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Information Technology, Repeated Contracts, and the Number of Suppliers

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Abstract. Many theories address how information technology (IT) affects the number of suppliers and supply chain governance. However, their predictions are at times contradictory and there is relatively little empirical evidence with which to evaluate them. We therefore develop an integrated, multiperiod model of the optimal number of suppliers that combines search and coordination theory, transaction cost economics, and incomplete contracts theory, and we assess our theoretical predictions using a large new data set on the global IT sourcing decisions of 1,355 firms in 12 countries. Our empirical results support three key predictions about trust, IT, and supply base size. First, investments in coordination IT, which reduce search and coordination costs, are correlated with using more suppliers, while use of vendor-specific IT is associated with fewer suppliers. Second, repeated relationships and trust play a major role in supply chain governance. As firms work with fewer suppliers, they also engage in more repeated relationships. At the same time asset specificity and the need to induce relationship-specific investments are correlated not only with fewer suppliers, but also with a larger fraction of repeated relationships. Third, supply chain governance differs in human capital-intensive and physical capital-intensive industries. The correspondence between asset specificity and repetition is strong in physical capital-intensive firms and not significant in human capital-intensive firms, while the correspondence between fewer suppliers and more repeated relationships is strong in human capital-intensive firms but not significant in physical capital-intensive firms. This corroborates the differential implications of human and physical capital for bargaining power, contractual risk, and trust in buyer–supplier relationships.

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1. Introduction

The Apple–Foxconn supply relationship is by now almost legendary. For years Apple relied solely on this single Taiwanese supplier for the production of its iPhones and iPads. In May 2013, however, Apple changed its supplier strategy, expanding its supply base size to include a relatively unknown new supplier called Pegatron. Pundits cited increased product variety, supply relationship dynamics and increased competition from Samsung as reasons for the strategic shift. Yet, despite such ad hoc explanations, managerial theory offers few unified frameworks that can explain these underlying considerations and help managers to analyze supply base size decisions, especially in the context of increased digitization.

In particular, numerous theories address how information technology (IT) may affect supply relationships, providing diverse and at times contradictory predictions about when firms are likely to work with more suppliers (Malone et al. 1987) or fewer suppliers (Bakos and Brynjolfsson 1993a, b) or when they are likely to "move to the middle" (Clemons et al. 1993). At the same time, despite widespread interest in supply chain structure and the role of information technology (IT) in business process outsourcing (Bardhan et al. 2006, Dong et al. 2009), there is little empirical evidence on the role of IT in influencing the number of suppliers and contract repetition. We address both of these gaps by developing an integrated theoretical model that formalizes trade-offs inherent in managing supply base size and contract repetition and by assessing the theoretical predictions of our model using a large new data set on IT supply relationships. In particular, we address three understudied dimensions of this debate.

First, different types of IT are likely to have different implications for supply chain governance. IT can increase the number of suppliers by reducing search costs (Bakos 1997) and by lowering coordination costs, thereby supporting arm's-length market transactions (Malone et al. 1987). At the same time, asset specificity can create lock-in and motivate firms to develop long-term partnerships with suppliers to build trust and motivate relationship-specific investments (Srinivasan et al. 1994, Helper 1995).[1] Vendor-specific IT can support such long-term trust-based relationships by creating dedicated, transparent information exchanges between firms, creating lock-in and dependence (Srinivasan et al. 1994, Iacovou et al. 1995). Prior evidence demonstrates the importance of distinguishing different types of IT when assessing firm performance (Aral and Weill 2007) and suggests that some types of IT, such as enterprise management systems, are associated with greater outsourcing, while others, such as operations management systems, are not (Bardhan et al. 2007). We argue that the same is true in supply chain strategy. Rather than having a unidirectional impact on the number of suppliers, IT's impact on supply base size will depend on whether it reduces search and coordination costs or, alternatively, increases switching costs and the importance of relationship-specific investments.

Second, supply base size (the number of vendors that firms employ on a regular basis) is intimately tied to the degree to which firms engage in long-term repeated relationships with suppliers over time. Despite an increased recognition of the importance of trust and repeated interaction in supply chain partnerships, theoretical models of the optimal number of suppliers still typically consider single-period settings (see Plambeck and Taylor 2006 for an exception that models repetition but does not examine supply base size or IT), and empirical analysis usually ignores the long-term repeated nature of these relationships. Case studies suggest that trust and repeated relationships provide a critical mechanism through which firms create incentives for suppliers to make noncontractible investments (e.g., Helper et al. 2000). Theoretical models of the optimal number of suppliers that do not consider repeated relationships may therefore place too much importance on reductions in supply base size as an incentive mechanism in supply relationships. Considering a multiperiod setting, with repeated relationships that create incentives and trust, can therefore generate more realistic predictions about supply base strategies.

Third, despite significant differences in the extent to which human and nonhuman assets affect bargaining power and suppliers' susceptibility to holdup (Brynjolfsson 1994, Rajan and Zingales 1998), there has been little focus on the role of differences between human capital-intensive and physical capital-intensive industries in shaping supply chain governance, perhaps because the sparse empirical evidence that exists examines manufacturing firms alone. Human and physical capital have different implications for bargaining power, contractual risk and trust in buyer–supplier relationships because human capital cannot be owned while physical capital can. If firms own the assets that complement suppliers' relationship-specific investments, they are likely to have greater ex post bargaining power. Thus, just as different types of IT are likely to have differing impacts on supply chain structure, industry differences, such as human and physical capital intensity, are also likely to affect the relationships among asset specificity, IT, repetition, and supply base size.

We therefore develop an integrated, multiperiod model of the relationship between IT and the optimal number of suppliers that combines search and coordination theory, transaction cost economics, and incomplete contracts theory. Most importantly, it explicitly formalizes the long-term nature of supplier relationships in a repeated setting. We assess predictions from our model using a new data set on the IT sourcing decisions of 1,355 global firms, obtained from a survey we designed for this purpose. As a result, we gain insight into the evolving nature of supplier relationships across industries in the context of global IT sourcing. The data reveal that the vast majority of supplier relationships (83%) involve repeated interaction over time, which highlights the critical importance of modeling supplier governance as a repeated game. The empirical evidence also supports three important theoretical predictions.

First, IT is not a monolith. Different types of IT have different implications for supply chain structure. Investments in technologies that reduce search and coordination costs are correlated with using more suppliers, while vendor-specific IT is associated with lock-in and fewer suppliers. This supports a contingent view of IT and supply chain structure in which firms simultaneously choose supply chain strategies and the specific technologies that support them.

Second, repeated relationships and trust play a key role in supply chain governance. Two results support this conclusion: (a) as firms work with fewer suppliers they also engage in more repeated relationships with those suppliers and (b) asset specificity and the need to induce relationship-specific investments are correlated with fewer suppliers and a larger fraction of repeated relationships.

Third, supply chain governance differs in human capital-intensive and physical capital-intensive industries. Asset specificity has a strong positive association with more repeated relationships in physical capital-intensive industries, but not in human capital-intensive industries. Furthermore, the correspondence between more suppliers and fewer repeated relationships holds in human capital-intensive industries, but not in physical capital-intensive industries. We argue that the differing roles of human capital and physical capital in creating incentives and vulnerability to holdup are likely responsible for this variation: because physical capital is owned by the buyer, suppliers experience a greater risk of holdup in physical capital-intensive industries, motivating buyers in these industries to create supplier incentives and trust through repetition.

Our work extends the literature on the role of IT in supply chain governance by providing an integrated model of the number of suppliers and contract repetition in a multiperiod setting, and by testing IT's impact using a large new multinational, multi-industry data set.[2] By simultaneously examining the fraction of repeated relationships and whether the fraction of repeated relationships is in turn associated with more or fewer suppliers, we address calls in the literature for research to "explicitly evaluate changes in the number of suppliers due to IT use" and "how firms, with the use of IT, adapt the way they govern economic activities in supply chains" (Dedrick et al. 2008, p. 67). This work also provides a unified framework to guide managers in considering IT sourcing relationships, as our empirical results support a more nuanced, contingent view of IT and supply chain governance than has been seen in prior work.

IT procurement is a natural context in which to study supply chain governance as vendor selection, contracting, incentives and fit are critical to sourcing strategies in this setting (Gurbaxani 1996). Prior research has focused almost exclusively on manufacturing and the auto industry in particular (Helper et al. 2000, Helper and Levine 1992, Helper 1991, Cusumano and Takeishi 1991), but it is not obvious that theoretical predictions from these industries apply directly to more high-tech supply relationships such as the supply of IT. We study the role of IT in relationships with IT suppliers because, in contrast to the auto industry, IT represents a more high-tech and potentially less physical capital-intensive materials supply. IT suppliers are more likely to be on the leading edge of knowledge about how to use IT in the supply chain, making changes in this context more likely to foreshadow changes in other industries.

2. Theory and Model Development

2.1. Economic Theories of the Optimal Number of Suppliers

Although markets offer choice and create competition, they also entail significant transaction costs, including the costs of negotiating, monitoring, and preventing malfeasance (Coase 1937; Williamson 1975, 1976). These costs influence the make–buy decision but also extend to selecting the optimal number of suppliers (Bakos and Brynjolfsson 1993a, b). Contracting with a larger number of suppliers typically entails arm's-length relationships with higher risks of malfeasance, while maintaining relationships with a smaller number of trusted suppliers generally lowers the risk of opportunism. The risk of opportunism also increases with asset specificity, since asset specificity makes it more difficult and costly to find an alternative supplier.

