strategy.

Moreover, the two options result in different product architectures. The flexibility in design provides the producer greater freedom in optimizing the overall design of the panel controller. In addition, some modules of the motherboard provided by Firm B are actually not needed to run the control panel and hence are dropped in the design of Firm A.

6.2. Boeing 787 Dreamliner

For the development and production of the commercial aircraft 787 Dreamliner Boeing significantly changed the common aircraft modularization, the supply chain as well as to its own role in the manufacturing process. Boeing's traditional role was to be the key manufacturer and assembler of the overall system as well as of subsystems orchestrating thousands of suppliers (Tang, Zimmerman 2010). In order to control the overall design suppliers were given very detailed instructions of how to

build components – a so-called “build to print” approach (Kotha, Srikanth 2013). For the 787 Boeing established a global partnership model empowering selected suppliers to have control and ownership of large modules of the aircraft that could be built independently (see Figure 10). Thus, Boeing reduced the number of direct (tier-1) suppliers to 15. These suppliers took over responsibility for producing the assigned structural sections according to the specifications provided by Boeing (“build to performance” approach) and managing the respective tier-2 suppliers. Thus, Boeing changed its role to be the high-level designer of the system and final integrator of the aircraft assembling the integrated subsystems supplied by their partners.

Primary goal of this new approach was reducing development and assembly time. However, the new approach had also an impact on the bargaining structure and therefore on value appropriation. Through the introduction of the tiered structure it changed its bargaining structure from non-hierarchical to a hierarchical. As some of the large structural sections include various essential modules, e.g., the forward fuselage section including as well the flight control system, Boeing could benefit from the new bargaining structure with regard to the hierarchy strategy.

7. Discussion and conclusion

Our analysis has shown that the structure of negotiations along the value chain affects the value capture of firms. Besides considerations of replaceability, firms can aim at creating a beneficial bargaining structure to increase value appropriation. Hence, the hierarchy strategy complements the established bottleneck strategy.

Although some firms have the power to change the bargaining structure without changing the underlying value chain, we suggest that industry and value chain architecture is a key determinant of bargaining structure. Driven by the coupling of value chain architecture and product architecture (Baldwin, Clark 2000), modular design can be used as a lever to implement a hierarchy strategy.

Consequently, firms designing the overall modular product architecture have the opportunity to shape the value chain architecture and bargaining structure given certain boundary conditions (e.g., technical limitations, capabilities of suppliers). Among other things, decisions on the number and composition of top-level modules determine the bargaining structure and value capture of the system designer. This leads to a necessary involvement of various organizational functions during the design of the product architecture, such as strategy and procurement besides the technical department, to identify beneficial product architectures with corresponding industry architectures and bargaining structures with regard to the hierarchy and bottleneck strategy.

The question arises why firms that lose from a particular bargaining structure would accept the current setup. We argue that a) firms only involved in lower level negotiation often do not have full transparency of the overall bargaining structure and b) not all firms have the power to influence bargaining structures. Nevertheless, to maintain a healthy and robust industry, there are limits to the

execution of the hierarchy strategy. In particular, the value capture of every firm needs to match at least the outside options beyond the focal value chain.

There are several limitations of our analysis. First, it does not take account of the fact that industry architecture and bargaining structure may affect the overall value created. For example, splitting essential positions in excess, and selling them in order to increase own value capture, will hurt the industry architecture not only because of increasing transaction costs, but also as with an increasing number of critical firms the industry is prone to the tragedy of the anticommons (Heller, Eisenberg 1998). This phenomenon can be observed, for example, in cases of patent royalty stacking (Shapiro 2001).

Similarly, the cost of changing bargaining structures has not been considered in the model. In particular in settings of existing buyer-supplier relationships the reorganization of the bargaining structure might negatively affect the relations between firms.

In addition, value distribution might differ from the HSV estimates used and be more “unfair,” meaning that some players can extract even more value. A test of the HSV is required to assess its predictive accuracy. Although the Shapley value showed fairly good predictive accuracy in empirical tests, some real world bargaining situation might favor certain players resulting in a more extreme distribution of value.

