WHO SHOULD OWN “IT”?
OWNERSHIP AND INCOMPLETE CONTRACTS IN INTERORGANIZATIONAL SYSTEMS

Kunsoo Han (contact author)
Information and Decision Sciences
Carlson School of Management
University of Minnesota
khan@csom.umn.edu

Robert J. Kauffman
Co-Director, MIS Research Center, and
Professor and Department Chair
Information and Decision Sciences
Carlson School of Management
University of Minnesota
rkauffman@csom.umn.edu

Barrie R. Nault
David B. Robson Professor in Management (MIS)
Haskayne School of Business
University of Calgary
nault@ucalgary.ca

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ABSTRACT

Interorganizational systems (IOSs) are becoming ever more important due to the rapid growth of business-to-business electronic commerce and firms’ increasing needs for collaboration to respond to today’s fast-paced business environment. However, the substantial investment in information technology (IT) that is required and the uncertain benefits have resulted in underinvestment. We use the theory of incomplete contracts to examine what ownership structures of IOS assets maximize firms’ incentives to invest and the resulting value that they can appropriate. Because the characteristics of IOSs affect the optimal ownership structure, we also propose a new typology of IOSs that facilitates our analysis of asset ownership and investment incentives. Finally, we apply our framework to analyze the asset ownership structures of a specific type of IOS to support vendor-managed inventory (VMI) in supply chain management.

KEYWORDS: Economic theory, incomplete contracts, information systems, information technology assets, interorganizational information systems, networks, ownership, property rights theory, supply chain management.
1. INTRODUCTION

Over the past decade, as competition became fiercer, we have witnessed an explosion of alliances in the supply chain management arena (Dyer and Singh, 1998). More firms are forming networks with others, including their suppliers and customers, to accumulate complementary capabilities and assets, while focusing on their core competencies (Afuah, 2000). For example, Cisco Systems has been concentrating on developing new products and selling products to customers, leaving the rest—such as assembly, materials management and delivery—to other companies. One of the key success factors for alliances and virtual integration is the implementation of interorganizational systems (IOSs) that allow rapid, low-cost communication and information sharing between business partners.

1.1. Background and Motivation

An IOS has been defined as “an automated information system (IS) shared by two or more companies” (Cash and Konsynski, 1985) or “an information system that links one or more firms to their customers or their suppliers, and facilitates the exchange of products and services” (Bakos, 1991a). With the rapid advances in information technologies (IT) over the past few decades, various types of IOSs have emerged. Widely cited examples of IOS include American Hospital Supply Corporation’s ASAP and American Airlines’ reservation system SABRE. These systems not only gave their owners significant advantages over competitors but also had a role in changing the industry structure (Applegate and Gogan, 1995). More recently, business-to-business (B2B) electronic marketplaces such as Covisint (www.covisint.com) in the automotive industry have emerged to provide a broad range of services. Infrastructures (e.g., networks and databases in financial industries) that are shared by firms (Weill and Vitale, 2001) are another important example of IOS.

Although IOSs have become increasingly important due to the rapid growth of B2B e-commerce, the increasing risks and costs associated with implementing new IT have been roadblocks to IOS adoption (Dai and Kauffman, 2002a). IOSs have also suffered the problem of underinvestment because of the substantial investments in IT that are required and the uncertain, hard-to-divvy-up benefits (Nault, 1997). Investments related to IOS include the costs of purchase, installation, and maintenance of system assets (e.g., hardware, software, network), process redesign, employee training, and data conversion. IOS investments are “cooperative”: they benefit not only the investing firm but also its partners as well (Che and Hausch, 1999). This means that a firm cannot reap the full benefit from its investment in IOS; part of the benefits will inevitably be dissipated to its partners, which aggravates the underinvestment problem. The investments are important because they determine the quality of the IOS in terms of system compatibility and data quality, which ensures proper execution of the transactions between business partners and the creation of business value that they can capture. Thus, underinvestment in an IOS can
have a detrimental consequence on the business relationships that the IOS supports.¹

How can we strengthen the investment incentives of the participants in an IOS? Some researchers and practitioners emphasize the importance of developing a proper methodology for measuring and splitting the value that is created from IOS (Dai and Kauffman, 2002a). However, business value of IOS is not measurable and not contractible, making division of the value among the participants difficult. Instead, creating the right ownership structure of IOS assets can alleviate the problem of underinvestment by giving the participants proper incentives to invest.

Broadly-accepted theoretical foundations for explaining IOS ownership have not emerged in the IS research literature. Moreover, there has not been much guidance offered on how senior managers should think about how to arrive at optimal ownership structures for the IOSs in which their firms participate. A notable exception lies in the work of Bakos and Nault (1997), who modeled network ownership and investments from the perspective of the theory of incomplete contracts attributable to Grossman and Hart (1986) and Hart and Moore (1990).

1.2. Theoretical Perspective and Research Questions

Over the past decade, the theory of incomplete contracts has emerged as a major economic theory to explain asset ownership and boundaries of the firm (Whinston, 2001). The theory posits that every contract is incomplete in the sense that it is impossible to write down every contingency when contracting parties interact. Thus, there are always contingencies left out, leading to residual rights of control: the right to decide the disposition of an asset under contingencies that are not specified in a contract, including the ability to exclude others from the use of the asset. Ownership of an asset implies possession of these residual rights. As a result, the owner will have stronger bargaining power relative to non-owners, and be able to capture more value ex post. This in turn affects the ex ante levels of the participating firms’ investments. And so ownership of an asset determines the ex post value created from the asset by affecting the ex ante levels of investments.

In the spirit of this theory, we further define an IOS as a set of IT assets that support or enable business relationships between firms (be it a buyer-supplier relationship or a horizontal relationship among competitors). By doing this, we expand the traditional scope of IOSs that was restricted to supporting exchange relationships between buyers to a broader context encompassing information sharing and collaboration among various types of firms including competitors.

The theory of incomplete contracts is relevant to IOS research because how much value a firm can capture from IOS largely depends on its bargaining power relative to other participants (Riggins and Mukhopadhyay, 1994; Wang and Seidmann, 1995), and there are always unforeseen contingencies that

¹ A survey by Booz Allen Hamilton and Giga Information Group (2001) found that most companies are unsatisfied with B2B e-procurement exchanges they joined due to the slowdown in e-market investments.
cannot be fully specified in the implementation of IOSs. Ownership structure, in this context, is important because it determines the value created by the systems by affecting the levels of investments of the participants involved.

In this study, we propose a framework for analyzing ownership structure of IOS assets in various contexts and address the following questions:

- Why is analysis of ownership of IOS assets important in today’s business environment?
- How can the theory of incomplete contracts aid our understanding of IOS management issues?
- How should we decide on the ownership structure of assets in various types of IOS?

We next develop a typology for IOSs that enables us to structure the subsequent analysis.

1.3. A Typology for Analyzing IOS Investment and Ownership

We believe that the characteristics of IOSs are important in determining the optimal ownership structure. A widely-cited typology is *electronic markets and electronic hierarchies* based on transaction costs theory (Malone et al., 1987). However, their framework only deals with the exchange relationships between buyers and suppliers. Choudhury (1997) extended this framework to a three-type classification based on the underlying business relationship: electronic diads, multilateral IOS, and electronic monopolies. His typology is also limited to supplier-buyer exchange relationships. Recently, Hong (2002) proposed a typology based on the “role linkage” of participants and the system support level of IOS. The role linkage is *horizontal* if the IOS creates a link between firms that performing common value-producing activities (e.g., competitors in an industry) and *vertical* if the linkage involves different roles of participants (e.g., suppliers and buyers).

We develop a simple typology of IOSs that focuses on two dimensions: *underlying business relationship* and *configuration in value chain*. (See Table 1.) Underlying business relationship refers to whether the relationship that an IOS support is bilateral (i.e., one-to-one) or multilateral (i.e., many-to-many or one-to-many or many-to-one). Configuration in value chain refers to whether an IOS supports a vertical buyer-supplier exchange relationship within a value chain or is a linkage between firms that perform common value activities. The horizontal type includes IOSs supporting cooperation among competitors not only within an industry but across industries as well. Participants in vertical IOSs are likely to be firms that differ not only in the activities they perform in a value chain but also in their bargaining power. In contrast, firms that participate in horizontal IOSs tend to be more homogeneous in both aspects. With these two dimensions, we have four categories of IOS: *vertical-bilateral, vertical-multilateral, horizontal-bilateral*, and *horizontal-multilateral*.

The rest of this paper is organized as follows. Section 2 reviews related IOS research and explains how the theory of incomplete contracts can provide answers to questions that have yet to be answered. Section 3 explains why incomplete contracts are relevant and proposes a framework for analyzing the
ownership structure of IOS assets. Section 4 applies the framework to a specific IOS, a vendor-managed inventory system in supply chain management, to analyze the ownership structure of IT assets. Section 5 discusses the results and concludes the paper.

Table 1. A Typology of IOS

<table>
<thead>
<tr>
<th>UNDERLYING RELATIONSHIP</th>
<th>CONFIGURATION IN VALUE CHAIN</th>
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<tbody>
<tr>
<td></td>
<td>Vertical</td>
</tr>
<tr>
<td>Bilateral</td>
<td>• Electronic hierarchies</td>
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<tr>
<td></td>
<td></td>
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<tr>
<td>Multilateral</td>
<td>• Electronic markets (n-to-n)</td>
</tr>
<tr>
<td></td>
<td>• Electronic auction system (1-to-n)</td>
</tr>
<tr>
<td></td>
<td>• Electronic reverse auction system (n-to-1)</td>
</tr>
</tbody>
</table>

Note: Electronic markets and electronic hierarchies (Malone et al., 1987) belong to vertical IOS (left column).

2. REVIEW OF RELEVANT IOS RESEARCH

We classify prior IOS studies relevant to our research into three major categories: transaction structure, network externalities and adoption, and business value.

2.1. IOS and Transaction Structure

Several IS researchers have attempted to investigate how IOSs affect firms’ choice of transaction structure, in terms of markets and hierarchies, based on transaction cost theory and agency theory. An early study by Malone et al. (1987) proposed the electronic markets hypothesis, which posits that by reducing the costs of coordination, IT will tend to make electronic markets a preferred means of coordinating economic activities over electronic hierarchies. However, in spite of the apparent influence the authors have had on IOS research, their hypothesis has failed to get strong support from subsequent studies that attempted to test its efficacy (e.g., Hess and Kemerer, 1994).