Malone et al. (1987) argue that when IT reduces coordination costs it will disproportionately benefit market transactions and enable a move from single-supplier relationships to multiple-supplier relationships. IT reduces the information processing costs associated with the search for market partners and transaction facilitation activities such as contracting, monitoring, and the prevention of malfeasance. Searching a larger pool of suppliers increases the probability of finding the price and product characteristics that best fit firm needs, with search costs proportional to the number of suppliers searched (Salop 1979, Bakos 1997). As IT reduces information processing costs, it should enable firms to search among more suppliers and achieve better fit to their needs at lower cost. The growth of online B2B marketplaces demonstrates this in practice, as firms can search a large number of suppliers and conduct relatively sophisticated due diligence at low cost (Bakos 1991, Zhu 2004, Overby and Jap 2009, Zhu and Zhou 2010). Specific technologies for sharing information with partners and suppliers also reduce communication and coordination costs (Aral et al. 2006). These theories together predict that IT should drive firms to interact with more suppliers by reducing the costs of finding and interacting with them.

Since contracts are not completely verifiable by third parties (Williamson 1975), property rights provide asset owners with residual rights of control, which determine the bargaining power of parties to capture the ex post surplus they create (Grossman and Hart 1986, Hart and Moore 1990). Bargaining power affects the incentives of the relevant parties to make specific, noncontractible, ex ante investments that affect value creation in the relationship. It can therefore be optimal to limit the number of suppliers to create incentives for them to make greater noncontractible investments (Bakos and Brynjolfsson 1993a, b). Mithas et al. (2008) show that incentive costs of noncontractibility can inhibit buyer use of reverse auction supplier markets. Incomplete contracts theory predicts that, as the need for specific noncontractible supplier investments increases, firms should contract with fewer suppliers to give them incentives to make such investments.

However, cooperative behavior typically develops over time. Qualitative analyses of close-knit keiretsu supplier networks in Japan demonstrate that long-term loyalty makes such networks robust to periods of difficulty. Uzzi (1997) and others (e.g., Antonelli 1988, Piore and Sabel 1984) describe the trust that develops over long-term relationships, and case studies of value-added partnerships stress reciprocity benefits that develop between firms over the long term. Helper et al. (2000) note that firms engaged in longer-term relationships also benefit from "learning by monitoring," whereby monitoring a partner's activities and service quality generates organizational and process learning that contributes to the efficiency and quality of the partnership while at the same time reducing opportunism and increasing trust. This evidence indicates that, in situations of economic conflict over noncontractible surplus with longer time horizons, cooperative behavior develops despite selfish individual motives.

Single-period models limit equilibria to what is feasible in a one-shot game. The resulting outcomes have at least three important shortcomings from the firm's perspective. First, while reducing the number of suppliers induces relationship-specific investments, these investments are typically second best as suppliers take into account only the portion of the return on their investment that they can retain in ex post bargaining. Suppliers are therefore likely to severely underinvest. Second, reducing the number of suppliers reduces the expected fit between the firm's needs and suppliers' ability to fill those needs, which in turn reduces the expected economic surplus produced by the relationship. Third, contracting with a smaller number of suppliers reduces the buyer's bargaining power and the share of the ex post surplus they can appropriate. Increased incentives for supplier investment therefore come at a cost of decreased profits and decreased investment incentives for the firm. As a result, in a single-period setting, most firms would likely limit the number of suppliers to increase supplier incentives for relationship-specific investments only in situations where such investments are of critical importance.

On the other hand, in settings with repeated interaction, firms can induce suppliers to make relationship-specific investments via reputation, trust, reciprocity, and loyalty. The set of Nash equilibria significantly expands in repeated games. Any feasible payoff in the stage game can give rise to a subgame perfect equilibrium if each player is sufficiently patient and guaranteed a minimum level of utility (Fudenberg and Maskin 1986). There is a voluminous literature on the emergence of cooperation in multiperiod settings (e.g., Axelrod 1984, Fudenberg et al. 1990), but a key factor enabling this expanded range of outcomes and in particular enabling sustainable cooperative behavior is the possibility of punishment for noncooperating participants. Such punishment can be accomplished through reputational mechanisms (Kreps et al. 1982) but also through the threat of expulsion from the game (Hirshleifer and Rasmusen 1989), both of which depend critically on the ability to observe defection (which in this case is represented by suppliers' underinvestment). Our approach addresses the influence of long-term cooperative behavior on buyer–supplier relationships and the overall importance of trust in these relationships by including considerations of the discounted value of future partnership and the threat of partnership termination in the traditional property rights framework.

2.2. Contributions in the Context of Prior Literature

Although Malone et al. (1987) argue that IT should lower coordination costs and increase the number of suppliers, and Clemons et al. (1993, p. 9) theorize "a move toward long-term relationships with a smaller set of suppliers," current work has not (a) formalized these theories in models, (b) integrated these models into a unified theoretical framework, or (c) tested hypotheses with data. We therefore present a unified model and test the hypotheses implied by that model with a large, multinational, multi-industry data set. Some limited literature has examined repeated interactions in supply chain strategy (e.g., Plambeck and Taylor 2006); however, this literature does not (a) examine supply base size or the number of suppliers and the relationship between supply base size and repetition, (b) test the repeated game theoretical framework with empirical evidence, (c) examine the role of IT, or (d) examine the role of human capital and physical capital, either theoretically or empirically.

Extending Bakos and Brynjolfsson (1993a) into a multiperiod setting addresses the importance of repetition and long-term contracting for creating incentives for supplier investments. This is a novel contribution to the literature on cooperation in multiperiod settings because it enables predictions about the number of vendors firms will use, the amount of supplier investments, and the economic surplus created by the relationship. These advances are not replicated either in the general literature on the emergence of cooperation in multiperiod settings (e.g., Axelrod 1984, Fudenberg et al. 1990) or the single-period literature on the number of vendors and incentives for supplier investment (e.g., Bakos and Brynjolfsson 1993a). The results in prior literature have at least three important shortcomings from the perspective of researchers and managers. First, while reducing the number of suppliers induces relationship-specific investments in single-period settings, these investments are typically second best as suppliers take into account only the portion of the return on their investment that they can retain in ex post bargaining. Suppliers are therefore likely to invest less than the first best level. Second, reducing the number of suppliers reduces the expected fit between the firm's needs and suppliers' ability to fill those needs, which in turn reduces the expected economic surplus produced by the relationship. Third, contracting with a smaller number of suppliers reduces the buyer's bargaining power and the share of the ex post surplus they can appropriate. Increased incentives for supplier investment therefore come at a cost of decreased profits and decreased investment incentives for the firm in a single-period setting. As a result, in a single-period setting, most firms would likely limit the number of suppliers to increase supplier incentives for relationship-specific investments only in situations where such investments are of critical importance. On the other hand, in settings with repeated interaction, firms can induce suppliers to make relationship-specific investments via reputation, trust, reciprocity, and loyalty without unduly limiting the number of suppliers.

We also specifically examine the roles of investments in complementary physical and human capital assets in influencing supply chain governance. This is a central concept in incomplete contracts theory, starting with the founding seminal papers (e.g., Grossman and Hart 1986, Hart and Moore 1990). A literature has developed analyzing human and physical capital, focusing on how their complementarities with other factors of production affect the susceptibility to holdup of economic agents such as firms and their employees. Such issues have been analyzed in the context of information assets (e.g., Brynjolfsson 1994) and more generally in a power-based analysis of firms (e.g., Rajan and Zingales 1998). Although the roles of physical and human assets differ dramatically for property rights-based incentives and the threat of holdup (Brynjolfsson 1994), there has been little focus on the role of differences between human capital-intensive and physical capital-intensive industries in shaping relationships between asset specificity, repeated supplier relationships, and supply base size, perhaps because the sparse empirical evidence that exists examines manufacturing firms in isolation. Human capital and physical capital have different implications for bargaining power, contractual risk, and trust in buyer–supplier relationships. So, just as different types of IT are likely to have differing impacts on supply chain structure, industry differences are also likely to change the relationships between asset specificity, repeated supplier relationships, and supply base size.

The parameter in the model that describes the difference between human and physical capital is the susceptibility to holdup (β). We argue that if the buyer firm employs complementary human (as opposed to physical) assets, suppliers will be less vulnerable to holdup in ex post bargaining for three related reasons, which we develop in the theory. First, when complementary assets to supplier investments are human capital assets, they could plausibly move to a different firm, transferring with them some of the value of the specific supplier investment. Second, human capital-intensive industries require more ex post support, increasing the ex post bargaining power of suppliers. Third, human assets, like expert employees (and thus their knowledge), can be hired away from the buyer by the supplier, requiring firms in physical capital-intensive industries to provide greater assurances to suppliers, in the form of reductions in supply base size and more repeated interactions.

We incorporate these differences into the revised theory and the empirical analysis. We find that supply chain governance differs in human capital-intensive and physical capital-intensive industries. Asset specificity has a strong positive association with more repeated relationships in physical capital-intensive industries, but not in human capital-intensive industries. Furthermore, the correspondence between more suppliers and fewer repeated relationships holds in human capital-intensive industries, but not in physical capital-intensive industries. The differing roles of human capital and physical capital in creating incentives and vulnerability to holdup are likely responsible for this variation. Specifically, because physical capital is owned by the buyer, suppliers experience a greater risk of holdup in physical capital-intensive industries, motivating buyers in these industries to foster supplier incentives and trust through repetition. These results align with incomplete contracts theory and are important new findings for how bargaining over residual value plays out in different types of industries. These findings are thus not only important to managers making decisions about supply chain strategy and IT procurement, but also for academics attempting to apply the Grossman–Hart–Moore (GHM) theory in real-world empirical settings. Table 1 summarizes related work and frames our contributions in the context of prior studies.