Possible extensions of the model could consider the emergence of the value chain, which determines the overall value generated and distributed. Taking the value as non-constant, which could potentially be modeled as biform game as proposed by Brandenburger and Stuart (2007), might provide an interesting perspective on how eventual bargaining structures could already drive the phase of establishing the value chain.

We contribute with this paper to the discussion of industry architectures as driving forces for value appropriation. We show how firms can enhance value appropriation through strategically shaping the structure of negotiations along the value chains. Thus, the hierarchy strategy complements the bottleneck strategy.

The findings of the paper can assist managers in identifying and shaping beneficial value chain and bargaining structures. Seeing a firm as a portfolio of business activities which might target different parts of the same value chain, the results shed light on the question of the most beneficial organizational setup. Depending on the positions in the bargaining structure, managing the respective units as separate organizations with separate bargaining positions might enhance value capture compared to bundling them under one umbrella.

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Tables and Figures

number of essential firms in M	Characteristic function $v(J)$ for $J \subseteq M$		
0	$v(N) = \alpha$	$v(NN) = \beta$	$v(NNN) = 1$
1	$v(E) = \alpha$	$v(EN) = \beta$	$v(ENN) = 1$
2	$v(E) = 0$	$v(EE) = \beta$	$v(EEN) = 1$
3	$v(E) = 0$	$v(EE) = 0$	$v(EEE) = 1$

Table 1: Characteristic function for 3-firm bargaining structure with varying number of essential firms

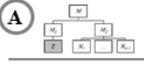
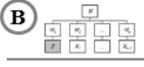
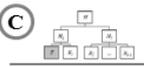
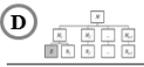
Δ_m^{HSV} for essential firm E	# of L1 clusters of firms											
	Minimum (2)		Maximum									
E not clustered with any non-essential firm on L1		Number of firms (n)					Number of firms (n)					
		3	10	100	10^6		3	10	100	10^6		
	Level of	1.5	1.7	6.5	9.5	10.0	Level of	1.5	0	0	0	0
	comple-	2.0	3.7	12.0	16.2	16.7	comple-	2.0	0	0	0	0
	mentarity	2.5	5.7	16.4	20.9	21.4	mentarity	2.5	0	0	0	0
(x)	3.0	7.4	19.8	24.5	25.0	(x)	3.0	0	0	0	0	
	20	16.7	38.7	44.7	45.2		20	0	0	0	0	
E clustered with 1 non-essential firm on L1		Number of firms (n)					Number of firms (n)					
		3	10	100	10^6		3	10	100	10^6		
	Level of	1.5	1.7	5.4	9.3	10.0	Level of	1.5	1.7	1.0	0.1	+0
	comple-	2.0	0.3	8.6	15.7	16.7	comple-	2.0	0.3	0.1	+0	+0
	mentarity	2.5	-1.1	11.2	20.3	21.4	mentarity	2.5	-1.1	-0.6	-0.1	-0
(x)	3.0	-2.4	13.3	23.8	25.0	(x)	3.0	-2.4	-1.2	-0.1	-0	
	20	-8.3	16.7	40.2	45.2		20	-8.3	-4.3	-0.4	-0	
E clustered with $n-2$ non-essential firms on L1		Number of firms (n)										
		3	10	100	10^6		3	10	100	10^6		
	Level of	1.5	1.7	1.0	0.1	+0	Level of	1.5	1.7	1.0	0.1	+0
	comple-	2.0	0.3	0.1	+0	+0	comple-	2.0	0.3	0.1	+0	+0
	mentarity	2.5	-1.1	-0.6	-0.1	-0	mentarity	2.5	-1.1	-0.6	-0.1	-0
(x)	3.0	-2.4	-1.2	-0.1	-0	(x)	3.0	-2.4	-1.2	-0.1	-0	
	20	-8.3	-4.3	-0.4	-0		20	-8.3	-4.3	-0.4	-0	

Table 2: Relative difference (Δ_m^{HSV}) between value appropriation in hierarchical and non-hierarchical bargaining structures for essential module E