Other studies in this area have been inconclusive about the impact of IOS on transaction structure or suggested that IT will lead to a mixed or hybrid structure rather than either of the two extremes (i.e., markets and hierarchies). Based on transaction cost theory and agency theory, Gurbaxani and Whang (1991) argued that by lowering both external coordination costs and internal coordination costs and increasing operational efficiency, IOSs can increase the use of both markets and hierarchies.

Holland and Lockett (1997) have argued that IOSs have enabled firms to increasingly adopt mixed mode network structures that have elements of both markets and hierarchies, by facilitating tight hierarchical links and close monitoring of performance. This is similar to a governance structure proposed by the move-to-the-middle hypothesis (Clemons et al., 1993), which posits that by reducing coordination costs, operations risk, and opportunism risk, IOSs will lead to a mixed transaction structure, involving long-term partnerships between a buyer and a small number of suppliers. In a similar vein,
Bakos and Brynjolfsson (1993a; 1993b) argued that when the non-contractible investments by suppliers (e.g., quality, innovation, and responsiveness) are important, the optimal number of supplier decreases. Why? Because when the number of competing suppliers is small, they will have stronger *ex post* bargaining power and a stronger incentive to make *ex ante* non-contractible investments.

Although the research has focused on the impact of IOSs on interfirm relationships and firm boundaries (i.e., ownership and governance structure), it does not analyze asset ownership structures for IOSs that support the relationships. We argue that the ownership structure of IOS assets significantly affects the value that firms can appropriate from their IOS, and model what ownership structure of IOS assets under a given transaction structure maximizes the value that can be created and shared.

### 2.2. Network Externalities and Adoption of IOS

Networks including IOS are subject to network externalities (Katz and Shapiro, 1985 and 1986; Shapiro and Varian, 1999). Existing adopters’ benefits increase with new adopters joining the network. Network externalities play an important role in IT adoption because firms’ *ex post* network size affects the *ex ante* valuation of IT adoption. Kauffman et al. (2000) empirically examined the impact of network externalities in the context of electronic banking, suggesting that firms’ heterogeneous valuation of externalities lead to their different adoption behaviors.

Although most studies on network externalities deal with positive externalities between adopters, some analytical work on EDI suggests that there are also negative, competitive externalities between competing adopters (Riggins et al., 1994; Wang and Seidmann, 1995). Although a buyer’s operational savings may increase in the number of suppliers adopting EDI, a supplier’s incremental profit due to adopting EDI decreases as more and more suppliers adopt EDI. Apparently EDI adoption is affected not only by the adopters’ incentives for adopting EDI (Barua and Lee, 1997; Riggins et al., 1994) but also by their characteristics, such as sophistication of their IS (Barua and Lee, 1997; Wang and Seidmann, 1995) and their productivity (Wang and Seidmann, 1995). These studies also show that initiators’ policies (i.e., mandating and subsidizing adoption) can influence EDI adoption. For example, Chrysler used a mandatory policy for adoption of EDI by its suppliers (Mukhopadhyay et al., 1995).

Other researchers have studied IOS adoption and investment issues in a broader context of B2B electronic commerce. Dai and Kauffman (2002b) investigated buyers’ e-procurement channel adoption decision between public electronic markets and closed private networks, and showed that the decision is influenced by such factors as benefits from adopting electronic markets, the degree of competition between the suppliers, and the importance of information sharing between the suppliers and the buyer. In a similar vein, Kauffman and Mohtadi (2002) modeled the trade-offs between procurement costs and supply uncertainty. They showed that smaller firms are more likely to adopt open B2B platforms while larger ones are more likely to adopt proprietary IOS. Nault and Dexter (2001) derived conditions that
assure the existence of a pure strategy Nash equilibrium in investments of participants in electronic markets where there are interactions between the electronic market’s investment and buyers’ and sellers’ own IT investment.

This stream of research is related to the incomplete contracts perspective: the value firms can extract from a network (or an IT) significantly affects their decision to adopt the network. We argue that ownership of IOS assets is an important determinant of firms’ valuation of the IOS.

2.3. Business Value of IOS

IOSs can create significant value ranging from inventory reduction (e.g., Lee et al., 1999; Mukhopadhyay et al., 1995) to timely processing of materials (e.g., Srinivasan et al., 1994), and higher product quality (e.g., Venkatraman, 1994). The Operations Management literature has examined value of information sharing though IOSs in a supply chain in terms of alleviating the “bullwhip effect” (Lee et al., 1997), which refers to the phenomenon of amplification of demand variance as one moves up the supply chain. The magnitude of the problem can be reduced when the manufacturer shares the retailers’ demand information (Chen et al., 2000; Lee et al., 2000). Chrysler realized significant cost savings and improved coordination for JIT shipments by deploying EDI with suppliers and sharing their shipment information (Mukhopadhyay et al., 1995; Srinivasan et al., 1994).

In addition to these operational benefits, IOSs create strategic value for participants. By sharing buyers’ sales and inventory information, a supplier can improve demand forecasting and production planning (Dai and Kauffman, 2002b; Seidmann and Sundararajan, 1997). Another example is concurrent engineering between automotive manufacturers (e.g., Ford) and tire manufacturers (e.g., Goodyear), which reduces the time of new product introduction to market (Venkatraman, 1994). Electronic markets can create value for participants by reducing search costs and transaction costs, often resulting in lower prices, better allocation, and higher social surplus (Bakos, 1991b; 1997).

Although an IOS can provide an efficient channel for information exchange and transaction-making, it is only through corresponding changes in organizational structures and processes (i.e., interorganizational process reengineering) that firms can realize exceptional value (Clark and Lee, 1997; Clark and Stoddard, 1996; Venkatraman, 1994). Because the initiator’s benefits are dependent on the adopters’ successful implementation due to positive externalities, the former has to encourage or subsidize its trading partners to reengineer their internal processes (Riggins and Mukhopadhyay, 1994 and 1999). Most of the prior work on EDI suggests that EDI initiators reap most of the benefits from implementing EDI (Mukhopadhyay et al., 1995; Riggins and Mukhopadhyay, 1994; Srinivasan et al., 1994; Wang and Seidmann, 1995) due to their superior bargaining power. However, Lee et al. (1999) provided empirical evidence that adopters also realize gains by combining IT implementation with appropriate changes in process and policy.
Although prior research has investigated what kinds of value can be created through IOSs, it has been relatively silent about how value materializes and should be divided among the participants. This is important because *ex post* value distribution directly affects firms’ incentives to invest.

### 2.4. Unanswered Questions: Investment Incentives and Value Sharing

Prior literature on incentive mechanisms for business partners to invest in their IOS and to share information is also limited. It has been argued that the biggest challenge to information sharing in a supply chain is that of aligning incentives of partners (Lee and Whang, 1998). There are only a few studies on how value that is created from IOSs is shared between business partners (e.g., Dai and Kauffman, 2002b; Seidmann and Sundararajan, 1997). In an important study, Clemons and Kleindorfer (1992) modeled firms’ investments in IOS and value sharing among the participants by applying a Nash bargaining solution. They examined the impact of relationship specificity of investments and switching costs on firms’ *ex post* surplus and, in turn, *ex ante* levels of investments in the IOS. In a setting with a single supplier and multiple identical buyers they showed that the more specific the investments and the higher the switching costs of a participant are, the lower its surplus (due to its lower relative bargaining power), and the lower its level of investment will be.

Their work is closely related to our study in that participants in an IOS are called upon to make relationship-specific investments, and the surplus is divided through *ex post* bargaining. However, in their model IOS ownership is predetermined: the supplier is the owner who earns rents in the form of transfer payments from the buyers. In addition, they assume that investments and contingencies are verifiable so that trade occurs based on these variables. In contrast, following incomplete contracts theory we view investments and contingencies as observable but non-verifiable, so the participants cannot enter into a contract based on the outcomes of these variables.

Recently, IOS ownership structure for B2B e-commerce has attracted some attention. In B2B e-markets with different ownership structures in the presence of network effects, Yoo et al. (2001) showed that biased (i.e., buyer-owned or supplier-owned) marketplaces can provide services at a lower price, attract more buyers and suppliers, and generate larger total surplus relative to neutral (i.e., intermediary-owned) marketplaces. Their work is related to ours in that ownership structure affects bargaining power and surplus even though the level of analysis is different. Although we do not explicitly model how exchange occurs (e.g., how the price is set, etc.), we assume that once an ownership structure is decided, exchange occurs so that the participants involved maximize their surpluses according to their bargaining power under the given ownership structure.

### 3. INCOMPLETE CONTRACTS AND IOS OWNERSHIP: AN ANALYSIS FRAMEWORK

In this section, we first explain what the main elements of the incomplete contracts theory are and
why they are relevant to analyzing IOSs. Then, we propose a framework to guide research in this area. Finally, we examine how the theory can provide insights into how firms should optimize the ownership structure of IOSs in which they participate.

3.1. The Theory of Incomplete Contracts

To understand the concept of incomplete contracts, we must define what we mean by “complete” contracts. A complete contract occurs when each party’s obligations in every conceivable contingency are specified (Hart, 1987). However, contracts between firms may be incomplete for several reasons. First, the firms cannot define or foresee all possible contingencies that may arise in the future. For example, an IOS may not work as the firms initially planned, one of the firms may become unable to invest as much money as it promised at the time of contracting, or there can be technological changes that were not expected at the time of contracting. Second, even if the firms could foresee all contingencies, it would be too costly in negotiation terms to describe them in a contract. Third, even if the firms can foresee all contingencies and actions and describe them in a contract, it may by very difficult for a third party, e.g., a court or an arbitrator, to figure out what they mean and enforce them. Such variables may include investment level or product quality, which may be too complex or multidimensional to specify in a contract. Such observable but non-verifiable variables are not contractible.

Based on these observations, Grossman and Hart (1986) and Hart and Moore (1990) developed an incomplete contracts theory of the firm to explain asset ownership and boundaries of the firm. The theory posits that every contract is incomplete, since it is impossible to write down every possible contingency. Instead, the participants must divide the surplus based on their relative bargaining power. Hart and Moore assume that ex post bargaining results in the division of value between the participants according to the Shapley value – a value that specifies for each participant an amount equal to that participant’s expected marginal contribution. This is the incremental contribution by the participant to each potential coalition multiplied by the probability of each such coalition (Shapley, 1953). (See Appendix A.)

The key result in Hart and Moore (1990) is that participants always underinvest relative to first-best (i.e., integrated firm) investment levels. As a consequence of three positive externalities assumptions in their model – investment externalities, network externalities, and marginal network externalities – it is in the interest of every participant to join the grand coalition (i.e., the coalition that contains all the participants). (See Appendix B for the Hart and Moore (1990) assumptions.) This underinvestment occurs because each participant cannot fully capture the gain resulting from their investment because some of the gain will be dissipated in ex post bargaining.