2.3. An Integrated Model of the Optimal Number of Suppliers

2.3.1. Suppliers and Fit. We model a multiperiod setting with a firm and N potential suppliers. The suppliers are heterogeneous, which we model by having them occupy differentiated positions in a space of product characteristics and skills. The firm's needs in each period correspond to a point in the same space, with the distance x from each supplier offering representing the "fit" of the corresponding supplier; a smaller x indicates better fit and thus a lower fit cost (e.g., because of higher ability to help the firm fill its demand). Specifically, the fit cost for a supplier offering at a distance x equals the decrease in the firm's payoffs from adopting that offering compared to adopting an offering with perfect fit, which would be at distance 0. We assume that firm needs and supplier offerings change in each period and that the N suppliers are equally attractive ex ante but differ in their ex post fit, which can be assessed only after the period's demand is realized.[3] In each period each supplier's distance is drawn from a probability distribution ϕ and the importance of fit is indicated by a parameter α that takes values in a bounded interval $[\underline{\alpha}, \bar{\alpha}]$; a higher α indicates

Table 1. Examples of Related Work in Previous Literature

Study	Focus	Theoretical perspectives considered	IT considered?	Number of suppliers considered?	Formal analytical model?	Multiperiod model?	Empirical analysis?	Setting
Malone et al. (1987)	IT, markets, hierarchies	TCE, CT	Yes	Yes	No	No	No	None
Clemons et al. (1993)	IT, number of suppliers	TCE, CT, GHM	Yes	Yes	No	No	No	None
Bakos and Brynjolfsson (1993a)	IT, number of suppliers	TCE, CT, GHM	Yes	Yes	Yes	No	No	None
Plambeck and Taylor (2006)	Dynamic relational production contracts	CRG	No	No	Yes	Yes	No	None
Brynjolfsson (1994)	Incentive effects of asset ownership	TCE, CT, GHM	Yes	No	Yes	No	No	None
Gurbaxani (1996)	Outsourcing, strategic intent	TCE, CT	Yes	No	No	No	Yes	Outsourcing deals
Helper et al. (2000)	Learning by monitoring	TCE, GHM	No	No	No	No	Yes	Auto industry
Helper and Levine (1992)	Long-term contracting	GHM, TCE	No	No	Yes	No	No	Auto industry
Helper (1991)	US/JPN supply relations	GHM, TCE	No	No	No	No	Yes	Auto industry
Levina and Su (2008)	Global multisourcing	TCE, CT, SC, GT, PT	Yes	Yes	No	No	Yes	Case study fin. services
Levina and Vaast (2008)	Offshore collaboration, status, boundaries	GT, PT	Yes	No	No	No	Yes	Case study fin. services
Levina and Ross (2003)	Vendor strategy, complementarity	GT, PT	Yes	No	No	No	Yes	Case study IT vendor
Craighead et al. (2007)	Supply chain disruptions	OT	No	No	No	No	Yes	Case study, interview, focus groups
Dyer (1997)	Transaction costs, asset specificity	TCE	No	No	No	No	Yes	Auto industry
Dedrick et al. (2008)	IT, product type, number of suppliers	TCE, CT, SC	Yes	Yes	No	No	Yes	Manufacturing firms
Cusumano and Takeishi (1991)	U.S./JPN supply relationships	TCE	No	Yes	No	No	Yes	U.S./JPN auto industry
Mithas et al. (2008)	Reverse auctions in supply relationships	TCE, CT, GHM	Yes	No	No	No	Yes	U.S. auto industry
Zhu et al. (2006)	Open IOS adoption in supply relationships	TCE, CT	Yes	No	No	No	Yes	Multicountry multi-industry
Overby and Jap (2009)	IT, product type	TCE, CT	Yes	No	No	No	Yes	Auto auctions
Zhu and Zhou (2010)	Transparency in supply relationships	TCE, CT	Yes	No	Yes	No	No	None
Aral et al. (2012)	IT, repeated contracts, number of suppliers	TCE, CT, GHM, CRG, SC	Yes	Yes	Yes	Yes	Yes	Multicountry multi-industry

Notes. The theoretical perspectives considered include the following: TCE = transaction cost economics (including the role of asset specificity); GHM = Grossman–Hart–Moore incomplete contracts theory; CT = coordination theory; CRG = cooperation in repeated games; SC = search costs (fit); GT = grounded theory; PT = practice theory; OT = operations theory.

that fit is more important and thus fit cost is higher for a given distance x.[4]

2.3.2. Long-Term Suppliers. The firm maintains a set S of n "long-term" suppliers ($0 \leq n \leq N$) from which it solicits bids in each period. Suppliers are costly to initiate and maintain, for instance because of qualification and coordination costs: the firm incurs a one-time cost K and a per period cost κ for each supplier in S, and a cost $\kappa' \geq \kappa$ to solicit a bid from a supplier outside S. The firm and its suppliers are risk neutral and discount future costs and benefits at a discount factor δ per period ($0 < \delta \leq 1$). We denote by $f(\alpha, n)$ the expected surplus generated by the firm (which is expected value generated less expected fit cost) when employing n long-term suppliers; f is decreasing in α since fit cost is increasing in it. Given supplier heterogeneity and variability in the firm's demand, a larger number of suppliers will improve expected fit and thus $f(\alpha, n)$ is increasing in n.

2.3.3. Supplier Investment. In each period, the selected supplier is expected to make a firm-specific investment X that is essential to generate surplus from the relationship; both the supplier's investment and the resulting surplus are observable but noncontractible as in Hart and Moore (1990): they can be observed but cannot be contractually enforced. Since X is noncontractible, the firm has no legal recourse against a selected supplier that fails to invest, although X is observable and thus the firm knows that the supplier did not invest.[5]

2.3.4. Supplier Payoffs. Since X and the surplus it enables are noncontractible, the firm cannot make payment to the supplier contingent on X or the resulting surplus, although the two can bargain over this surplus since it is observable. If the supplier has no residual control after investing it will not be able to appropriate any of the resulting surplus since it will have no ex post bargaining power. On the other hand, if the supplier retains some bargaining power, for instance because its cooperation is required to provide certain postsale services, it will be able to appropriate some fraction of the resulting surplus that we denote by β. Thus suppliers obtain two types of payoffs: they receive a payment Y from the firm and, if they invest, they also receive a fraction β of the resulting surplus. This setting is in the spirit of Baker et al. (2002) in the sense that suppliers' susceptibility to ex post holdup determines the need for investment incentives through mechanisms like trust and repeated interaction and it also extends an incomplete contracts analysis to a multiperiod setting.

2.3.5. Conduct and Optimal Number of Suppliers. This is a setting with search in a spatially differentiated market with known distributions of product offerings (e.g., Bakos 1997). In each period the firm realizes its demand and solicits bids from its suppliers. The optimal strategy is a "threshold" strategy: the firm first considers the best-fitting supplier in S as the period search cost κn for these suppliers is sunk. If the realized fit $\hat{f}(\alpha, n)$ is below a certain threshold t,[6] the firm will solicit suppliers outside S at cost κ' until a new supplier with acceptable fit is identified. We denote the probability of selecting such a supplier outside S by ν.

Once a supplier is selected it decides whether to invest X; then production takes place, and, if the supplier invested, the firm realizes the corresponding surplus. We consider long-run Markov perfect equilibria (MPE) (Maskin and Tirole 1988).

Proposition 1 (Optimal Number of Suppliers). *At equilibrium, the optimal number of suppliers increases* (a) *as α increases,* (b) *as X decreases,* (c) *as κ decreases,* (d) *as K decreases, and* (e) *as β increases.*

Proof. Denote by Π the period payoff to the firm. Strategies that lead to equilibria with no supplier investment result in $\Pi \leq 0$ and are thus dominated by any strategy that results in $\Pi > 0$. Consider a long-run MPE with n suppliers in S. The firm will first consider the best-fitting supplier in S; the resulting expected surplus will be $f(\alpha, n)$, provided that the supplier invests X. If the realized fit $\hat{f}(\alpha, n)$ is below threshold t, which will happen with probability ν, the firm will access suppliers outside S at cost κ' until a new supplier with acceptable fit is identified.