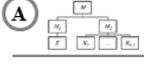
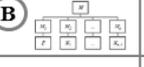
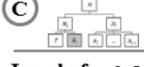
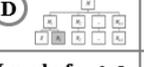
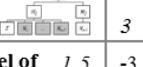
Δ_m^{HSV} for non-essential firm clustered with E (on L1)	# of L1 clusters of firms													
	Minimum (2)		Maximum											
E not clustered with any non-essential firm on L1		Number of firms (n)					Number of firms (n)							
		3	10	100	10^6		3	10	100	10^6				
	Level of completeness (x)	1.5				1.5								
		2.0			n/a	2.0				n/a				
		2.5				2.5								
		3.0				3.0								
		20				20								
E clustered with 1 non-essential firm on L1		Number of firms (n)					Number of firms (n)							
		3	10	100	10^6		3	10	100	10^6				
	Level of completeness (x)	1.5	-3.5	-2.1	-0.2	-0	1.5	-3.5	-2.5	-0.3	-0			
		2.0	-4.0	-1.9	-0.2	-0	2.0	-4.0	-2.8	-0.3	-0			
		2.5	-4.5	-1.5	-0.1	-0	2.5	-4.5	-3.0	-0.4	-0			
		3.0	-5.0	-0.9	-0	-0	3.0	-5.0	-3.2	-0.4	-0			
		20	-8.3	12.1	3.6	+0	20	-8.3	-4.3	-0.5	-0			
E clustered with $n-2$ non-essential firms on L1		Number of firms (n)					Number of firms (n)							
		3	10	100	10^6		3	10	100	10^6				
	Level of completeness (x)	1.5	-3.5	-0.3	-0	-0	1.5	-3.5	-0.3	-0	-0			
		2.0	-4.0	-0.3	-0	-0	2.0	-4.0	-0.3	-0	-0			
		2.5	-4.5	-0.4	-0	-0	2.5	-4.5	-0.4	-0	-0			
		3.0	-5.0	-0.6	-0	-0	3.0	-5.0	-0.6	-0	-0			
		20	-8.3	-3.7	-0.1	-0	20	-8.3	-3.7	-0.1	-0			

Table 3: Relative difference (Δ_m^{HSV}) between value appropriation in hierarchical and non-hierarchical bargaining structures for a non-essential module being part of the same cluster as E

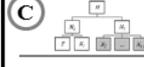
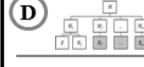
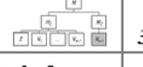
Δ_m^{HSV} for non-essential firm not clustered with E	# of L1 clusters of firms													
	Minimum (2)		Maximum											
E not clustered with any non-essential firm on L1		Number of firms (n)					Number of firms (n)							
		3	10	100	10^6		3	10	100	10^6				
	Level of completeness (x)	1.5	-0.9	-0.7	-0.1	-0	1.5	0	0	0	0			
		2.0	-1.9	-1.3	-0.2	-0	2.0	0	0	0	0			
		2.5	-2.8	-1.8	-0.2	-0	2.5	0	0	0	0			
		3.0	-3.7	-2.2	-0.2	-0	3.0	0	0	0	0			
		20	-8.3	-4.3	-0.5	-0	20	0	0	0	0			
E clustered with 1 non-essential firm on L1		Number of firms (n)					Number of firms (n)							
		3	10	100	10^6		3	10	100	10^6				
	Level of completeness (x)	1.5	1.7	-0.4	-0.1	-0	1.5	1.7	0.2	+0	+0			
		2.0	3.7	-0.8	-0.2	-0	2.0	3.7	0.3	+0	+0			
		2.5	5.6	-1.2	-0.2	-0	2.5	5.7	0.5	+0	+0			
		3.0	7.4	-1.5	-0.2	-0	3.0	7.4	0.6	+0	+0			
		20	16.7	-3.6	-0.4	-0	20	16.7	1.1	+0	+0			
E clustered with $n-2$ non-essential firms on L1		Number of firms (n)					Number of firms (n)							
		3	10	100	10^6		3	10	100	10^6				
	Level of completeness (x)	1.5	1.7	1.2	0.1	+0	1.5	1.7	1.2	0.1	+0			
		2.0	3.7	2.7	0.3	+0	2.0	3.7	2.7	0.3	+0			
		2.5	5.6	4.2	0.5	+0	2.5	5.6	4.2	0.5	+0			
		3.0	7.4	5.8	0.7	+0	3.0	7.4	5.8	0.7	+0			
		20	16.7	34.1	8.1	+0	20	16.7	34.1	8.1	+0			