The importance of asset ownership stems from contract incompleteness. Because a typical contract cannot specify all aspects of asset use, it is important who has the right to decide about the value-

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2 In reality, contracts are rarely complete and are subject to renegotiation or revision (Williamson, 1975 and 1985).
producing uses that are left out of the contract (Hart, 1995). Grossman and Hart (1986) defined the ownership of an asset as the possession of *residual rights* of control over that asset: the right to decide the disposition of the asset under the contingencies that are not specified in a contract. As a result, owners have a relatively stronger bargaining position compared with other non-owners. This concept of ownership is different from the possession of residual income. It does not necessarily give the owner the residual income streams associated with the asset, but rather the residual income streams accrue to asset owners because of their strong bargaining position.

The incompleteness of contracts is related to the concept of *relationship-specific investments* that have little or no value outside the relationship. When firms make relationship-specific investments, they are locked in to each other, and, thus, they need a long-term relationship (and a contract) to regulate and divide up the gains from their trade. This is appropriate because they can no longer rely on the market once their investments are sunk (Hart, 1987). Because contracts are incomplete, firms making relationship-specific investments face the risk of expropriation of value by the other party at the bargaining stage (Klein et al., 1978). As a result, firms are more likely to make non-specific investments. For example, a supplier will want to adopt an EDI system that is compatible with the industry standard, and not adopt a proprietary EDI system from a certain buyer.

### 3.2. Incomplete Contracts and IOS

There are several reasons why the theory of incomplete contracts, property rights and asset ownership are important in IOS. First, contracts involving IOS implementations are inherently incomplete; again, firms cannot specify every contingency related to the IOS in their contracts. For example, firms deploying an IOS may have to terminate their business relationship due to some unexpected incident (e.g., bankruptcy). As a result, there are always residual rights of control.

Second, an IOS implementation often requires substantial relationship-specific investments by the participants that are not contractible. To realize the potential value of an IOS, the implementing firms are required to make relationship-specific investments in such IT assets as hardware, software, and network-technology, but also in complementary assets, such as information, expertise, business process, and training. These investments may be observable for the participants involved, but it would be impossible for a third party (e.g., a judge) to verify the levels of the investments due to their complexity and intangibility.

Third, because they cannot anticipate or specify *ex ante* how much and what kinds of value will be created from the IOS, participants often have to divide up the resulting value through a bargaining process. How much value each participant is able to capture depends on their relative bargaining power. For example, prior EDI studies suggest that the dominant buyer reaps most of the benefits due to superior bargaining power relative to the suppliers (Mukhopadhyay et al., 1995; Riggins and Mukhopadhyay,
With IOSs, it is important to distinguish between creating value and capturing that value (Saloner and Spence, 2002). If firms cannot appropriate enough value from the investments they make, they will have less incentive to invest, which further reduces the potential value that can be created.

Finally, there are positive investment externalities among investments by the participants in an IOS (Nault and Dexter, 2001). All the participants must make joint investments to create value. However, because these externalities reduce their incentives to invest (they cannot reap the full benefit from their investments), it is important to devise a mechanism to restore the appropriate incentives. The theory of incomplete contracts suggests that creating an optimal ownership structure can in part alleviate the problem of underinvestment by providing the participants with the appropriate incentives.

The relationships among ownership structure, investments, and business value in IOSs are shown in Figure 1. First, ownership of IOS assets affects participants’ ex post bargaining power which, in turn, affects the ex post distribution of surplus. Second, each participant’s expectation about the surplus affects ex ante levels of specific investments. Finally, the levels of investments determine the value that is created from the IOS. The ownership structure further determines the value the systems create by affecting the levels of specific investments of the participants involved.

3.3. Determinants of the Optimal IOS Ownership Structures

Hart and Moore suggested two key factors affecting the optimal ownership structure: relative importance of a participant’s investment and a participant’s indispensability as a coalition partner. The

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**Figure 1. The Relationships between Ownership, Investment, and Value**

- **Ex post Bargaining Power** → **Ex post Surplus Distribution** → **Value Created from IOS Assets**

**Note:** Ownership of IOS assets determines the ex post value created from the system by affecting firms’ ex ante specific investments.

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3 Brynjolfsson (1994) employed the concept of information asset and argued that the factors determining an participant’s ownership rights are how necessary that participant’s information is to the productivity of the firm and how important it is to maximize the participant’s incentives relative to those of others. Van Alstyne et al. (1995) used the same conceptual and theoretical basis and derived principles for data ownership for database maintenance.
first means that a participant with an important investment decision should own an asset. This is related
to the benefits and costs that the ownership of an asset by one participant entails (Grossman and Hart,
1986; Hart, 1995). The benefit of ownership is that the incentive of the owner of an asset to make
specific investments increases because the owner will receive a greater fraction of the surplus created by
its investments in the asset due to its strong bargaining position. The cost of ownership is that the
incentive of the non-owners to make relationship-specific investments decreases because they will receive
a smaller fraction of the surplus created by their investments in that asset. Therefore, the relative
importance of a participant’s investment is a key determinant of ownership rights. This implies that if
only one participant has to make an investment, then that participant should own all the assets.

To understand the meaning of the second factor, a participant’s indispensability as a coalition
partner, we introduce the concept of idiosyncratic assets and indispensable participants. (See Table 2.)
An asset is idiosyncratic to a participant if the asset affects the marginal benefit of that participant only.
A participant is indispensable to an asset if without the participant in a coalition the asset has no effect on
the marginal benefit of the members of the coalition. If an asset is idiosyncratic to a participant, then the
participant is also indispensable to that asset. Hart and Moore (1990) showed that if an asset is
idiosyncratic to a participant, who is then indispensable to that asset, then the participant should own it.
An additional factor is the complementarities of assets. The authors showed that highly complementary
assets should be under common ownership and independent assets should be separately owned.

Applying Hart and Moore’s model to electronic networks, Bakos and Nault (1997) derived three
results that are relevant to IOSs. First, if one or more assets are essential to all participants—if the
participants cannot create any marginal value without access to the assets—then all the assets should be
controlled together. Second, if a participant is indispensable to an asset that is essential to all participants,
then that participant should own all the assets. Traditional IOSs (e.g., EDI) typically had proprietary
architectures specific to the initiators who were indispensable to their IOS. As a result, the entire systems
were usually owned by the initiators. An example is McKesson Drug Company’s Economost, an IS for
direct customer order entry (Clemons and Row, 1988). With the advances in communications
technologies, more companies are adopting widely-used standard technologies (e.g., Internet-based EDI)
that have made the initiator of an IOS less indispensable (or even dispensable).

Third, if at least two participants must cooperate to derive value from the network and no participants
are indispensable to the entire network, sole ownership is always dominated by some form of joint
ownership. This concept is especially important in IOS where both participants (e.g., a supplier and a
manufacturer) should make a joint effort to reap the benefits of their IOS. We can expect that some form
of joint ownership will prevail for control of IOS, as the initiator becomes less indispensable. The
determinants of the optimal ownership structure of IOS assets are summarized in Table 2.
Table 2. Determinants of Optimal IOS Ownership Structure

<table>
<thead>
<tr>
<th>DETERMINANTS</th>
<th>DESCRIPTION</th>
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<tbody>
<tr>
<td>Idiosyncraticity</td>
<td>An IT asset is idiosyncratic to a participant if the asset contributes to the participant’s productivity, and does not affect anyone else’s.</td>
</tr>
<tr>
<td>Complementarities</td>
<td>Two IT assets are complementary if either one of the assets cannot create value without the other.</td>
</tr>
<tr>
<td>Essentiality</td>
<td>An IT asset is essential to a participant if the participant can create value only through the asset.</td>
</tr>
<tr>
<td>Indispensability</td>
<td>A participant is indispensable to an IT asset if the asset cannot create any value without the participant.</td>
</tr>
<tr>
<td>Relative importance</td>
<td>The relative magnitude of participants’ marginal return on investment.</td>
</tr>
</tbody>
</table>

3.4. A Conceptual Framework for Analyzing IOS Ownership and Investment

Based on the determinants drawn from the incomplete contracts literature and the typology of IOS that we developed, we present a conceptual framework for analyzing ownership structure of IOS assets. (See Figure 2.) Because IOS characteristics affect asset ownership, we first select a category and a context of IOS to analyze from the typology. A vertical-bilateral IOS or a horizontal-multilateral IOS are among our possible choices. Vendor-managed inventory initiatives are an example of the former and shared electronic banking networks are an example of the latter. Selecting a specific IOS context permits us to define the participants and the IT assets that compose the IOS. IT Assets include hardware, software, data, and network. With the defined IOS participants and assets, we then can evaluate different ownership structures based on the determinants to arrive at the optimal ownership structure.

Figure 2. A Conceptual Framework for Analyzing Ownership Structure of IOS Assets

3.5. The Hart and Moore (1990) Model

The Hart and Moore (1990) model consists of a set $S$ of $I$ risk neutral participants and a set $A$ of assets. There are two periods. In Period 0, each participant noncooperatively chooses its level of
investment $x_i$, which affects its productivity at the cost of $C_i(x_i)$. (See Table 3 for notation.)