A cooperating supplier receives a payoff of $(Y - X + \beta f(\alpha, n))$ every $n/(1-\nu)$ periods on expectation, for a present value of $(Y - X + \beta f(\alpha, n))/(1 - \delta^{n/(1-\nu)})$. A defecting supplier receives Y and is subsequently fired.[7] To induce cooperation, the net present value of supplier payoffs must exceed Y. Solving $(Y - X + \beta f(\alpha, n))/(1 - \delta^{n/(1-\nu)}) \geq Y$ gives an upfront payment for the selected supplier of $Y = \delta^{-n/(1-\nu)}(X - \beta f(\alpha, n))$ for a total period payoff of $\delta^{-n/(1-\nu)}(X - \beta f(\alpha, n)) - X + \beta f(\alpha, n)$. The firm's payoff is given by $\Pi(n) = (1-\beta) f(\alpha, n) - n(\kappa + \mathrm{K}) - \delta^{-n/(1-\nu)}(X - \beta f(\alpha, n))$.[8]

Taking derivatives and since $\partial f(\alpha, n)/\partial n > 0$ and $\partial^2 f(\alpha, n)/\partial n^2 < 0$,[9] $\partial^2 \Pi(n)/\partial n^2 < 0$, and thus $\partial \Pi/\partial n = 0$ has a single solution and the firm's profit is maximized by a unique optimal number of long-term suppliers $n^* > 0$. Also, over the range $[1, N]$ we get $\partial^2 \Pi/\partial n \partial \alpha > 0$, $\partial^2 \Pi/\partial n \partial X < 0$, $\partial^2 \Pi/\partial n \partial \kappa < 0$, $\partial^2 \Pi/\partial n \partial K < 0$ and $\partial^2 \Pi/\partial n \partial \beta > 0$, which implies that n^* increases as α increases, as X decreases, as κ decreases, as K decreases, and as β increases. □

Thus, the number of suppliers is likely to be limited by the coordination cost if κ or K is large, or by the need to provide incentives that will support cooperation if X is large or β is small.

Proposition 2 (Repeated Supplier Relationships). *Let ρ denote the probability of selecting the same supplier over successive periods;* (a) *ρ will increase as X increases, and* (b) *ρ will increase as α decreases.*

Proof. Each period a supplier outside the set S is selected with probability ν and each supplier in the set S with probability $(1-\nu)/n$; thus $\rho=(1-\nu)/n$. We can write $\partial\rho/\partial X=(\partial\rho/\partial n)(\partial n/\partial X)$, and since both partial derivatives on the right-hand side are negative, we get $\partial\rho/\partial X>0$. Last, $\partial\rho/\partial\alpha=(\partial\rho/\partial\nu)(\partial\nu/\partial\alpha)$ and, since $\partial\nu/\partial\alpha>0$, it follows that $\partial\rho/\partial\alpha<0$. □

The lower the value of β, the higher the importance of repeated interactions in inducing the supplier to invest, and thus the higher the fraction of repeated relationships. On the other hand, if $\beta f(\alpha,n)\geq X$ then no positive payment Y is required, and thus there is no need to rely on repeated interaction. In that case, the number of suppliers considered is only limited by κ and K.

To allow partially contractible supplier investments, let μ denote the degree to which supplier performance can be contracted, with $0\leq\mu\leq1$. A supplier that fails to make its noncontractible investment must return a fraction μ of the upfront payment, receiving a net defection payoff of $(1-\mu)Y$; the base model corresponds to $\mu=0$. For partially observable supplier investments, let m denote the degree to which supplier performance can be monitored, with $0\leq m\leq1$. A supplier that fails to invest will be detected with probability m; the base model corresponds to $m=1$. The minimum supplier payment required to induce cooperation satisfies $(Y-X+\beta f(\alpha,n))/(1-\delta^{n/(1-\nu)})\geq Y+(1-m)\cdot(Y-X+\beta f(\alpha,n))/(1-\delta^{n/(1-\nu)})$, as defection will only be detected with probability m; thus, in addition to Y, the defecting supplier will continue to receive with probability $1-m$ the value of the game next time it is selected, on expectation after n periods.

Proposition 3 (Partially Contractible and Partially Observable Investments). *The optimal number of suppliers increases* (a) *as μ increases and* (b) *as m increases.*

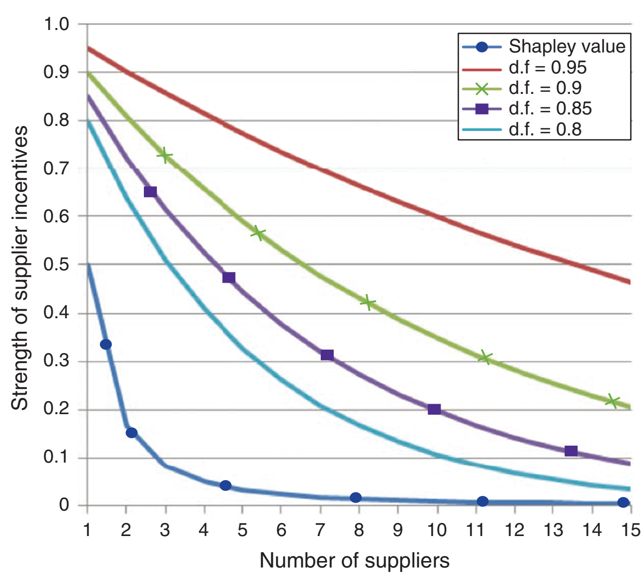
Proof. In the partially contractible case, the minimum payment to the supplier required to induce cooperation is now obtained by solving $(Y-X+\beta f(\alpha,n))/(-\delta^{n/(-\nu)})\geq(-\mu)Y$, and this gives $Y=(X-\beta f(\alpha,n))/(\mu+(1-\mu)\delta^{n/(1-\nu)})$ and $\Pi(n)=(1-\beta)f(\alpha,n)-\kappa n-\nu K-((X-\beta f(\alpha,n))/(\mu+(1-\mu)\delta^{n/(1-\nu)}))$. Increasing μ is equivalent to decreasing X and thus n^* increases as μ increases.

In the partially observable case, the minimum supplier payment required for cooperation is $Y=(1+((1-\delta^{n/(1-\nu)})/(m\delta^{n/(1-\nu)})))(X-\beta f(\alpha,n))$ and the firm's period payoff is $(1-\beta)f(\alpha,n)-\kappa n-\nu K-(1+((1-\delta^{n/(1-\nu)})/(m\delta^{n/(1-\nu)})))(X-\beta f(\alpha,n))$. Increasing m is equivalent to decreasing X and thus n^* increases as m increases: a defecting supplier is more likely to be detected and thus a lower future expected benefit is required to induce cooperation. □

2.4. Model Predictions

The theoretical model has two main implications. First, it establishes the importance of factors like trust that arise in a multiperiod setting and explores how supplier cooperation can be sustained in such a setting. Bakos and Brynjolfsson (1993a, b) developed a single-period model where supplier incentives are provided by reducing the number of suppliers to the point that they acquire significant bargaining power. In the incomplete contracting framework, a participant's bargaining power and corresponding incentives are proportional to its Shapley value (Hart and Moore 1990), which with n suppliers is $n/(n+1)$ for the firm and $1/n(n+1)$ for each supplier. By contrast, in a multiperiod setting, supplier incentives from future interaction are proportional to $\delta^{n/(1-\nu)}/(1-\delta^{n/(1-\nu)})$. For reasonable discount rates and for typical numbers of suppliers, repeat relationships are significantly more powerful in providing incentives than mechanisms based on reducing the number of suppliers. This is illustrated in Figure 1 for the case $\nu=0$; if $\nu>0$, the x axis of Figure 1 will need to be scaled accordingly by $1/(1-\nu)$. While a mechanism based on the Shapley value quickly loses its power as the number of suppliers increases beyond two or three, a mechanism

Figure 1. (Color online) Shapley Value vs. Multiperiod Incentives Under Different Discount Factors



Notes. The x axis shows the number of suppliers. The y axis shows the present value of the surplus a supplier would appropriate based on their bargaining power (based either on the Shapley value in a one-shot game or their payoff in a multiperiod equilibrium under different discount rates). Since we have assumed decreasing returns to supplier investments, the larger this y-axis value, the more the supplier will invest.

based on repeated interaction can provide considerable incentives with a significantly higher number of suppliers.[10] This allows firms to provide suppliers' incentives without inordinate fit penalties.

Thus our theory argues that an important motivation for reducing the number of suppliers is to make it easier to maintain repeated relationships with the remaining suppliers. This is an argument that is absent in the most cited prior papers on this topic (e.g., Malone et al. 1987; Bakos and Brynjolfsson 1993a, b; Clemons et al. 1993). Firms may reduce the number of suppliers while also reducing the amount of repetition (e.g., by practicing "serial monogamy" with one supplier at a time without returning to a previous supplier), but our theory of trust predicts that a reduction in suppliers will be empirically correlated with increased repetition.

Additionally, our model also explains how the characteristics of the setting affect the optimal number of suppliers and the frequency of repeated relationships, leading us to a number of testable hypotheses about both organizational factors and IT. As the specificity of supplier investments increases, we would expect firms to employ fewer suppliers and have a higher fraction of repeated relationships, in accordance with Propositions 1(b) and 2(a), as $\partial n/\partial X < 0$ and $\partial \rho/\partial X > 0$:

Hypothesis 1. *As relationship-specific supplier investment increases,* (a) *the number of suppliers decreases and* (b) *the fraction of repeated supplier relationships increases.*

Finding suppliers with good fit is more important for firms with increasingly heterogeneous or unpredictable supplier needs. Such firms are likely to place a premium on supplier fit and therefore are more likely to employ more suppliers. Furthermore, the attractiveness of exploring new suppliers will increase, thus decreasing the fraction of repeated supplier relationships. Hypothesis 2 follows from Propositions 1(a) and 2(b), as $\partial n/\partial \alpha > 0$ and $\partial \rho/\partial \alpha < 0$.

Hypothesis 2. *As the importance of supplier fit increases,* (a) *the number of suppliers increases and* (b) *the fraction of repeated supplier relationships decreases.*

Firms that invest in technologies to reduce the cost of coordinating with suppliers, such as extranets that enable them to identify and evaluate potential suppliers, third-party hosted intranets that facilitate communication, or project management software that facilitates coordination of planning and production, are expected to use more suppliers. Hypothesis 3 follows from Proposition 1(c) as $\partial n/\partial \kappa < 0$.