Table 4: Relative difference (Δ_m^{HSV}) between value appropriation in hierarchical and non-hierarchical bargaining structures for a non-essential module not being part of the same cluster as E

# essential positions in M		Splitting positions $m_{1,2}$ is beneficial if
m_1, m_2	m_3	
0	0	$\beta - \alpha < \frac{1}{3}$
1	0	$\beta - \alpha < 1 - \beta$
2	0	$\beta < 1$, that is always
1	1	$\beta < 1$, that is always
2	1	$\frac{1}{2} < \frac{2}{3}$, that is always

Table 5: Splitting positions in a non-hierarchical bargaining structure

$J \subseteq M$	$v(J)$
m_{int}	0
$m_i, m_i m_{int}$ for $i \in \{1,2,3\}$	α
$m_i m_j, m_i m_j m_{arch}$ for $i, j \in \{1,2,3\}, i \neq j$	β
$m_1 m_2 m_3, m_1 m_2 m_3 m_{arch}$	1

Table 6: Characteristic function v in the hypothetical case of integration services not being required

$J \subseteq M \cup m_{NVA}$	$v''(J)$
m_{NVA}, m_1, m_2, m_3	α
$m_1 m_2, m_1 m_3, m_1 m_{NVA}, m_2 m_3, m_2 m_{NVA}, m_3 m_{NVA}$	β
$m_1 m_2 m_3, m_1 m_2 m_{NVA}, m_1 m_3 m_{NVA}, m_2 m_3 m_{NVA}$	γ
$m_1 m_2 m_3 m_{NVA}$	1

Table 7: Characteristic functions $v'' : 2^{M \cup \{OS\}} \rightarrow \mathbb{R}$ for a 3-firm bargaining structure with NVA firm present in the value chain

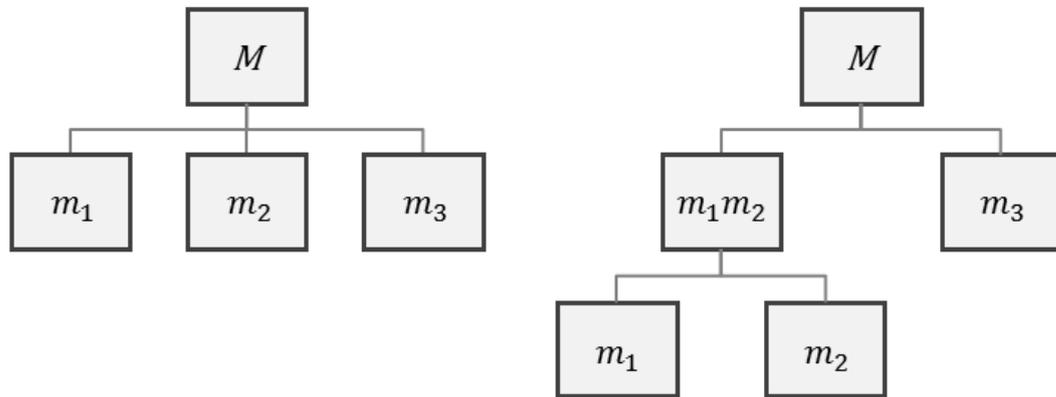


Figure 1: Illustration of non-hierarchical and hierarchical bargaining structures in 3-firm value chains