**Table 3. Notation for Analysis of Asset Ownership**

<table>
<thead>
<tr>
<th><strong>ELEMENT</strong></th>
<th><strong>DESCRIPTION</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{S}$</td>
<td>The set of all participants (i.e., the “grand coalition”)</td>
</tr>
<tr>
<td>$\mathcal{A}$</td>
<td>The set of all assets</td>
</tr>
<tr>
<td>$\mathcal{S}$</td>
<td>A non-empty subset of all participants, $\mathcal{S}$ (i.e., a coalition)</td>
</tr>
<tr>
<td>$\mathcal{A}$</td>
<td>A non-empty subset of all assets, $\mathcal{A}$</td>
</tr>
<tr>
<td>$x_i$</td>
<td>Participant $i$’s relationship-specific non-contractible investment</td>
</tr>
<tr>
<td>$x = {x_1, x_2, \ldots, x_I}$</td>
<td>Vector of all participants’ investments</td>
</tr>
<tr>
<td>$C_i(x_i)$</td>
<td>Cost of investment $x_i$ to participant $i$</td>
</tr>
<tr>
<td>$v(S, \mathcal{A}</td>
<td>x)$</td>
</tr>
<tr>
<td>$\frac{\partial v(S, \mathcal{A}</td>
<td>x)}{\partial x_i}$</td>
</tr>
</tbody>
</table>

In Period 1, production and trade take place, and the total value created is divided through multilateral bargaining leading to the Shapley value. (See Appendix A.) From the formation of the grand coalition the maximum total value in Period 1 is $v(\mathcal{S}, \mathcal{A})$. For simplicity, we suppress investments in the value function. If we let $A(S)$ be the set of assets owned by $S$ under ownership structure $\alpha$, participant $i$’s share of $v(\mathcal{S}, \mathcal{A})$ under $\alpha$ is given by $B_i(\alpha) = \sum_{S \in \mathcal{S}} p(S)\left[v(S, A(S)) - v(S \setminus \{i\}, A(S \setminus \{i\})\right]$, where

$$p(S) = \frac{|S|! (I - |S|)!}{I!}.$$

Each participant chooses its level of investment, $x_i$, in Period 0 to maximize its net payoff. Each participant’s objective function is $B_i(\alpha) - C_i(x_i)$. The optimal level of investment must satisfy the first-order condition (FOC): $\sum_{S \in \mathcal{S}} p(S)v'(S, A(S)) = C'_i(x_i)$. The set of FOCs for all participants results in a Nash equilibrium in participant investments. The marginal cost of investment, $C'_i(x_i)$, is an increasing function of the investment level, $x_i$, so the greater is the left-hand side of the FOC for participant $i$, the greater the participant’s investment incentives. It suffices to compare the magnitude of the left-hand side for each ownership structure to determine the optimal one.

4. APPLYING THE FRAMEWORK: VENDOR-MANAGED INVENTORY (VMI)

We next apply our framework to a specific context of IOS implementation: VMI. First, we describe the general characteristics of VMI, including the definition, required investments, and benefits. Next, we identify the assets comprising VMI, and the relationships between those assets and the participants. Then, by evaluating the different ownership structures of VMI assets based on the determinants, we specify the incentive-maximizing ownership structure.
4.1. Understanding VMI

VMI is one of the most widely seen supply chain initiatives between a supplier (usually a manufacturer) and buyers (usually retailers or distributors) for improving supply chain efficiency. Pioneered by Wal-Mart and Procter & Gamble in the 1980s, VMI has been adopted as an integral part of such strategic initiatives as the “Efficient Consumer Response” in the grocery industry and the “Quick Response” in the apparel industry (Seidmann and Sundararajan, 1997; Waller et al., 1999).

In VMI, the supplier makes inventory replenishment decisions for the buyer based on demand and inventory information sent by the buyer. Thus, the supplier is responsible for managing the buyer’s inventory. A typical process of inventory replenishment with VMI is depicted in Figure 3.

Figure 3. Typical Components and Inventory Replenishment Process of a VMI program

Note: The numbers indicate the order in which the transactions take place.

In the chemical industry, the costs for developing a VMI system range from $150,000 for a manual system to $500,000 for an automated system (Challener, 2000). As described in Table 1, the supplier needs to implement EDI for data communication and VMI software for forecasting and placing orders based on the buyer’s data. The buyer also needs to implement EDI and a point-of-sale (POS) system for gathering sales information. Additionally, both participants should integrate these new systems with their existing internal systems, such as enterprise resource planning and inventory management systems.

Between the participants, it is essential to achieve technological interoperability, and standardization and synchronization (or alignment of key data such as new items and inventory counts, etc.). VMI implementation also requires other complementary investments in creating the necessary organizational structure. Waller et al. (1999) argued that successful implementation of VMI depends heavily on sound business processes, interpersonal relationships, effective teamwork, and trust between the supply chain partners. At the same time, organizational incentives and metrics must be aligned with VMI goals.
The most important benefit of VMI for both the supplier and the buyer is increased sales from improved service levels (i.e., a decrease in stockouts). The buyer’s other important benefits include a decrease in inventory levels, and planning and ordering costs. The supplier’s costs decrease because the increased visibility to the buyer’s sales and inventory data allows it to better forecast and reduce its inventory levels. With the increased visibility, the supplier can better prioritize production and transportation, resulting in improved resource utilization. To achieve these benefits, both participants should make substantial investments. (See Table 4.)

**Table 4. Investments and Benefits Associated with VMI Implementation**

<table>
<thead>
<tr>
<th>SUPPLIER</th>
<th></th>
<th>BUYER</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Investments</strong></td>
<td></td>
<td><strong>Benefits</strong></td>
</tr>
<tr>
<td>• EDI implementation</td>
<td>• EDI implementation</td>
<td>• Increased sales (due to improved service levels and reduced stockouts)</td>
</tr>
<tr>
<td>• Standardization of data for EDI</td>
<td>• Standardization of data for EDI</td>
<td>• Reduced inventory levels</td>
</tr>
<tr>
<td>• VMI software implementation</td>
<td>• POS implementation</td>
<td>• Eliminating planning/ordering costs</td>
</tr>
<tr>
<td>• Systems integration (ERP or order processing system, VMI, EDI, etc.)</td>
<td>• Systems integration (EDI, POS, and inventory management, etc.)</td>
<td>• Reduced time for order fulfillment</td>
</tr>
<tr>
<td>• Process reengineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Data standardization, synchronization</td>
<td>• Increased sales</td>
<td></td>
</tr>
<tr>
<td>• Network service for data interchange</td>
<td></td>
<td>• Improved demand forecasting and reduced demand uncertainty</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Smaller buffers of production capacity and inventory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Reduced transportation costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• More efficient route planning</td>
</tr>
</tbody>
</table>

### 4.2. Analyzing VMI Asset Ownership Using the Framework

**Basic Setup.** We assume that VMI consists of two participants (i.e., a supplier and a buyer), denoted $s$ and $b$, and five assets: network and EDI ($N$), sales and inventory data ($D$), buyer’s inventory management system ($I$), buyer’s POS system ($P$), and forecasting software ($F$). We treat the network and EDI as a single asset because EDI is an optional part for exchanging data.

**Analyzing Asset and Participant-Related Determinants.** We analyze how the participants and assets of VMI are interrelated for five determinants: complementarities, essentiality, idiosyncraticity, indispensability, and relative importance of non-contractible investments. For each asset, we ask:

- Is the asset *strictly complementary* with any other assets? Are there any other assets that need to be present to create marginal benefit?
- Is the asset *essential* to any participant? Does any participant need it to create value?
- Is the asset *idiosyncratic* to any participant? Does the asset contribute to a specific participant’s marginal return only (and not those of others)?
- Is the supplier or the buyer *indispensable* to the asset? Does the asset need a specific participant to create marginal benefit?
- Whose non-contractible investment in the asset exhibits greater *relative importance* by creating
greater marginal return?

We start with the asset-related determinants: idiosyncraticity, essentiality, and complementarities. The buyer’s inventory management system (I) and POS system (P) are idiosyncratic to the buyer (b) because these are the buyer’s internal systems and the supplier (s) cannot gain any value by owning them. Network/EDI (N) is essential to both participants because without the medium of data exchange neither of them can create any value from the VMI system. By the same token, the sales and inventory data (D) are essential to both supplier and buyer because without the sales and inventory data from the buyer, the VMI system cannot function properly. The forecasting software (F) and the data (D) are strictly complementary: neither can create any value unless they are together. Forecasting software cannot accurately forecast future inventory levels without the data and the supplier cannot get accurate forecasts without sophisticated forecasting software even though it has the data.

Next, we consider the participant-related determinants: indispensability and relative importance. Because the idiosyncraticity of an asset to a participant implies the participant’s indispensability to the asset, the buyer (b) is indispensable to both the buyer’s inventory management system (I) and the POS system (P). Relative importance of non-contractible investment requires a closer look. No prior studies provide a clear definition let alone a formal representation. We define relative importance as the relative magnitude of participants’ marginal return on investment. So if the supplier’s investment is more important than the buyer’s investment, then \( v^s (s, A) \geq v^b (b, A) \). Results from analysis of these determinants are summarized in Table 5, and are represented as equalities and inequalities in Tables 6.

Based on the conditions from Table 6, we can identify possible ownership structures of assets and determine the optimal ownership structure.

1. We first reduce the number of sets of assets by eliminating those sets that create zero marginal return on investment to yield the feasible sets of assets.
2. Then we compare first order conditions to determine investments in the remaining structures.

Identifying the Feasible Sets of Assets. With five assets, there are 31 possible combinations (i.e., five singletons, ten with two assets, ten with three assets, five with four assets, and the full set). Because N and D are essential to both participants, any coalition that does not own both assets has no marginal return on investment. Eliminating sets without both N and D, we are left with eight sets of assets:

\[ \{N, D\}, \{N, D, I\}, \{N, D, P\}, \{N, D, F\}, \{N, D, I, P\}, \{N, D, I, F\}, \{N, D, P, F\}, \{N, D, I, P, F\}. \]

Because F and D are strictly complementary, any coalition that does not own both assets creates zero marginal return on investment. Thus, we can eliminate those sets that do not contain both F and D, yielding four sets of assets that create positive marginal returns on investment:

\[ \{N, D, F\}, \{N, D, I, F\}, \{N, D, P, F\}, \{N, D, I, P, F\}. \]
Analyzing Ownership Structures. Based on the conditions in Table 6 and these four sets of assets, we can now analyze various ownership structures of assets to determine the optimal ownership structure.

Table 5. Analysis of the Determinants of the Ownership of VMI Assets

<table>
<thead>
<tr>
<th><strong>DETERMINANTS</strong></th>
<th><strong>VMI ASSETS</strong></th>
<th><strong>NETWORK/EDI (N)</strong></th>
<th><strong>FORECAST SOFTWARE (F)</strong></th>
<th><strong>SALES/INVENTORY DATA (D)</strong></th>
<th><strong>INVENTORY MGMT SYSTEM (I)</strong></th>
<th><strong>POS (P)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Asset-Related</td>
<td>Complementarities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Supplier</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Buyer</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Idiosyncraticity</td>
<td>Supplier</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Buyer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participant-Related</td>
<td>Indispensability</td>
<td>Supplier</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Buyer</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Relative importance</td>
<td>Supplier</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>buyer</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Each check symbol, ✓, represents a relationship between the corresponding participant and asset. The bold line, ——, represents complementarities between the two assets. Based on the Hart and Moore (1990) result that idiosyncraticity implies indispensability, we omit the formal representation of indispensability.