Hypothesis 3. *As firms use more technologies that reduce coordination costs with suppliers, the number of suppliers increases.*

Use of technology highly specific to a vendor can lead to lock-in. Vendors typically take strategic actions intended to increase switching costs (Chen and Forman 2006). For instance, prior research has demonstrated that asset specific information technologies such as electronic data interchange (EDI), which are generally tailored to a given firm or pair of firms, can lock firms into a relationship (Srinivasan et al. 1994, Iacovou et al. 1995, Zhu et al. 2006). Hypothesis 4 follows from Proposition 1(d) as $\partial n/\partial \mathrm{K} < 0$.

Hypothesis 4. *As firms use more vendor-specific technologies, the number of suppliers decreases.*

When the terms and requirements of supplier contracts are relatively easy to spell out and communicate in a legal contract (i.e., contractibility μ is high), and when the activities and deliverables of these suppliers can be easily measured and monitored, (i.e., observability m is high), there is less need to provide incentives for noncontractible investments (Fitoussi and Gurbaxani 2012), and therefore in these situations we would expect firms to employ more suppliers. Hypothesis 5 follows from Proposition 3.

Hypothesis 5. *As* (a) *the ability to codify the requirements and* (b) *the ability to measure performance in supplier relationships increases, the number of suppliers increases.*

The higher the threat of holdup after suppliers invest, the more assurances the firm must provide to induce the necessary relationship-specific investments. Thus, factors that increase the threat of holdup are likely to increase the need for trust-based cooperative repeated relationships. For example, since ownership of complementary assets influences the threat of holdup, the types of assets involved in different industries are likely to affect the nature of the supply relationship. In physical capital-intensive industries, the complementary physical assets are owned by the buyer firm, creating additional vulnerability to holdup for suppliers. For example, when a vendor designs, develops, and supplies the software platform for a factory automation system, the buyer firm makes complementary investments in the physical factory assets that it owns. In contrast, in human capital-intensive industries, the complementary human or knowledge assets cannot as easily be owned by the buyer, mitigating the vulnerability of suppliers to holdup (Brynjolfsson 1994).

The threat of holdup for suppliers is likely to be greater in physical capital-intensive industries than in human capital-intensive industries for three related reasons. First, when the complementary assets to supplier investments are physical assets owned and controlled by the buyer, suppliers may find themselves in a position of diminished ex post bargaining power, reducing their incentives to invest. In contrast, the buyer cannot own or as easily control complementary human capital assets in human capital-intensive industries, and those assets could plausibly move to a different firm, transferring with them some of the value of the specific supplier investment. For example, if a team of financial analysts were to move to a new firm, their suppliers of financial analysis software are particularly well positioned to sell their technology to the new firm as the analysts have experience using it. The same is true for asset-specific software supplied to investment banking firms, hedge fund managers, specialized medical professionals, and other similarly situated human capital-intensive firms. Such possibilities moderate the risk of ex post holdup for the supplier, compared to the case of complementary physical assets that cannot choose to leave a buyer for another firm.

Second, human capital-intensive industries require more ex post support, increasing the ex post bargaining power of the suppliers. In human capital-intensive industries, firms rely more on continued supplier training and support; for instance, when complementary human capital assets leave the firm, their replacements need training to work with the IT supplied by the vendor. In the case of physical capital assets, IT is more easily transferred. If a machine breaks down, it is typically replaced by another machine that works with the firm's IT systems without requiring postsales training by the vendor. This increased need for ex post supplier service increases supplier bargaining power and therefore reduces the threat of ex post holdup.

Third, human assets like expert employees (and thus their knowledge) can be hired away from the buyer. For instance, enterprise resource planning (ERP) vendors frequently hire away IT personnel from clients because of the skills they have developed in implementing the vendor's solutions.[11] As a result, firms in physical capital-intensive industries are likely to have a stronger need to provide assurances to suppliers, in the form of reductions in the supply base and more repeated interactions, to create stronger incentives for these suppliers to make the specific investments that maximize relationship value. We therefore expect more reductions in the supply base and more repeated interactions in physical capital-intensive industries. Hypothesis 6 follows from Proposition 1(e) about the threat of holdup experienced by suppliers.

Hypothesis 6. *As supplier susceptibility to holdup increases, the fraction of repeated relationships increases and the number of suppliers decreases.*

Table 2 summarizes the key variables determining the optimal number of suppliers. A larger number of suppliers creates opportunities for better fit between firm needs and supplier skills as well as improved bargaining power, while a smaller number of suppliers increases suppliers' incentives to make relationship-specific investments. IT affects this trade-off by lowering search and coordination costs, which tend to increase the number of suppliers, but also by creating opportunities for technological lock-in to vendor-specific technologies, which tend to decrease the number of suppliers. In industries where the complementary assets can be easily owned by the buyer, the need for greater assurances and trust increases. As a result, the optimal outcome will depend on the specific characteristics of the setting and the technology, demonstrating the need for a flexible, integrated model and a contingent empirical view.

3. Empirical Methods

3.1. Data

To test our theory, we partnered with the research firm Illuminas to develop and implement a global web-based survey of IT sourcing decisions. The survey was conducted from November 14, 2007, to December 5, 2007, and the respondents were responsible for the management of IT suppliers[12] in 1,355 firms in 12 countries.[13] The survey solicited data on IT sourcing behavior (e.g., number of bids solicited, number of vendors contracted with, number of vendors used for implementation, and the ongoing nature of relationships), organizational and technological determinants of supply base size (e.g., asset specificity, technology use, codifiability of contracts, and mutual monitoring), IT investments and use (e.g., total IT expenditures, percent of IT expenditures outsourced, and deployment of coordination IT and vendor-specific IT), and firm characteristics (e.g., size and industry). Descriptive statistics are provided in Tables 3A and 3B.[14]

Table 2. Organizational and Technological Determinants of the Optimal Number of Suppliers

	Organizational determinants	Technological determinants	Asset ownership determinants
More suppliers	• Better fit between firm needs and vendor skills • Improved bargaining power	• Lower search and coordination costs	• Supplier asset ownership creates vulnerability to holdup for buyers
Fewer suppliers	• Relationship-specific investments • Noncontractible investments • Trust	• Technological lock-in	• Buyer asset ownership creates vulnerability to holdup for suppliers

Table 3A. Descriptive Statistics and Correlations

	Total		Physical capital-intensive		Human capital-intensive		HC vs. PC
Variable	Obs.	Mean (SD)	Obs.	Mean (SD)	Obs.	Mean (SD)	t-value
1. *Number of IT Vendors*	1,189	5.58 (11.5)	256	5.89 (11.8)	293	5.22 (9.13)	0.74
2. *Percent of Repeated Relationships*	1,193	82.4% (26.1)	249	81.1% (24.8)	279	83.8% (25.6)	1.24
3. *Total Employees*	1,331	10,463 (39,705)	255	11,023 (39,097)	290	8,288 (29,810)	0.91
4. *Total IT Expenditures*	651	$22.1 M ($94 M)	256	$25.9 M ($115 M)	293	$19.6 M	0.73
5. *Percent IT Outsourced*	957	34.5% (23.5)	242	36.4% (23.2)	282	35.1% (23.6)	0.65
6. *Application Breadth*	1,355	5.36 (2.82)	256	6.04 (2.74)	293	5.95 (2.55)	0.36
7. *Asset Specificity* (1–5)	1,345	3.98 (0.90)	255	4.09 (1.08)	293	4.03 (1.12)	0.19
8. *Codifiable Terms* (1–5)	1,355	3.33 (1.11)	256	3.48 (0.91)	293	3.29 (0.93)	2.07**
9. *Clear Requirements* (1–5)	1,355	3.52 (0.99)	256	3.62 (0.91)	293	3.59 (0.93)	0.39
10. *Measurable Performance* (1–5)	1,355	3.49 (1.02)	256	3.66 (0.98)	293	3.54 (1.01)	1.46
11. *Monitorable Activities* (1–5)	1,355	3.32 (1.04)	256	3.46 (0.96)	293	3.34 (1.05)	1.39
12. *Coordination IT* (0–3)	1,355	0.53 (0.81)	256	0.65 (0.87)	293	0.66 (0.90)	0.04
13. *Vendor-Specific IT* (0–3)	1,355	0.51 (0.84)	256	0.66 (0.92)	293	0.66 (0.94)	0.03

Note. Statistical significance of t-values: $^{**}p < 0.05$.