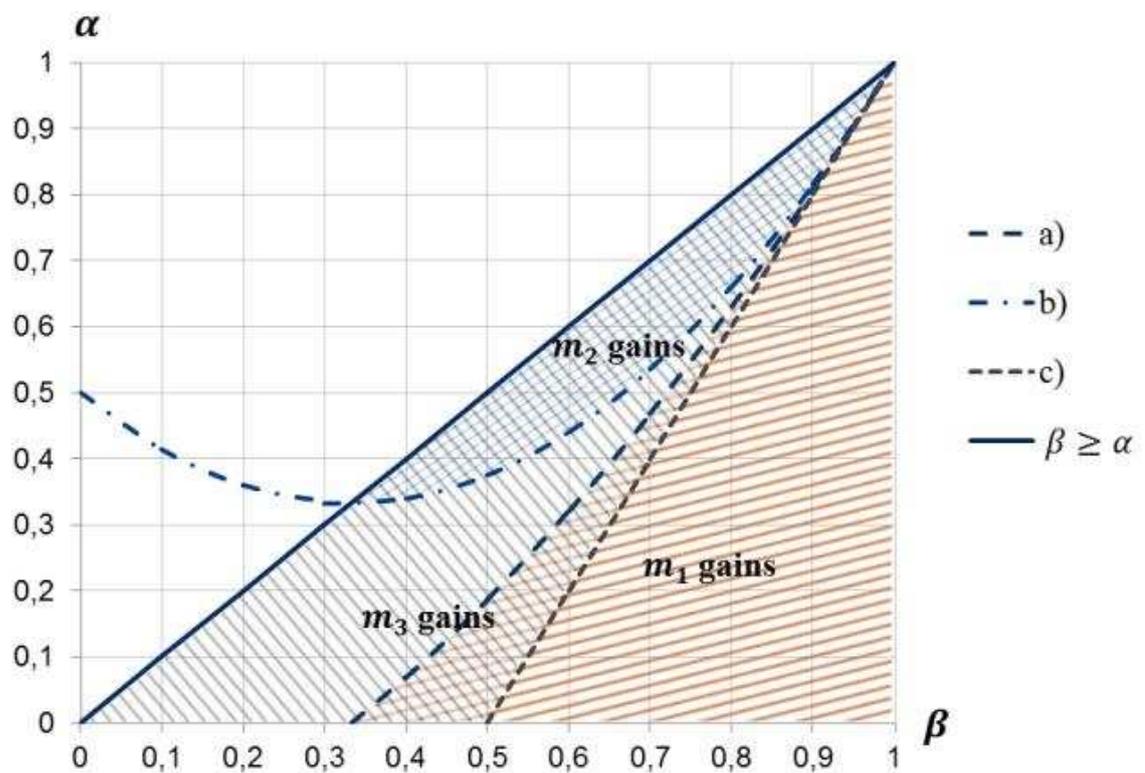


Figure 2: Benefits through hierarchical bargaining structure in 3-firm value chains