Table 6. Formal Representation of the Characteristics of VMI Assets and Participants

<table>
<thead>
<tr>
<th><strong>DETERMINANT</strong></th>
<th><strong>PARTICIPANT/ASSET</strong></th>
<th><strong>FORMAL REPRESENTATION OF THE DETERMINANTS IN TERMS OF MARGINAL RETURNS</strong></th>
<th><strong>EXPLANATION</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Essentiality</td>
<td>s, N</td>
<td>( v^b (S, A) = v^b (b, A) = 0 ) if ( N \notin A )</td>
<td>Without access to asset ( N ), the supplier cannot create any marginal value to the coalition</td>
</tr>
<tr>
<td></td>
<td>b, N</td>
<td>( v^i (S, A) = v^i (s, A) = 0 ) if ( N \notin A )</td>
<td>Without access to asset ( N ), the buyer cannot create any marginal value to the coalition</td>
</tr>
<tr>
<td></td>
<td>s, D</td>
<td>( v^b (S, A) = v^b (b, A) = 0 ) if ( D \notin A )</td>
<td>Without access to asset ( D ), the supplier cannot create any marginal value to the coalition</td>
</tr>
<tr>
<td></td>
<td>b, D</td>
<td>( v^i (S, A) = v^i (s, A) = 0 ) if ( D \notin A )</td>
<td>Without access to asset ( D ), the buyer cannot create any marginal value to the coalition</td>
</tr>
<tr>
<td>Idiosyncraticity</td>
<td>b, I</td>
<td>( v^i (S, A) = v^i (S, A \setminus {I}) ) if ( I \in A )</td>
<td>Asset ( I ) contributes only to the buyer’s marginal return on investment.</td>
</tr>
<tr>
<td></td>
<td>b, P</td>
<td>( v^i (S, A) = v^i (S, A \setminus {P}) ) if ( P \in A )</td>
<td>Asset ( P ) contributes only to the buyer’s marginal return on investment.</td>
</tr>
<tr>
<td>Complementarities</td>
<td>F, D</td>
<td>( v^i (S, A \setminus {D}) = v^i (S, A \setminus {F}) = v^i (S, A \setminus {D,F}) ), ( i \in {s,b} )</td>
<td>( D ) and ( F ) can contribute to participants’ marginal return on investment only when the coalition owns both assets.</td>
</tr>
<tr>
<td>Relative importance</td>
<td>s, F</td>
<td>( v^i (S, A) \geq v^b (b, A) ) if ( F \in A )</td>
<td>For any set of assets that contains ( F ), the supplier’s marginal return on investment is at least as large as that of the buyer.</td>
</tr>
<tr>
<td></td>
<td>b, D</td>
<td>( v^i (S, A) \leq v^b (b, A) ) if ( D \in A )</td>
<td>For any set of assets that contains ( D ), the buyer’s marginal return on investment is at least as large as that of the supplier.</td>
</tr>
</tbody>
</table>

**Note:** The second column represents the participant and asset involved in each determinant, and the third column is a representation (in Hart and Moore’s notation) of each participant-asset relationship identified in Table 5.
With two participants, we have three possible basic ownership structures: sole ownership by the buyer, sole ownership by the supplier, and joint ownership. With the four sets of assets that have been identified, there are nine distinct ownership structures after eliminating duplicates. (See Table 7.)

### Table 7. Comparison of Ownership Structures with Equal Share Voting Rule in Joint Ownership

<table>
<thead>
<tr>
<th>SET OF ASSETS</th>
<th>ASSET OWNERSHIP STRUCTURE</th>
<th>FIRST ORDER CONDITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDF</td>
<td>[NDF→s, IP→b]</td>
<td>Supplier: ( \frac{1}{2}v'(s,NDF) + \frac{1}{2}v'(S,A) )</td>
</tr>
<tr>
<td></td>
<td>[NDF→b, IP→s]</td>
<td>Buyer: ( \frac{1}{2}v^b(b,NDF) + \frac{1}{2}v^b(S,A) )</td>
</tr>
<tr>
<td>NDF</td>
<td>[NDF→s, P→b]</td>
<td>Supplier: ( \frac{1}{2}v'(s,NDF) + \frac{1}{2}v'(S,A) )</td>
</tr>
<tr>
<td></td>
<td>[NDF→b, P→s]</td>
<td>Buyer: ( \frac{1}{2}v^b(b,NDF) + \frac{1}{2}v^b(S,A) )</td>
</tr>
<tr>
<td>NDF</td>
<td>[NDIF→s, I→b]</td>
<td>Supplier: ( \frac{1}{2}v'(s,NDIF) + \frac{1}{2}v'(S,A) )</td>
</tr>
<tr>
<td></td>
<td>[NDIF→b, I→s]</td>
<td>Buyer: ( \frac{1}{2}v^b(b,NDIF) + \frac{1}{2}v^b(S,A) )</td>
</tr>
<tr>
<td>NDF</td>
<td>[NDPF→s]</td>
<td>Supplier: ( \frac{1}{2}v'(s,NDPF) + \frac{1}{2}v'(S,A) )</td>
</tr>
<tr>
<td></td>
<td>[NDPF→b]</td>
<td>Buyer: ( \frac{1}{2}v^b(b,NDPF) + \frac{1}{2}v^b(S,A) )</td>
</tr>
<tr>
<td>NDF</td>
<td>[NDPIF→s]</td>
<td>Supplier: ( \frac{1}{2}v'(s,NDPIF) + \frac{1}{2}v'(S,A) )</td>
</tr>
<tr>
<td></td>
<td>[NDPIF→b]</td>
<td>Buyer: ( \frac{1}{2}v^b(b,NDPIF) + \frac{1}{2}v^b(S,A) )</td>
</tr>
<tr>
<td>NDF</td>
<td>[NDPIF→sb]</td>
<td>Supplier: ( \frac{1}{2}v'(s,NDPIF) + \frac{1}{2}v'(S,A) )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Buyer: ( \frac{1}{2}v^b(b,NDPIF) + \frac{1}{2}v^b(S,A) )</td>
</tr>
</tbody>
</table>

**Note:** Due to the equal share voting rule (i.e., 50% of vote for each participant), whenever some of the assets are jointly owned, both participants are required to control the assets. There are twelve additional ownership structures, but each of them is equivalent to one of the above structures in terms of the first order condition. Hence, each is omitted.

In Table 7, we use the notation \([ASSET→participant, …]\) for ownership structures. For example, \([NDF→s, IP→sb]\) represents an ownership structure in which \(N, D,\) and \(F\) are owned by the supplier, and \(I\) and \(P\) are jointly owned by both participants. We say that an ownership structure is **integrated** if all the assets are owned together (e.g., \([NDIF→s]\)) and **non-integrated** if ownership is divided among participants (e.g., \([NDF→s, IP→b]\)). For each ownership structure, we calculate the participants’ FOCs.

Notice that we consider **all** of the five assets in each ownership structure even though some of the feasible sets of assets do not contain all the assets (e.g., \(NDF\)). This is due to positive marginal network externalities: the marginal returns (weakly) increase with more assets. For example, consider ownership structure \([NDF→s, IP→b]\). Although \(I\) and \(P\) alone cannot create marginal return, the grand coalition’s marginal return is greater when it owns all the assets than when it owns \(N, D,\) and \(F\) only.

We can see that joint ownership of all the assets (i.e., \([NDPIF→sb]\)) is dominated by all the other cases. Then, because \(I\) and \(P\) are idiosyncratic to the buyer, they do not contribute to the supplier’s marginal return. That is, \(v'(s,NDF) = v'(s,NDIF) = v'(s,NDPF) = v'(s,A)\). Therefore, ownership
structures \([NDF\rightarrow s, IP\rightarrow b], [NDIF\rightarrow s, P\rightarrow b], [NDPF\rightarrow s, I\rightarrow b]\), and \([NDIPF\rightarrow s]\) are equivalent in terms of the participants’ FOCs.

Due to positive marginal network externalities, \([NDF\rightarrow b, IP\rightarrow s]\) is dominated by \([NDIF\rightarrow b, P\rightarrow s]\) and \([NDPF\rightarrow b, I\rightarrow s]\), and each of them, in turn, is dominated by \([NDIPF\rightarrow b]\). Note that we have used the results that only four sets of assets create positive marginal return on investment: \(v'(S,I) = v'(S,P) = v'(S,IP) = v'(S,\emptyset) = 0\). Finally, we compare the participants’ FOCs for \([NDIPF\rightarrow s]\) (or any of the three equivalent structures) and \([NDIPF\rightarrow b]\) to determine the optimal ownership structure. However, because of the term \(\frac{1}{2}v'(s,A)\) in the former and \(\frac{1}{2}v'(b,A)\) in the latter, there is no clear dominance relationship between the two ownership structures. If we compare these two structures with \([NDIPF\rightarrow sb]\), in \([NDIPF\rightarrow s]\) the supplier’s incentives for investment are stronger while those of the buyer remain the same. In contrast, in \([NDIPF\rightarrow b]\), the buyer has stronger incentives while the supplier’s incentives do not change. Therefore, roughly speaking, if it is more important to increase the buyer’s incentives for non-contractible investment relative to those of the supplier, then sole ownership by the buyer (i.e., \([NDIPF\rightarrow b]\)) will be optimal, whereas if it is more important to increase the supplier’s incentives, then any ownership structure in which the supplier owns \(N, D, F\) will be optimal.

However, because the optimal ownership structure maximizes overall social surplus, to precisely determine which one is optimal, we have to compare the overall surplus under the two ownership structures. In other words, we need to compare the increase in the total surplus due to the stronger incentives of one participant (i.e., supplier in \([NDIPF\rightarrow s]\) and buyer in \([NDIPF\rightarrow b]\)) in each case. Unfortunately, without specific functional forms for \(v(\cdot)\) and \(C(\cdot)\), we cannot compare the total surplus. Note that we have assumed an equal share voting rule (50% of vote for each participant) in the above analysis. In Appendix C, we analyze an unequal share voting rule case to compare the results.

4.3. Extending Analysis of VMI By Incorporating a Third Party

The role of third parties in business relationships has become more important due to increases in outsourcing. So we incorporate a third party in our model and analyze how it affects optimal ownership.

Analyzing Determinants. In addition to the relationships among VMI assets and participants that we identified in the two-player case, we now include a third party (denoted \(t\)) that has the sole expertise for managing the network/EDI asset \((N)\) and so \(t\) is indispensable to \(N\). We can represent this as:

\[v^j(S,A) = v^j(S,A \setminus \{N\}), j \in \{s,b\} \text{ if } t \notin S.\]

This means that if the supplier \((s)\) or the buyer \((b)\) is in a coalition that does not include the third party \((t)\), the network/EDI asset \((N)\) has no effect on their marginal return to investment. Further, because \(N\) is essential to both \(s\) and \(b\), they cannot create positive marginal return without \(t\) in the coalition (e.g., \(v^s(s,NDPIF) = v^s(s,DPPIF) = 0\)).