Table 3B. Correlations Matrix

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. *Number of IT Vendors*	1											
2. *Percent of Repeated Relationships*	−0.09	1										
3. *Total Employees*	0.07	0.02	1									
4. *Total IT Expenditures*	0.31	0.04	0.28	1								
5. *Percent IT Outsourced*	0.05	−0.03	0.00	0.04	1							
6. *Application Breadth*	0.08	−0.02	0.01	0.04	0.04	1						
7. *Asset Specificity* (1–5)	−0.01	0.05	0.05	0.04	0.04	0.14	1					
8. *Codifiable Terms* (1–5)	0.02	0.03	0.07	0.09	−0.03	0.11	0.33	1				
9. *Clear Requirements* (1–5)	0.03	0.01	0.03	0.04	−0.02	0.12	0.29	0.53	1			
10. *Measurable Performance* (1–5)	0.01	0.01	0.04	0.04	0.05	0.15	0.31	0.51	0.66	1		
11. *Monitorable Activities* (1–5)	0.02	−0.004	0.04	0.08	0.04	0.14	0.29	0.62	0.61	0.63	1	
12. *Coordination IT* (0–3)	0.13	−0.13	0.03	0.06	0.13	0.28	0.07	0.07	0.11	0.13	0.14	1
13. *Vendor Specific IT* (0–3)	0.05	−0.12	0.02	0.05	0.10	0.27	0.09	0.10	0.12	0.16	0.17	0.61

These data provide some of the first empirical evidence on IT supplier networks across countries and industries, from what to our knowledge is the largest global survey of IT procurement and governance to date. IT procurement is a natural context in which to study supply chain governance as vendor selection, contracting, incentives, and fit are critical to sourcing strategies in this setting (Gurbaxani 1996). Prior research has focused almost exclusively on manufacturing and the auto industry in particular (e.g., Helper et al. 2000, Helper and Levine 1992, Helper 1991, Cusumano and Takeishi 1991), but it is not obvious that theoretical predictions from these industries apply directly to the supply of IT. We study the role of IT in relationships with IT suppliers to understand a more high-tech and more human capital-intensive set of relationships. In addition, IT suppliers are more likely to be on the leading edge of using IT in the supply chain, making changes in this context more likely to foreshadow changes in other industries.

3.2. Variable Construction

3.2.1. Dependent Variables. The dependent variables in our empirical analysis are (1) the number of IT vendors, which we measure by asking firms to report the number of IT vendors they work with on a regular basis (*Number of IT Vendors*); and (2) the fraction of vendors with which the firm is in a repeated relationship, which we measure by dividing the number of vendors they are currently working with and with whom they also have previously worked with in the last five years by the total number of vendors they are currently working with, including new vendors and vendors they have worked with but not in the last five years (*Percent of Repeated Relationships*). As these two variables are likely simultaneously determined, we estimate their relationship in a system of equations and use instrumental variables to address endogeneity and identify the underlying relationships.

3.2.2. IT and Coordination Costs. To measure the use of IT to communicate and coordinate with suppliers, we asked respondents to report their firms' use of (a) extranets, (b) project management software, and (c) third-party-hosted intranets to communicate and coordinate with suppliers; all were measured as binary variables. We summed these responses to measure the overall use of *Coordination IT*.

3.2.3. Vendor-Specific IT. Some coordination technologies are highly specific to the relationship or the vendor. This can lead to lock-in by increasing switching costs. We measure the use of vendor-specific IT by asking respondents whether they used (a) "custom client web-portals provided by your vendors" (*Vendor-Specific Portals*), (b) "vendor collaboration and document management tools" (*Vendor Collaboration Tools*), and (c) "vendor relationship management tools" (*Vendor Management Tools*) to "communicate with your IT vendors," all measured as binary variables. We summed these responses to measure the overall use of *Vendor-Specific IT*.

3.2.4. Scope, Heterogeneity, and Fit. To measure firm scope, the likely heterogeneity of firms' IT requirements, and the difficulty firms face in fulfilling or "fitting" their IT needs, we measured the breadth of the application types each firm implemented. IT suppliers offer multiple products, and firms procure "baskets" of such products from multiple heterogeneous suppliers. Firms in our data set procure a basket of 10 types of IT applications, and the fit cost is the decrease in the firm's payoffs from adopting a given set of supplier offerings compared to the ideal set. In this market, suppliers generally have product offerings for most or all 10 of the types of applications that we consider, but each supplier is typically best of breed in a different product type. A larger number of applications procured by a firm would increase the diversity of its needs and, if the number of suppliers were held fixed, would increase the expected fit cost as the existing suppliers are not likely to perfectly fit the firm's needs in the new application categories. The number of applications procured can thus serve as a proxy for the importance of fit. To measure application breadth, which estimates firms' variety of IT needs, we asked respondents whether they had implemented any of a list of 10 solution types. Application breadth is the number of distinct application types the firm implemented (*Application Breadth*).

3.2.5. Codifiability and Measurability. To measure the degree to which the terms and requirements of vendor contracts are codifiable and the degree to which suppliers' activities and output are observable, we asked respondents to "think about formal expectations, including contracts and formally specified deliverables." To measure codifiability we asked respondents: "When thinking about the specific terms and requirements you agree to with IT vendors, how many of those terms and requirements would you classify as codified—meaning that a written and agreed upon document specifies in detail your terms and requirements?" (*Codifiable Terms*). We also assessed whether requirements were easy to communicate and understand by asking: "When thinking about the specific terms and requirements you agree to with IT vendors, how many of those terms and requirements would you classify as easy to communicate and understand—meaning that your terms and requirements are easy to explain and vendors find them easy to understand?" (*Clear Requirements*). We then asked respondents whether the specific contractual terms and requirements they agree to with IT vendors can be classified as "measurable in outcome" (*Measurable Performance*) and also assessed the monitorability of vendors' activities by asking "how many of the terms and requirements were monitorable—meaning that vendor activities specified in your terms and requirements can be easily observed and monitored?" (*Monitorable Activities*). All of these variables were assessed on a five-point Likert scale.

3.2.6. Asset Specificity and Supplier Investment. To assess asset specificity and to serve as a proxy for relationship-specific investments, we rated respondents' agreement or disagreement with the following statement on a five-point Likert scale: "Your vendors must acquire significant information, knowledge, and skills specific to your company to adequately deliver on either formal or informal terms and requirements" (*Asset Specificity*). We normalized the above five variables (*Codifiable Terms*, *Clear Requirements*, *Measurable Performance*, *Monitorable Activities*, and *Asset Specificity*) by subtracting the mean from each observation and dividing by the standard deviation of the variable.

3.2.7. Control Variables. To control for scale effects, we asked respondents to report the firms' total number of employees (*Total Employees*). To control how a firm's total IT budget might affect the number of IT suppliers, we asked respondents to report their firms' "total IT expenditures including all computers, software, data communications (including via phone line), and people" (*Total IT Expenditures*). Firms that rely more on market procurement may have experience with outsourcing and may have developed processes for selecting and vetting suppliers and a proclivity for market procurement. To control for unobservable firm characteristics correlated with a reliance on the market, we control for the percentage of IT expenditures outsourced (*Percent IT Outsourced*), measured independently of the number of suppliers firms work with. Table 4 shows the variables we constructed from survey data, the parameters they represent in our theoretical model, and the expected sign of the regression coefficients in predicting the number of suppliers and the fraction of repeated supplier relationships based on the hypotheses derived from our theoretical model.

3.3. Model Specification, Estimation, and Identification

We are interested in estimating the effects of firm characteristics, contracting environment, and IT use on supply base size and repeated relationships, but firms are likely to choose the number of suppliers and the fraction of repeated relationships simultaneously, and IT choices are also likely endogenous. We therefore estimate the effects of our variables of interest on the number of suppliers and the fraction of repeated relationships as a system of simultaneous equations as follows:

$$n = \alpha_1 + \beta_{1,1}te + \beta_{1,2}it + \beta_{1,3}po + \beta_{1,4}r + \beta_{1,5}ab + \beta_{1,6}as + \beta_{1,7}ct + \beta_{1,8}cr + \beta_{1,9}mp + \beta_{1,10}ma + \beta_{1,11}cit + \beta_{1,12}vit + \sum_j \beta^C_{j1}C_j + \sum_n \beta^I_{n1}C_n + \varepsilon_1 \quad (1)$$

$$r = \alpha_2 + \beta_{2,1}te + \beta_{2,2}it + \beta_{2,3}po + \beta_{2,4}n + \beta_{2,5}ab + \beta_{2,6}as + \beta_{2,7}ct + \beta_{2,8}cr + \beta_{2,9}mp + \beta_{2,10}ma + \beta_{2,11}cit + \beta_{2,12}vit + \sum_j \beta^C_{j2}C_j + \sum_n \beta^I_{n2}C_n + \varepsilon_2 \quad (2)$$

where n represents the number of suppliers that firms work with on a regular basis, te represents total employees, it represents total IT expenditures, po represents the percent of IT that is outsourced, r represents the fraction of repeated relationships, ab represents application breadth, as represents asset specificity, ct represents the degree to which contract terms are codifiable, cr represents the degree to which the contract terms are clear, mp represents the degree to which the suppliers' performance is measurable, ma represents the degree to which suppliers' activities are monitorable, cit represents coordination IT adoption, vit represents vendor-specific IT adoption, and C_j and C_n represent country and industry dummies, respectively.