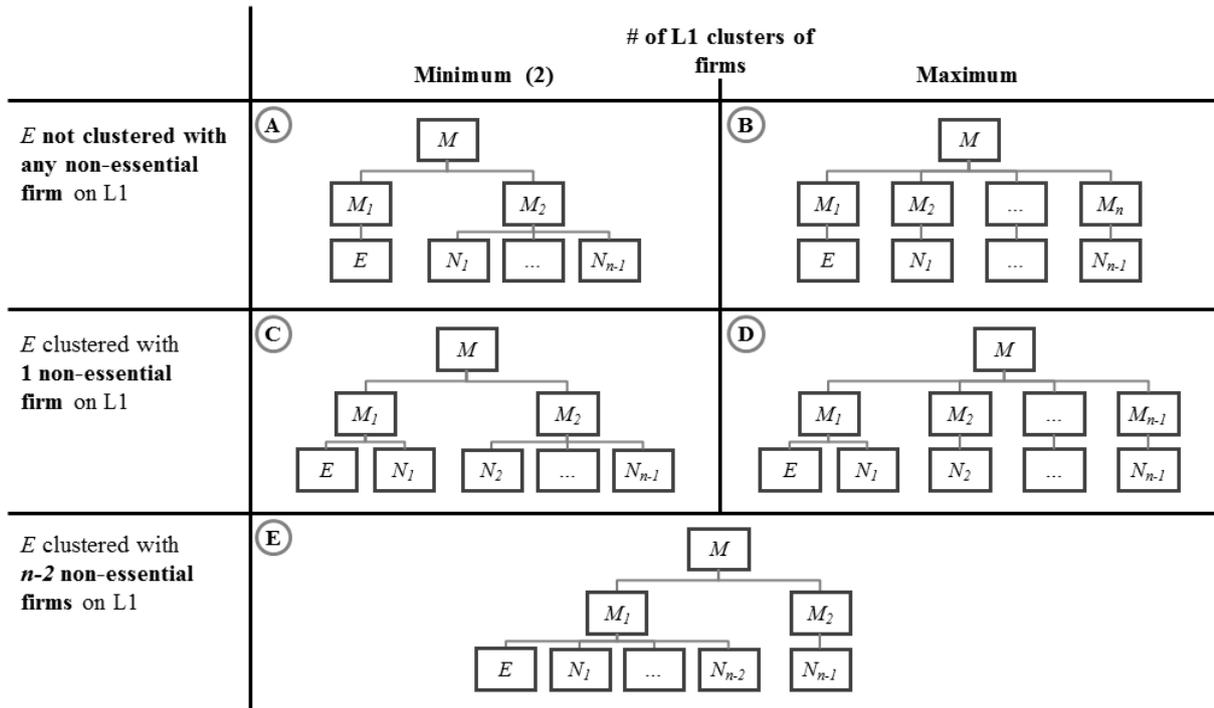


Figure 3: Illustration of extreme 2-level hierarchical bargaining structures for an n -firm value chain with one essential module