Identifying the Feasible Sets of Assets. Because the characteristics of the assets and the participants
shown in Table 6 do not change (except for the indispensability of $t$ to $N$ mentioned above), we have the same feasible sets of assets: \{N,D,F\}, \{N,D,I,F\}, \{N,D,P,F\}, \{N,D,I,P,F\}.

**Analyzing Ownership Structures.** With three players, we have more ownership structures to consider. There are three sole ownership structures: sole ownership by the supplier, sole ownership by the buyer, and sole ownership by the third party. Also, we have four joint ownership structures: buyer-supplier, buyer-third party, supplier-third party, and buyer-supplier-third party.

With four feasible sets of assets and seven basic ownership structures, there are 133 possible ownership structures (42 possible ownership structures for each of $NDF$ (and $IP$), $NDIF$ (and $P$), and $NDPF$ (and $I$), and seven additional ownership structures for $NDIPF$). From the two-player case (Table 7), we can see that the three non-integrated ownership structures (i.e., $NDF$, $NDIF$, and $NDPF$) are almost identical except for the buyer’s FOCs. Thus, we first analyze the possible ownership structures for $NDF$ (and $IP$) and then will see if we can generalize the findings to the other two sets of assets. All possible ownership structures for $NDF$ and $IP$ are shown in Table 8. We also included integrated ownership structures (i.e., $NDIPF$) for comparison.

The results of analyzing the FOCs of each ownership structure in Table 8 are provided in Table 11. (See Appendix D for the table.) We considered two types of rules, a consensus rule and a majority rule, wherever some assets are jointly owned (Bakos and Nault, 1997). *Consensus rule* means that all three participants must cooperate to control the assets. *Majority rule* means that a majority of participants (at least two in this case) is required to control the assets.

We found the following from the comparison of ownership structures.\(^4\) First, integrated ownership structures (i.e., sole or joint ownership of $NDIPF$) weakly dominate non-integrated ownership structures. For example, $[NDIPF\rightarrow b]$ weakly dominates $[NDF\rightarrow b, IP\rightarrow s]$, $[NDF\rightarrow b, IP\rightarrow t]$, $[NDF\rightarrow b, IP\rightarrow bt]$, and so on. By the same token, $[NDIPF\rightarrow t]$ weakly dominates $[NDF\rightarrow t, IP\rightarrow s]$, $[NDF\rightarrow t, IP\rightarrow b]$, $[NDF\rightarrow t, IP\rightarrow st]$ and so on. As with the two-player case, this is because of positive marginal network externalities. In other words, the marginal returns increase with more assets, and therefore the participants’ marginal returns will be greatest when all the assets are together. Second, whenever some of the assets are jointly owned by the three players (e.g., $[NDF\rightarrow s, IP\rightarrow sbt]$), majority rule outperforms the consensus rule. For example, in $[NDF\rightarrow t, IP\rightarrow sbt]$ the participants’ FOCs (and hence their investment incentives) are greater under majority rule than consensus rule. This is consistent with Bakos and Nault’s result that asset ownership based on consensus rule is undesirable.

Third, ownership structure $[NDIPF\rightarrow t]$ (i.e., sole ownership of $NDIPF$ by the third party) is optimal in the three-player case. (See Table 9.) Why? Because we assume the third party is indispensable to $N$.

---

\(^4\) We can generalize these findings to the other two non-integrated ownership structures (i.e., $NDIF$ and $NDPF$) because we show that integrated ownership dominates non-integrated ownership.
which, in turn, is essential to the buyer and the supplier. This means that the marginal return to any coalition without the third party is zero. Both the supplier and the buyer need $N$ to create value, but, at the same time, that cannot happen without the third party. As a result, it is optimal to give the ownership of $N$ (and all the other assets because of the positive externalities) to the third party so that whenever the supplier and the buyer are in a coalition with the third party, the coalition controls $N$. This ownership structure gives the third party close-to-first-best incentives.

Table 8. Possible Ownership Structures for $NDF$ and $IP$

<table>
<thead>
<tr>
<th>Sole Ownership of $NDF$</th>
<th>Joint Ownership of $NDF$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier ($s$)</td>
<td>Buyer ($b$)</td>
</tr>
<tr>
<td>$[NDF\rightarrow s, IP\rightarrow b]$</td>
<td>$[NDF\rightarrow b, IP\rightarrow s]$</td>
</tr>
<tr>
<td>$[NDF\rightarrow s, IP\rightarrow t]$</td>
<td>$[NDF\rightarrow b, IP\rightarrow t]$</td>
</tr>
<tr>
<td>$[NDF\rightarrow s, IP\rightarrow sb]$</td>
<td>$[NDF\rightarrow b, IP\rightarrow sb]$</td>
</tr>
<tr>
<td>$[NDF\rightarrow s, IP\rightarrow st]$</td>
<td>$[NDF\rightarrow b, IP\rightarrow st]$</td>
</tr>
<tr>
<td>$[NDF\rightarrow s, IP\rightarrow bt]$</td>
<td>$[NDF\rightarrow b, IP\rightarrow bt]$</td>
</tr>
<tr>
<td>$[NDIPF\rightarrow s]$</td>
<td>$[NDIPF\rightarrow b]$</td>
</tr>
</tbody>
</table>

Note: Integrated ownership structures (i.e., NDIPF) have been included in the last row for comparison.

Table 9. Optimal Ownership Structures for the Three-Player Case

<table>
<thead>
<tr>
<th>Structure</th>
<th>Supplier</th>
<th>First Order Conditions</th>
<th>Buyer</th>
<th>Third-party</th>
</tr>
</thead>
<tbody>
<tr>
<td>$[NDF\rightarrow t, IP\rightarrow b]$</td>
<td>$\frac{1}{6} v^f(st, NDF) + \frac{2}{3} v^f(S, A)$</td>
<td>$\frac{1}{6} v^f(bt, A) + \frac{1}{3} v^f(S, A)$</td>
<td>$\frac{1}{6} v^f(t, NDF) + \frac{1}{3} v^f(ts, NDF) + \frac{1}{6} v^f(tb, A) + \frac{1}{3} v^f(S, A)$</td>
<td></td>
</tr>
<tr>
<td>$[NDF\rightarrow t, IP\rightarrow bt]$</td>
<td>$\frac{1}{6} v^f(st, NDF) + \frac{1}{3} v^f(S, A)$</td>
<td>$\frac{1}{6} v^f(bt, A) + \frac{1}{3} v^f(S, A)$</td>
<td>$\frac{1}{6} v^f(t, NDF) + \frac{1}{3} v^f(ts, NDF) + \frac{1}{6} v^f(tb, A) + \frac{1}{3} v^f(S, A)$</td>
<td></td>
</tr>
<tr>
<td>$[NDIPF\rightarrow t]$ (majority)</td>
<td>$\frac{1}{6} v^f(st, A) + \frac{1}{3} v^f(S, A)$</td>
<td>$\frac{1}{6} v^f(bt, A) + \frac{1}{3} v^f(S, A)$</td>
<td>$\frac{1}{6} v^f(t, A) + \frac{1}{3} v^f(ts, A) + \frac{1}{6} v^f(tb, A) + \frac{1}{3} v^f(S, A)$</td>
<td></td>
</tr>
</tbody>
</table>

Note: These four ownership structures are equivalent because $I$ and $P$ do not contribute to the marginal return of the supplier and the third party.

Finally, there are three ownership structures that perform as well as $[NDIPF\rightarrow t]$ in terms of the FOCs: $[NDF\rightarrow t, IP\rightarrow b]$, $[NDF\rightarrow t, IP\rightarrow bt]$, and $[NDF\rightarrow t, IP\rightarrow sbt]$ with the majority rule. This means that the optimal ownership structures are such that the third party who is indispensable to an essential asset ($N$) controls the most important assets (i.e., $NDF$), and the buyer can control $I$ and $P$ that are idiosyncratic to the buyer whenever the buyer is in the same coalition with the third party. This is because $I$ and $P$
contribute only to the buyer’s marginal return.

5. DISCUSSION AND CONCLUSION
5.1. Results and Implications

First, our results are generally consistent with the propositions of prior research. One of Hart and Moore’s propositions says that strictly complementary assets should be owned together. In our case, the data \(D\) and forecasting software \(F\) are complementary and they are owned together in the optimal ownership structures discussed above. Also, one of Bakos and Nault’s propositions states that if one or more assets are essential to all participants \(N\) and \(D\) in our example), then all the assets should be owned together. Our results indicate that it is optimal for all the assets to be owned by a single participant. We showed that when a participant (the third party in the three-player case) is indispensable to an essential asset \(N\), it is optimal to give the participant the ownership of all the assets. We also showed that majority rule is more desirable than consensus rule for joint ownership of assets by all three players, which is consistent with Bakos and Nault’s result.

Second, some of our findings go beyond the propositions from prior studies and provide additional insights. Another of Hart and Moore’s propositions says that if an asset is idiosyncratic to a participant, then the participant should own the asset. Our result in the two-player case suggests that as long as the supplier’s investment is more important relative to that of the buyer, it does not matter who owns the buyer’s inventory management system \(I\) and POS system \(P\) even though they are idiosyncratic to the buyer. When there are assets essential to all participants, i.e., the network/EDI \(N\) and the data \(D\), \(I\) and \(P\) cannot contribute to the buyer’s marginal benefit without the essential assets. So some determinants may override others. Essentiality overrides idiosyncraticity in our VMI example. If we weaken the essentiality condition by assuming that \(I\) and \(P\) alone can contribute to the buyer’s marginal return (i.e., \(v^b(b, IP) > 0\)) in Table 7, then \([NDF\rightarrow s, IP\rightarrow b]\), in which the buyer does own \(I\) and \(P\), will be optimal when the supplier’s investment is more important. (\([NDF\rightarrow s, IP\rightarrow b]\) will dominate \([NDIF\rightarrow s, P\rightarrow b]\), \([NDPF\rightarrow s, I\rightarrow b]\), \([NDIPF\rightarrow s]\), and \([NDIPF\rightarrow b]\).)