The equations in our model may not be consistently estimated using ordinary least squares (OLS) because the endogenous variables, including the number of suppliers, the fraction of repeated relationships, and the four IT variables (total IT spending, percent of IT outsourced, vendor-specific IT adoption, and coordination IT adoption), are all jointly determined by the exogenous variables and the structural shocks. They

Table 4. Empirical Variables Predicting the Number of Suppliers and Repeated Relationships

Constructed variable	Characteristic of organizational setting	Corresponding model parameter	Predicted coefficients DV: *Number of suppliers*	Predicted coefficients DV: *Repeated relationships*
1. *Total Employees*	Firm scale	Control variable	—	—
2. *Total IT Expenditures*	Firm scale	Control variable	—	—
3. *Percent IT Outsourced*	Firm scale	Control variable	—	—
4a. *Fraction of Repeated Relationships*	Trust	Probability to select same supplier (ρ)	$\beta_{1,4} < 0$	—
4b. *Number of Suppliers*	Supplier base	Number of suppliers (n)	—	$\beta_{2,4} < 0$
5. *Application Breadth*	Scope/heterogeneity of requirements	Fit parameter (α)	$\beta_{1,5} > 0$	$\beta_{2,5} < 0$
6. *Asset Specificity*	Asset specificity	Supplier investment (X)	$\beta_{1,6} < 0$	$\beta_{2,6} > 0$
7. *Codifiable Terms*	Codifiability	Contractibility (μ)	$\beta_{1,7} > 0$	No prediction
8. *Clear Requirements*	Codifiability	Contractibility (μ)	$\beta_{1,8} > 0$	No prediction
9. *Measurable Performance*	Measurability	Measurability (m)	$\beta_{1,9} > 0$	No prediction
10. *Monitorable Activities*	Measurability	Measurability (m)	$\beta_{1,10} > 0$	No prediction
11. *Coordination IT*	Coordination cost	Coordination cost (κ)	$\beta_{1,11} > 0$	No prediction
12. *Vendor-Specific IT*	Switching cost/lock-in	Supplier setup cost (K)	$\beta_{1,12} < 0$	No prediction

Note. DV, dependent variable.

may therefore be correlated with the error terms in the equations in which they are right-hand-side variables. We first apply two-stage least squares (2SLS) estimation to estimate Equations (1) and (2) and then estimate a full system of six equations using three-stage least squares (3SLS) in which each of the six endogenous variables appear on the left-hand side of one of the equations.

We instrument for the fraction of repeated contracts with the fraction of repeated solicitations and for the total number of vendors with the total number of vendors solicited. In the survey, we asked about bid solicitation behavior to understand how firms search for vendors. The fraction of repeated solicitations is theoretically orthogonal to the total number of suppliers because our theory predicts that repeated relationships and the number of suppliers are related based on punishment and incentives to invest on the part of the supplier, which would not apply to suppliers who are solicited but not contracted with. For the same reason, the number of vendors solicited should not be correlated with the fraction of repeated relationships. We construct Hausman-style instruments for *Coordination IT*, *Vendor-Specific IT*, *IT Expenditures*, and the *Percent IT Outsourced* by measuring the average levels of these variables within a firm's own industry (excluding the firm itself), which addresses firm-specific simultaneity because technology adoption by similarly situated firms in other markets should be correlated with the firms' behavior but exogenous to the supply relationships in which the firm is itself engaged (Hausman 1996).[15] First-stage regressions indicate that these are strong instruments for our variables of interest.[16]

3.4. Specification Tests and Robustness Checks

We conducted several specification tests and robustness checks of our main empirical models to insure that our analyses were not confounded by data anomalies or specification errors. First, we conducted Breusch–Pagan and Cook–Weisberg tests for heteroskedasticity, which reject the null hypothesis of spherical disturbances (BP = 1237.47, $p < 0.01$). We therefore report Huber–White heteroskedasticity consistent standard errors. Second, though the number of suppliers ranges from 0 to 200, it could be considered a count variable. At the same time, the fraction of repeated relationships variable could be modeled as a probability that any given contract is repeated and thus estimated using a nonlinear logit or probit specification. We tested the robustness of our estimates to these specifications by estimating Poisson regression models for the number of suppliers. The fraction of repeated relationships is distributed approximately normally, with higher kurtosis, but there is a mass of observations at 100%. This reduces the goodness of fit of logit or probit specifications quite a bit. We therefore tested ordered logistic and beta regression models of this variable. We tested several versions of Poisson, ordered logistic, and beta regression models, and all produced very similar results to our main specifications (see the online appendix). We report and interpret estimates from the 2SLS and 3SLS specification as our main results because the instrumental variables techniques for nonlinear regressions are more involved and require more stringent assumptions, and the simultaneous equations models are more efficient and produce a better fit. Third, we calculated centered and uncentered variance inflation factors (VIFs) for the independent variables specified in our models to test for multicollinearity. A variance inflation factor of 10 has been proposed as a cutoff for acceptable levels of variance inflation due to multicollinearity (Kutner et al. 2004). No variance inflation factors for any of the independent variables in our models exceeded 6.0, and only 3 of 43 variables exceeded 4.5, indicating little chance that multicollinearity affected our results. Fourth, we clustered standard errors by country and by industry as additional checks, and the results are robust to these changes. We also conducted robustness checks by including controls for industry/country simultaneously to test the effects of particular industries in particular countries in the full-sample regressions, with no change in our results. Fifth, to ensure our results were robust to possible bias from nonrandom missing data, we repeated our analysis for the full data set and the two industry-based subsamples after imputing missing data using expectation maximization with sampling (EMs) algorithm (e.g., see King et al. 2001). The results show no changes in the significance or sign of the coefficients, indicating that our results are unlikely to stem from missing data bias (see the online appendix). Sixth, to assess our vulnerability to common method variance we applied the correlational marker technique (CM), which indicated little chance of common method bias.[17] Finally, to check for the influence of outliers on our parameter estimates we calculated standardized dfbetas for each of our 43 variables in our two main specifications. Dfbetas show how much a coefficient would change if any given observation were dropped from the data. Calculating dfbetas for each independent variable produces variables that range from a minimum to a maximum change in the coefficients produced by removal of any single observation, one for each independent variable. Only 1 observation in 1 of 43 variables, *Total IT Expenditures*, produced a dfbeta greater than the cutoff of 2 proposed by Belsley et al. (1980), meaning that no influential outliers exist in any of our other independent variables. This one observation produced a dfbeta of 5.2. As a robustness check, we dropped the observation from the regressions to see how it would affect parameter estimates and found no qualitative change in any parameter estimates or the statistical significance of any parameters. We therefore retained the observation for analysis. The empirical results are robust to all of these specification tests and robustness checks and lend support to the hypotheses derived from our integrated theoretical model.

4. Results

Our integrated model generated six testable hypotheses that we assessed using data collected from the survey instrument we designed. The results are shown in Table 5 and they strongly support most, but, not all, of our hypotheses. First, as the need for relationship-specific investments increases (as measured by increased asset specificity), firms contract with fewer suppliers ($\beta_{1,6} = -1.451$, $p < 0.01$, Model 2) and engage in more repeated relationships with those suppliers ($\beta_{2,6} = 2.142$, $p < 0.05$, Model 2). We also find that as firms work with fewer suppliers they also engage in more repeated relationships with those suppliers ($\beta_{2,4} = -0.461$, $p < 0.01$, Model 2). These results confirm Hypotheses 1(a) and 1(b).[18]

Second, we see qualified evidence of fit effects in the relationship between the breadth of applications used and the number of suppliers firms employ. After controlling for the size of the firm and total IT expenditures, implementation of three to four additional application classes is associated with one additional supplier on average ($\beta_{1,5} = 0.267$, $p < 0.10$, Model 2). However, we see no relationship between application breadth and the fraction of repeated relationships ($\beta_{2,5} = 0.194$, not significant (n.s.), Model 2). These results provide qualified support for Hypothesis 2(a) and no support for Hypothesis 2(b), providing partial evidence of fit effects.

Third, investments in technologies that reduce search costs and transaction costs are strongly correlated with using more suppliers in all models: use of an additional coordination IT system is associated on average with contracting with three additional suppliers ($\beta_{1,11} = 3.696$, $p < 0.01$, Model 2), confirming Hypothesis 3.

Fourth, investments in vendor-specific IT are associated with lock-in and fewer suppliers. Use of an additional vendor-specific IT system is associated on average with contracting with one less supplier ($\beta_{1,12} = -1.197$, $p < 0.05$, Model 2), confirming Hypothesis 4. These results are consistent with search and coordination theory and models of lock-in. They support a contingent view of IT and supply chain structure in which firms simultaneously choose supply chain strategies and the technologies that support them.

Fifth, we find partial evidence in support of Hypothesis 5. In particular, measurability is positively associated with increases in the number of suppliers ($\beta_{1,9} = 0.990$, $p < 0.10$, Model 2), providing marginal support for Hypothesis 5(b). However, we find no support for the relationship between codifiability and the number of suppliers (Hypothesis 5(a)).