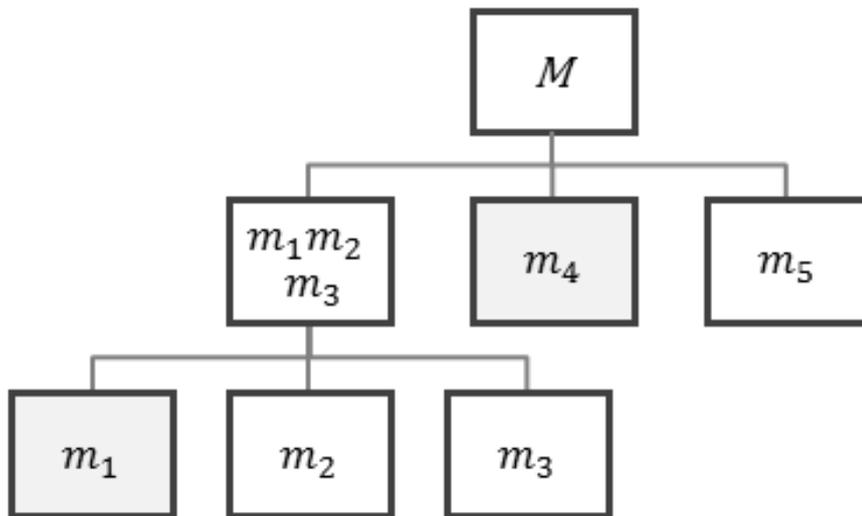


Figure 4: 5-position bargaining structure

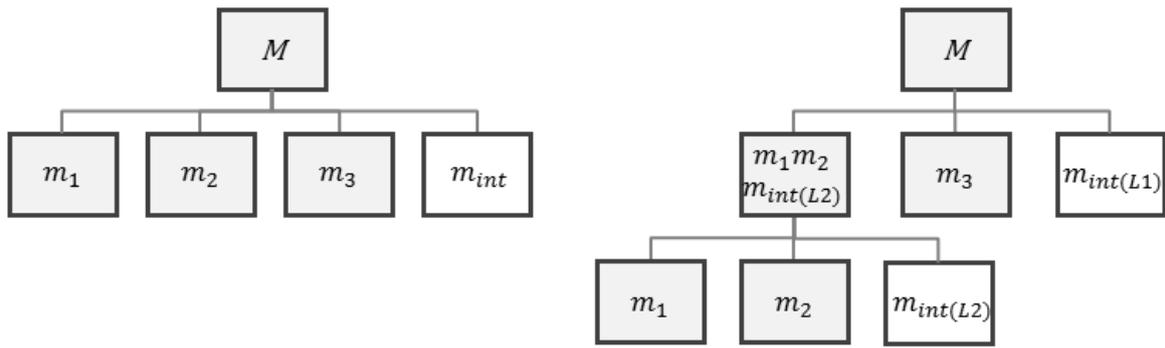


Figure 5: Illustration of non-hierarchical and hierarchical bargaining structures with integrators

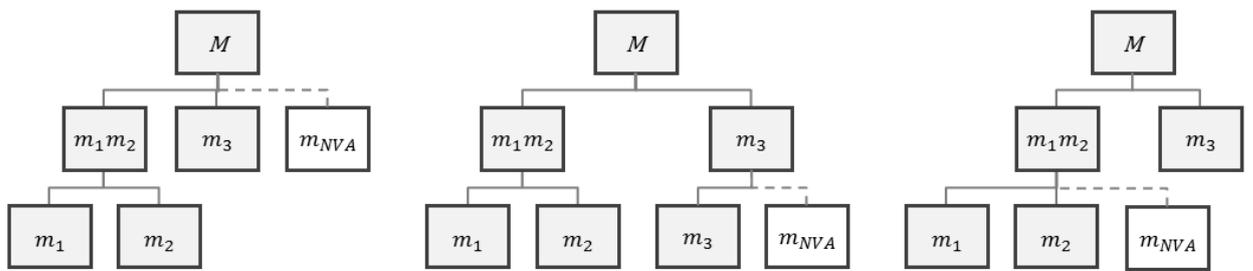


Figure 6: Positions of m_{NVA} in the value chain and illustration of the hypothetical hierarchical bargaining structures $M \cup m_{NVA}$



Figure 7: Panel controller Bosch FPA-5000 (left) and Siemens FC721-ZZ (right)

Source: Bosch (2014), Siemens (2012)



Figure 8: Embedded Mini-ITX Motherboard from Kontron

Source: Output (2012)

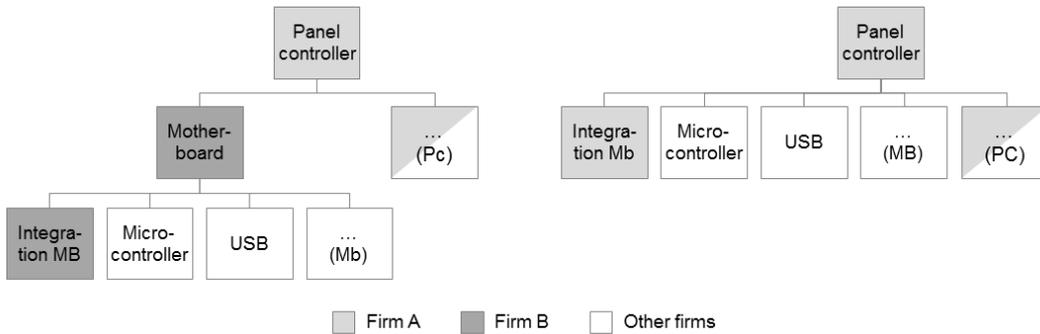


Figure 9: Illustration of bargaining structures for fire alarm panel controller: integration by Firm B (left) and integration by Firm A (right)