Third, and most important, we showed that in addition to those optimal ownership structures suggested by prior studies, there are other ownership structures that can perform as well. For example, although the sole ownership of all the assets by the third party is optimal in the three-player case, it is equally optimal to give the buyer the ownership of the assets idiosyncratic to the buyer (i.e., inventory management system and POS) while letting the third party control the rest of the assets. This is important because when giving ownership of all IOS assets to the third party is infeasible or impractical (as is true with VMI because giving the third party the ownership of the buyer’s internal systems is not common), the firms can achieve the same level of efficiency by splitting the ownership as described above.
Finally, we found that different determinants are used at different stages of analyzing ownership structures. We used complementarities and essentiality conditions to identify the feasible sets of assets that create positive marginal benefit, whereas we used idiosyncraticity, indispensability, and relative importance of investment to rank the ownership structures and to determine which is optimal.

5.2. On Relative Importance

The optimal ownership structure for the two-player VMI case depends on whose non-contractible investments are more important. The construct of relative importance with respect to non-contractible investments has been mentioned in the incomplete contracts literature as a key determinant of the optimal ownership structure. However, although Hart and Moore’s interpretation of relative importance for non-contractible investments offers a compelling argument, they failed to create a construct that can be applied in a variety of real world contexts. As an example, consider one of their core propositions: if only one participant makes an investment, then that participant should own all the assets. Because this proposition deals with an extreme case where only one participant’s investment decision is important, it is not applicable when there are multiple participants making investments, as is true for our VMI case.

As we defined in Section 4.2, the supplier’s investments are relatively more important than the buyer’s if the supplier’s investments make a greater marginal contribution for the value of the coalition to which the supplier belongs. We argue that the most critical source of relative importance is the difference in the participants’ “specific knowledge” which is not transferable as per Jensen and Meckling (1992). When one participant possesses knowledge specific to an asset and this knowledge is important in creating value for the business relationship, it is optimal to give that participant ownership of the asset because the knowledgeable participant’s investment is more valuable than that of the other participant. Thus, the more knowledgeable participant has greater incentives to invest when owning the asset.

Woodruff (2002) provides a good example of this in a recent study on vertical integration between manufacturers and retailers in the Mexican footwear industry. He found that when fashion changes are fast, the manager’s knowledge of clients’ tastes at the retail store level become more valuable. This tends to make the manager’s ownership of the retail store more valuable (and possibly optimal) relative to the manufacturer’s ownership. As Woodruff (2000, p. 1208) puts it, “… proper matching of store inventory to demand […] depends more heavily on the retailer’s knowledge. So the value [of] the extra investment made by the retailer increases as the rate of fashion change increases.”

In our VMI example, the supplier has specific knowledge and skills about how to forecast demand because it is one the supplier’s routine tasks. Additionally, it is important to integrate the forecasting system with the supplier’s order management system to make sure that the replenishment orders are placed in a timely manner. So the supplier’s investments are more important in creating joint value relative to the buyer’s investments. However, if consumer demand is not stable over time (because tastes
change quickly, for example), then the supplier may not accurately forecast demand based on historical data. In this case, the buyer’s specific knowledge of consumers’ changing tastes (which is hard to transfer) becomes crucial in forecasting future demand. Therefore, the buyer’s investment will be more important, and it will be optimal to give the buyer the ownership of the assets.

Brynjolfsson’s analysis of a non-contractible “information asset” or specific knowledge provides additional insights into how we should think about relative importance and its relationship with indispensability. He argues that if a participant has specific knowledge essential to the productivity of a physical asset, then the participant is indispensable to the physical asset, and it is optimal to give ownership of the physical asset to the participant. The indispensability of a participant stems from the strict complementarities between the participant’s specific knowledge and the physical asset. Now, consider a situation where each of the two participants has specific knowledge that is not completely essential to the productivity of the physical asset (i.e., the specific knowledge and the physical asset are not completely complementary). In this case, to determine the optimal ownership structure, we have to compare whose specific knowledge has a greater impact on the productivity of the physical asset. Moreover, if we interpret participants’ investments as investments in knowledge, this requires comparing whose investment in knowledge has a greater impact on the productivity of the physical asset. So the relative importance of a participant’s investment depends on how efficient the investment in the participant’s specific knowledge is and how complementary the knowledge and the physical asset are.

In addition to specific knowledge, there can be other sources of relative importance. The relative size of the firm is a possible source because larger firms tend to benefit from economies of scale by using the same or similar system assets in their relationships with a number of business partners. Related to this, a firm’s ability to create network externalities can influence the relative importance of investments; the greater a firm’s “network” the more value it can create from investment for the business relationship. Also, the effectiveness of management or “management productivity” (Strassmann, 1990) can affect firms’ return on investment. In addition to these sources that are internal to firms, there can be some external factors that affect whose investments can create more value for the relationship. For example, regulations can restrict some firms’ investment activities. So it may be optimal to give asset ownership to the participant with operating authority to make appropriate IT investments.

5.3. Conclusions

In this paper, we revisited the theory of incomplete contracts to examine how it can provide answers to issues that require new managerial insights: how to increase firms’ incentives to invest in IOS and share value in an efficient way. We believe that creating the optimal ownership structure can provide answers.

To make the theory more accessible and leveragable, we suggested a framework for analyzing the
ownership structure of IOS assets and applied it to an illustrative IOS context. We believe this framework will help managers make decisions regarding who should own what assets when multiple firms engage in IOS implementation to appropriate maximum value from their system investments. It will also help IS researchers better understand the mechanisms by which optimal ownership structure is determined.

To the best of our knowledge, this study is the first attempt to apply the Hart and Moore framework to a real world e-procurement IOS context that involves multiple participants and multiple assets. We analyzed a two-player case and extended the analysis by adding a third party who plays a crucial role in the relationship between the buyer and supplier. We closed the loop by comparing our results with the propositions from previous studies. In general, our results are consistent with the prior studies’ propositions. Additionally, some of our results go beyond those propositions and provide further guidance on the ownership structure decision (e.g., ownership of idiosyncratic assets in the presence of essential assets). Our most important result is that in addition to the optimal ownership structures suggested by prior studies, there are other ownership structures that can perform as well. This has an important implication for firms because they can flexibly choose another ownership structure of their IOS while achieving the same level of efficiency if one is impractical or infeasible in their industry sector or business process design context.

We also showed that relative importance plays a key role in breaking ties and determining which of the two participants should own the IOS assets. To make the relative importance construct more applicable in an applied setting, we carefully defined it and stated the factors affecting whose investment is more important. We argue that the most critical source of relative importance is the difference in participants’ non-transferable specific knowledge. We believe that this perspective will generalize well.

Finally, we developed a new typology of IOS that can be useful for research on IOS and B2B e-commerce. Traditional IOS typologies have been limited to exchange relationships between suppliers and buyers within a value chain. In contrast, with configuration in value chain as one of the two dimensions, our typology covers a broader scope of IOSs, including those that support horizontal relationships among firms across value chains or among competitors within a value chain. In this study, we applied our analysis framework to vertical-bilateral IOSs, the simplest of the four types of IOSs. Future research should focus on analyzing more complex cases, such as horizontal-multilateral and vertical-multilateral IOSs.

REFERENCES


APPENDIX A. THE SHAPLEY VALUE

The mechanism for dividing *ex post* surplus in the theory of incomplete contracts comes from cooperative game theory (Myerson, 1991). In cooperative game theory, the Nash bargaining solution is used for two-person bargaining games. Nash started from a set of axioms that the solution must satisfy and proved that there is a unique solution for two-person bargaining games. However, for multi-person bargaining games, Nash bargaining is not appropriate because it ignores the possibility of cooperation among subsets or *coalitions* of participants.

Shapley approached this problem in an axiomatic way. He first defined three properties that a solution concept should satisfy, and then characterized a unique solution concept satisfying all the properties called the “Shapley value.” It permits the division of the *ex post* surplus created from the asset.

The basic concept of the Shapley value is to *give each participant an amount equal to that participant’s expected marginal contribution*, that is, the incremental contribution to each potential coalition multiplied by the probability of each such coalition occurring during the formation of the grand coalition. Suppose that \( I \) persons are lined up in a random order in the hallway and that we are forming the grand coalition (i.e., the coalition that contains all the participants) by admitting into a room one person at a time. If a person \( i \) enters the room and finds \( s – 1 \) other people there, then person \( i \) is considered to belong to coalition \( S \) consisting of \( s \) persons. If we assume every ordering of persons is equally likely, the probability that the person is placed \( s^{th} \) from the end is \( (s – 1)! (I – s)!/I! \). This also is the probability of person \( i \) joining the coalition \( S \). If we define \( v(S) \) as the value created by the coalition \( S \), the person’s incremental contribution is \( v(S) – v(S\setminus\{i\}) \). Finally, the Shapley value for person \( i \) can be obtained by summing the product of the probability and the incremental contribution over every possible coalition the person may belong to:

\[
\sum_{S \subseteq S} \frac{(s – 1)! (I – s)!}{I!} (v(S) – v(S\setminus\{i\})).
\]
APPENDIX B. ASSUMPTIONS IN THE HART AND MOORE (1990) FRAMEWORK

Hart and Moore’s (1990) model makes following six key assumptions. The first states that the cost of investment is an increasing and convex function:

- **Assumption 1 (Investment Cost Function).** \( C_i(x_i) \geq 0 \) and \( C_i(0) = 0 \). \( C_i \) is twice differentiable. If \( x_i > 0 \), then \( C'_i(x_i) > 0 \) and \( C''_i(x_i) > 0 \) for \( x_i \in (0, \bar{x}_i) \), with \( \lim_{x_i \to 0} C'_i(x_i) = 0 \) and \( \lim_{x_i \to \bar{x}_i} C'_i(x_i) = \infty \).

The second states that a non-empty coalition creates non-negative value, and that the participants’ non-contractible investments create non-decreasing but diminishing returns.

- **Assumption 2 (Value Function).** \( v(S, A | x) \geq 0 \) and \( v(\emptyset, A | x) = 0 \). \( v(S, A | x) \) is twice differentiable in \( x \). If \( \bar{x}_i > 0 \), then \( v'(S, A | x) \geq 0 \) for \( x_i \in (0, \bar{x}_i) \). \( v(S, A | x) \) is concave in \( x \).

The third states that a participant’s marginal investment cannot contribute to the value of a coalition to which the participant does not belong.

- **Assumption 3 (Non-Participation).** \( v'(S, A | x) = 0 \) if \( i \notin S \).

The fourth creates the formal basis for value-generating complementarities among the marginal investments by different participants.

- **Assumption 4 (Investment Externalities).** \( \frac{\partial}{\partial x_j} v'(S, A | x) \geq 0 \) for all \( j \neq i \).