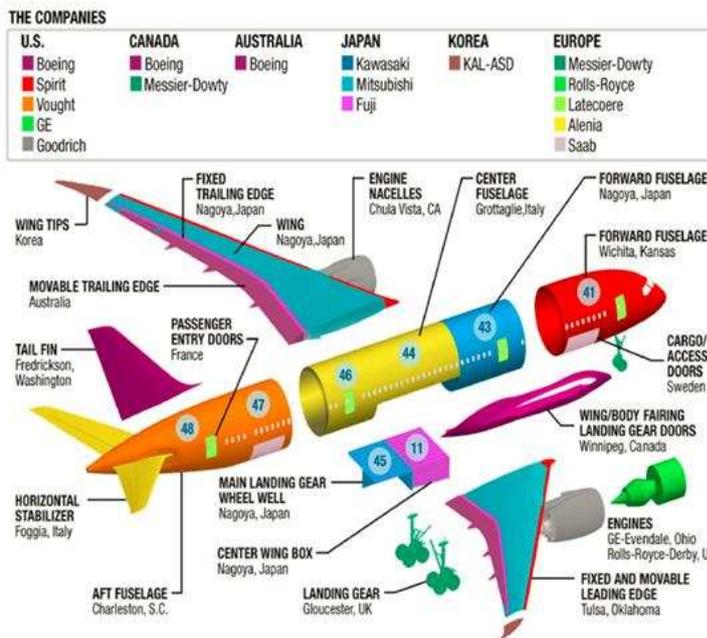


Figure 10: List of Boeing's tier-1 supplier and top-level modules

Source: Kotha and Nolan (2005)

Appendix

# of essential firms in $m_1 m_2 m_3$	Who gains and loses through hierarchy
0 0	Firms m_1 and m_2 gain if and only if $\frac{1}{4}(1 - \alpha + \beta) > \frac{1}{3} \Leftrightarrow \beta - \alpha > \frac{1}{3}$, this is if and only if the value-add of the second firm is larger than $\frac{1}{3}$.
1 0	The essential firm in $m_1 m_2$ gains if and only if $\frac{1}{4}(1 + \beta)^2 > \frac{1}{3}(1 + \alpha + \beta) \Leftrightarrow \alpha < \frac{1}{4}(\beta + 1)(3\beta - 1)$. This is only possible if $\beta > \frac{1}{3}$ and $\beta - \alpha > \frac{1}{4}(1 - \beta)$ (necessary constraints). The non-essential firm in $m_1 m_2$ gains if and only if $\frac{1}{4}(1 - \beta^2) > \frac{1}{6}(2 - \alpha - \beta) \Leftrightarrow \alpha > \frac{3}{2}\beta^2 - \beta + \frac{1}{2}$. This is only possible if $0 > (6\beta - 2)(\beta - 1)$ (as $\alpha \leq \beta$), so if $\beta > \frac{1}{3}$ (necessary constraint). The non-essential firm m_3 gains if and only if $\frac{1}{2}(1 - \beta) > \frac{1}{6}(2 - \alpha - \beta) \Leftrightarrow 1 - \beta > \beta - \alpha$, this is if and only if the value-add is larger in the second step (from two to three firms) than in the first step (for every 2 firms).
0 1	Firms in $m_1 m_2$ gain if and only if $\frac{1}{4}(1 - \alpha) > \frac{1}{6}(2 - \alpha - \beta) \Leftrightarrow \beta - \alpha > 1 - \beta$, this is if and only if the value-add is larger in the first step (for every 2 firms) than in the second step (from two to three firms).
2 0	m_1 and m_2 gain if and only if $\frac{1}{4}(1 + \beta) > \frac{1}{6}(2 + \beta) \Leftrightarrow \beta > 1$. Hence, they can never gain through hierarchy.
1 1	The essential firm in $m_1 m_2$ gains if and only if $\frac{1}{4}(1 + \beta) > \frac{1}{6}(2 + \beta) \Leftrightarrow \beta > 1$. Hence, the essential firm in $m_1 m_2$ can never gain through hierarchy. The non-essential firm in $m_1 m_2$ gains if and only if $\frac{1}{4}(1 - \beta) > \frac{1}{3}(1 - \beta) \Leftrightarrow \beta > 1$. Hence, the non-essential firm in $m_1 m_2$ can never gain through hierarchy.
2 1	Firms m_1 and m_2 gain if and only if $\frac{1}{4} > \frac{1}{3}$. Hence, m_1 and m_2 can never gain through hierarchy.