The fifth assumption states the value of a coalition is greater than the sum of the individual levels of value created by subsets of participants and assets of the coalition. This is also referred to as superadditivity.

- **Assumption 5 (Network Externalities).** For all subsets \( S' \subseteq S, A' \subseteq A \), \( v(S, A | x) \geq v(S', A' | x) + v(S \setminus S', A \setminus A' | x) \).

The final assumption states that the marginal return on investment by a participant increases with the number of participants and assets in the coalition. This is also referred to as marginal superadditivity.

- **Assumption 6 (Marginal Network Externalities).** For all subsets \( S' \subseteq S, A' \subseteq A \), \( v'(S, A | x) \geq v'(S', A' | x) \).
APPENDIX C. TWO-PLAYER CASE UNDER THE UNEQUAL SHARE VOTING RULE

Because the decision rules associated with joint ownership may affect the outcomes of the analysis, we consider the case of an unequal share voting rule here. Under an equal share voting rule, a coalition can control certain assets only when both participants are in the coalition, whereas under an unequal share voting rule, any coalition that contains the participant who has a larger share of the vote (e.g., 51%) can own the assets. Because we have only two participants in the VMI case, the unequal share voting rule in joint ownership means that the participant who has a larger share of the vote ends up controlling the assets that are supposed to be jointly owned. Therefore, each ownership structure degenerates into one of the structures that we have considered under the equal share voting rule. However, if we have more than two participants, the non-equal share voting rule in joint ownership will lead to different outcomes.

There are thirteen ownership structures in which some of the assets are jointly owned as shown in Table 10. We do not consider the ownership structures where no asset is jointly owned because they are not affected by voting rule. Each ownership structure in Table 10 degenerates into one of the first eight cases in Table 7. (See Table 7 and 10.)

Table 10. Comparison of Joint Ownership Structures with Unequal Share Voting Rule

<table>
<thead>
<tr>
<th>SET OF ASSETS</th>
<th>ASSET OWNERSHIP STRUCTURE</th>
<th>EQUIVALENT STRUCTURE IN EQUAL SHARE VOTING RULE CASE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>When Supplier Has 51% Vote</td>
</tr>
<tr>
<td>NDF</td>
<td>[NDF→s, IP→sb]</td>
<td>[NDIPF→s]</td>
</tr>
<tr>
<td></td>
<td>[NDF→b, IP→sb]</td>
<td>[NDIPF→s]</td>
</tr>
<tr>
<td></td>
<td>[NDF→sb, IP→s]</td>
<td>[NDIPF→s]</td>
</tr>
<tr>
<td></td>
<td>[NDF→sb, IP→b]</td>
<td>[NDF→s, IP→b]</td>
</tr>
<tr>
<td></td>
<td>[NDIF→s, P→sb]</td>
<td>[NDIPF→s]</td>
</tr>
<tr>
<td></td>
<td>[NDIF→b, P→sb]</td>
<td>[NDIPF→s]</td>
</tr>
<tr>
<td></td>
<td>[NDIF→sb, P→s]</td>
<td>[NDIPF→s]</td>
</tr>
<tr>
<td></td>
<td>[NDIF→sb, P→b]</td>
<td>[NDIF→s, P→b]</td>
</tr>
<tr>
<td></td>
<td>[NDPF→s, I→sb]</td>
<td>[NDIPF→s]</td>
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<tr>
<td></td>
<td>[NDPF→b, I→sb]</td>
<td>[NDIPF→s]</td>
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<td></td>
<td>[NDPF→sb, I→s]</td>
<td>[NDIPF→s]</td>
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<tr>
<td></td>
<td>[NDPF→sb, I→b]</td>
<td>[NDPF→s, I→b]</td>
</tr>
<tr>
<td></td>
<td>[NDPIF→s]</td>
<td>[NDIPF→s]</td>
</tr>
</tbody>
</table>

Note: With two players, each ownership structure under the unequal share voting rule degenerates into one of the ownership structures that we analyzed under the equal share voting rule. (See Table 7.)
APPENDIX D. OWNERSHIP STRUCTURE ANALYSIS IN THE THREE-PLAYER CASE

The results of analyzing the participants’ FOCs of the different ownership structures in the three-player case are shown in Table 11. Some of the ownership structures are just mirror images of other structures and have been omitted. For example, \([NDF→ b, IP→ s]\) is a mirror image of \([NDF→ s, IP→ b]\) and so on. These two are not different in terms of the incentives of the third-party who is indispensable to an asset \((N)\) that is essential to both supplier and buyer. Some ownership structures with consensus rule have also been omitted because we have already shown that majority rule always outperforms consensus rule in a given ownership structure. The optimal ownership structures that maximize participants’ investment incentives are highlighted.

Table 11. Comparison of First Order Conditions for Ownership Structures in Three-Player Case

<table>
<thead>
<tr>
<th>Structure</th>
<th>Supplier ((s))</th>
<th>Buyer ((b))</th>
<th>Third Party ((t))</th>
</tr>
</thead>
<tbody>
<tr>
<td>([NDF→ s, IP→ b])</td>
<td>(\frac{1}{6} v^s(st, NDF) + \frac{1}{3} v^b(S, A))</td>
<td>(\frac{1}{3} v^b(S, A))</td>
<td>(\frac{1}{6} v^t(ts, NDF) + \frac{1}{3} v^s(S, A))</td>
</tr>
<tr>
<td>([NDF→ s, IP→ s])</td>
<td>(\frac{1}{6} v^s(st, NDF) + \frac{1}{3} v^s(S, A))</td>
<td>(\frac{1}{3} v^b(S, A))</td>
<td>(\frac{1}{6} v^t(ts, NDF) + \frac{1}{3} v^s(S, A))</td>
</tr>
<tr>
<td>([NDF→ s, IP→ s])</td>
<td>(\frac{1}{6} v^s(st, NDF) + \frac{1}{3} v^s(S, A))</td>
<td>(\frac{1}{3} v^b(S, A))</td>
<td>(\frac{1}{6} v^t(ts, NDF) + \frac{1}{3} v^s(S, A))</td>
</tr>
<tr>
<td>([NDF→ s, IP→ s])</td>
<td>(\frac{1}{6} v^s(st, NDF) + \frac{1}{3} v^s(S, A))</td>
<td>(\frac{1}{3} v^b(S, A))</td>
<td>(\frac{1}{6} v^t(ts, NDF) + \frac{1}{3} v^s(S, A))</td>
</tr>
<tr>
<td>([NDF→ s, IP→ s])</td>
<td>(\frac{1}{6} v^s(st, NDF) + \frac{1}{3} v^s(S, A))</td>
<td>(\frac{1}{3} v^b(S, A))</td>
<td>(\frac{1}{6} v^t(ts, NDF) + \frac{1}{3} v^s(S, A))</td>
</tr>
<tr>
<td>([NDF→ s, IP→ s])</td>
<td>(\frac{1}{6} v^s(st, NDF) + \frac{1}{3} v^s(S, A))</td>
<td>(\frac{1}{3} v^b(S, A))</td>
<td>(\frac{1}{6} v^t(ts, NDF) + \frac{1}{3} v^s(S, A))</td>
</tr>
<tr>
<td>([NDF→ s, IP→ s])</td>
<td>(\frac{1}{6} v^s(st, NDF) + \frac{1}{3} v^s(S, A))</td>
<td>(\frac{1}{3} v^b(S, A))</td>
<td>(\frac{1}{6} v^t(ts, NDF) + \frac{1}{3} v^s(S, A))</td>
</tr>
<tr>
<td>([NDF→ s, IP→ s])</td>
<td>(\frac{1}{6} v^s(st, NDF) + \frac{1}{3} v^s(S, A))</td>
<td>(\frac{1}{3} v^b(S, A))</td>
<td>(\frac{1}{6} v^t(ts, NDF) + \frac{1}{3} v^s(S, A))</td>
</tr>
</tbody>
</table>

Note: We omitted some ownership structures that are mirror images of other structures. We also omitted some structures with consensus rule because they are dominated by majority rule. The four ownership structures that are highlighted are the optimal ownership structures.
Table 11. Comparison of First Order Conditions for Ownership Structures (continued)

| STRUC- | FIRST ORDER CONDITIONS | Supplier (s) | Buyer (b) | Third Party (t) |
| TURE | | | | |
| [NDF→IP→sh] | | | | |
| (majority) | | | | |
| [NDIPF→t] | | | | |
| | $\frac{1}{6}v'(st, A) + \frac{1}{3}v'(S, A)$ | | $\frac{1}{6}v'(bt, A) + \frac{1}{3}v'(S, A)$ | | $\frac{1}{6}v'(t, A) + \frac{1}{6}v'(ts, A) + \frac{1}{6}v'(tb, A) + \frac{1}{3}v'(S, A)$ |
| [NDF→s] | | | | |
| [IP→s] | | | | |
| ~ [NDF→s] | | | | |
| [IP→sh] | | | | |
| [NDIPF→sbt] | | | | |
| | $\frac{1}{3}v'(S, A)$ | | $\frac{1}{3}v'(S, A)$ | | $\frac{1}{3}v'(S, A)$ |
| [NDF→s] | | | | |
| [IP→s] | | | | |
| [NDIPF→sbt] | | | | |
| | $\frac{1}{3}v'(S, A)$ | | $\frac{1}{3}v'(S, A)$ | | $\frac{1}{3}v'(S, A)$ |
| [NDF→s] | | | | |
| [IP→s] | | | | |
| [NDIPF→sbt] | | | | |
| | $\frac{1}{6}v'(st, A) + \frac{1}{3}v'(S, A)$ | | $\frac{1}{6}v'(bt, A) + \frac{1}{3}v'(S, A)$ | | $\frac{1}{6}v'(t, A) + \frac{1}{6}v'(ts, A) + \frac{1}{6}v'(tb, A) + \frac{1}{3}v'(S, A)$ |
| [NDF→s] | | | | |
| [IP→s] | | | | |
| [NDIPF→sbt] | | | | |
| | $\frac{1}{6}v'(st, A) + \frac{1}{3}v'(S, A)$ | | $\frac{1}{6}v'(bt, A) + \frac{1}{3}v'(S, A)$ | | $\frac{1}{6}v'(t, A) + \frac{1}{6}v'(ts, A) + \frac{1}{6}v'(tb, A) + \frac{1}{3}v'(S, A)$ |
| Note: We omitted some ownership structures that are mirror images of other structures. We also omitted some structures with consensus rule because they are dominated by majority rule. The four ownership structures that are highlighted are the optimal ownership structures.