Finally, as suppliers' vulnerability to holdup increases, the fraction of repeated relationships increases, and the number of suppliers decreases, confirming Hypothesis 6. We test this hypothesis by examining differences in supply chain governance in human capital-intensive and physical capital-intensive industries (see Models 3 and 4).[19] Results from the split-sample models show that asset specificity has a strong positive association with more repeated relationships in physical capital-intensive industries ($\beta_{2,6} = 5.530$, $p < 0.01$, Model 4), but not in human capital-intensive industries ($\beta_{2,6} = -0.942$, n.s., Model 3).[20] Furthermore, the correspondence between more suppliers and fewer repeated relationships holds in human capital-intensive industries ($\beta_{2,4} = -1.146$, $p < 0.05$, Model 3) but not in physical capital-intensive industries ($\beta_{2,4} = -0.069$, n.s., Model 4). Differences across human capital-intensive and physical capital-intensive industries are also themselves statistically significant (*Asset Specificity* $\beta_{2,6}$ Model 3 versus Model 4: $p < 0.005$; *Fraction of Repeated Relationships* $\beta_{1,4}$ Model 3 versus Model 4: $p < 0.001$; *Number of Suppliers* $\beta_{2,4}$ Model 3 versus Model 4: $p < 0.002$). When physical capital is owned by the firm, suppliers experience a greater risk of holdup, motivating physical capital-intensive firms to foster supplier incentives and trust through repetition. As firms in human capital industries expand their supply base, they reduce their fraction of repeated relationships because they have less need to provide suppliers with assurances. In contrast, as firms in physical capital-intensive industries expand their supply base, they must do so while maintaining their fraction of repeated relationships in order to keep supplier incentives high through repetition. In the same way, physical capital-intensive firms with higher asset specificity must have more repeated relationships to induce trust, while human capital-intensive firms with higher asset specificity have less of a need to induce trust through repetition. The threat of holdup in the presence of asset specificity is simply lower in human capital-intensive industries because the inability of buyers to own the complementary assets reduces the amount of residual value about which the partners must negotiate.[21]

5. Discussion, Implications, and Limitations

The results from our empirical analysis map to the three main types of theories relevant to understanding IT's effects on supplier relationships. First, theories of coordination and search costs, as well as the related theories of lock-in, have strong empirical support. As fit needs increase, the attractiveness of searching and contracting with a greater number of suppliers also

Table 5. Results of 2SLS, 3SLS, and Split-Sample Estimation

	Model 1: 2SLS	Model 2 3SLS	Model 3: 3SLS Human capital	Model 4: 3SLS Physical capital
	Dependent variable: *Number of IT Vendors*			
1. *Normalized Total Employees*	−0.464	0.294	−0.284	0.169
	(0.619)	(0.403)	(0.695)	(0.530)
2. *Normalized Total IT $*	4.160***	2.773***	1.761**	4.514***
	(1.223)	(0.389)	(0.594)	(0.684)
3. *Percent IT Outsourced*	0.022	−0.001	0.009	−0.002
	(0.018)	(0.002)	(0.029)	(0.003)
4. *Fraction of Repeated Relationships*	−0.044**	−0.065***	−0.110***	−0.015
	(0.019)	(0.023)	(0.032)	(0.042)
5. *Application Breadth*	0.338*	0.267*	0.603**	0.053
	(0.196)	(0.164)	(0.236)	(0.276)
6. *Normalized Asset Specificity*	−1.290***	−1.451***	−1.260**	−1.869**
	(0.461)	(0.423)	(0.538)	(0.808)
7. *Normalized Codifiable Terms*	−0.126	−0.020	−0.564	0.160
	(0.437)	(0.517)	(0.675)	(0.999)
8. *Normalized Clear Requirements*	−0.112	−0.159	−0.087	−0.676
	(0.501)	(0.595)	(0.806)	(1.037)
9. *Normalized Measurable Performance*	1.06*	0.990*	1.60**	0.635
	(0.561)	(0.571)	(0.751)	(0.999)
10. *Normalized Monitorable Activities*	−0.419	−0.184	−0.095	−0.044
	(0.630)	(0.566)	(0.742)	(1.032)
11. *Coordination IT*	3.06***	3.696***	1.857**	5.242***
	(0.877)	(0.697)	(0.852)	(1.243)
12. *Vendor-Specific IT*	−1.130*	−1.197*	−0.401	−2.203**
	(0.602)	(0.637)	(0.803)	(1.092)
Chi^2 (Prob. > chi^2)	75.16***	187.93***	87.79***	227.94***
Pseudo-R^2	0.24	0.20	0.15	0.29
Observations	573	595	272	244
	Dependent variable: *Fraction of Repeated Relationships*			
1. *Normalized Total Employees*	−0.473	0.104	−2.476	−0.220
	(0.950)	(1.060)	(1.997)	(1.607)
2. *Normalized Total IT Expenditures*	3.971***	2.243**	1.606	2.343
	(1.164)	(1.113)	(1.849)	(1.681)
3. *Percent IT Outsourced*	−0.061	0.002	−0.189**	0.005
	(0.047)	(0.006)	(0.082)	(0.005)
4. *Number of IT Vendors*	−0.558***	−0.461***	−1.146**	−0.069
	(0.213)	(0.166)	(0.375)	(0.189)
5. *Application Breadth*	0.074	0.194	1.387**	−0.284
	(0.484)	(0.434)	(0.705)	(0.592)
6. *Normalized Asset Specificity*	2.329*	2.142**	−0.942	5.530***
	(1.237)	(1.128)	(1.634)	(1.692)
7. *Codifiable Terms*	0.571	0.394	−2.198	2.552
	(1.452)	(1.357)	(1.950)	(1.126)
8. *Normalized Clear Requirements*	−2.877	−2.246	−1.622	−3.302
	(1.872)	(1.555)	(2.327)	(1.201)
9. *Normalized Measurable Performance*	1.817	0.816	1.860	0.489
	(1.635)	(1.507)	(2.255)	(2.139)
10. *Normalized Monitorable Activities*	−0.243	0.299	1.339	−0.934
	(1.517)	(1.486)	(2.144)	(2.205)
11. *Coordination IT*	0.148	−0.400	−0.194	−2.737
	(1.830)	(1.930)	(2.582)	(2.827)
12. *Vendor-Specific IT*	−0.571	−0.965	−1.336	0.443
	(1.474)	(1.682)	(2.326)	(2.371)
Chi^2 (Prob > chi^2)	176.18***	76.45***	3,657.86***	72.36***
Pseudo-R^2	0.10	0.11	0.05	0.23
Observations	573	595	272	244

Notes. Cells show parameter estimates with standard errors in parentheses. All regressions included industry and country dummies.
*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

increases (Hypothesis 2). However, IT is not a monolith, so it is important not only to distinguish these effects theoretically, but also to explicitly identify and measure the different types of IT that apply to each. Investments in technologies that reduce search and transaction costs are strongly correlated with using more suppliers in all models (Hypothesis 3). At the same time, investments in vendor-specific IT are associated with lock-in and fewer suppliers (Hypothesis 4). These results support a contingent view of IT and supply chain structure in which firms simultaneously choose supply chain strategies and the specific technologies that support them. Furthermore, they establish a baseline for the assessment of the other theories we explore.

Second, according to game theory, repeated relationships can foster trust and support equilibria which are better for both buyers and suppliers. In particular, by extending Bakos and Brynjolfsson (1993a) into a multiperiod setting, we are able to make predictions about the number of vendors firms will use, the amount of supplier investments, and the economic surplus created by the relationship. As predicted, we find that repeated relationships and trust play a key role in supply chain governance: (a) as firms work with fewer suppliers, they also engage in more repeated relationships with those suppliers and (b) asset specificity and the need to induce relationship-specific investments are correlated with fewer suppliers and a larger fraction of repeated relationships.[22]

Repeated relationships allow firms to provide suppliers with stronger investment incentives without having to sacrifice their own bargaining power or ability to employ a large number of suppliers. This finding provides empirical support both for the general literature on how repeated relationships can affect incentives (e.g., Fudenberg et al. 1990, Baker et al. 2002) and the specific literature on the number of suppliers and the resulting incentives (Bakos and Brynjolfsson 1993a, b). While the Bakos and Brynjolfsson model shows that a firm can increase supplier incentives for noncontractible, relationship-specific investments by limiting the number of suppliers in a one-shot game, the provision of these incentives comes at significant efficiency costs. In contrast, in settings with repeated interaction, firms can induce suppliers to make relationship-specific investments via reputation, trust, reciprocity and loyalty without unduly limiting the number of suppliers.

Third, according to incomplete contracts theory, human and non-human assets will have different effects on the incentives for noncontractible investments (Brynjolfsson 1994). Thus, just as different types of IT are likely to have differing impacts on supply chain structure, our model predicts that supply chain governance will also differ between human capital-intensive and physical capital-intensive industries (see Models 3 and 4). Results from the split-sample analysis were consistent with the theoretical predictions. As the threat of holdup increases for suppliers, buyers are forced to provide them with assurances that create incentives for them to make relationship-specific investments. In physical capital-intensive industries, complementary nonhuman assets (plant, property, equipment, and machinery) are owned by the buyer, creating additional vulnerability to holdup for suppliers. Consequently, buyers in physical capital-intensive industries make additional assurances to suppliers, like reductions in the supply base and more repeated interactions, to create stronger incentives for supplier investments. This effect is magnified in the presence of greater asset specificity because asset-specific investments can be held up.

Our model and empirical findings have several implications for management practice. The framework clarifies not only the role of individual factors, including coordination costs, supply base size, contract repetition, asset specificity, and human capital intensity, but also the trade-offs among them. For example, we show that supply base reductions not only can counteract high coordination costs, as suggested in earlier work, but also can foster trust and thus increase noncontractible investments by increasing the number of interactions with each supplier. Our model and empirical findings also support the hypothesis that optimal ownership structures differ depending on the relative amounts of human capital and physical capital and suggest that greater physical capital intensity can increase the level of required assurances to suppliers, e.g., by contracting with fewer suppliers or entering into longer-term relationships.

This finding, however, should be considered in the context of the limitations in the empirical test of Hypothesis 6, which arguably is the most important limitation of this work. We want to test whether the marginal effect of asset specificity will be increasing in the presence of complementary investments in physical capital (relative to human capital). In our test of Hypothesis 6 we characterize certain industries as being either physical capital intensive or human capital intensive, and we use a firm's industry (i.e., whether it operates in a physical capital-intensive or human capital-intensive industry) as a proxy for the level of the firm's complementary investment in physical or human capital. It is arguable whether a firm operating in a physical capital-intensive or human capital-intensive industry is a good proxy for the level of complementary investments in physical or human capital, respectively, and this is a serious concern. Unfortunately, we are limited by our data in our ability to test this hypothesis in ideal conditions. For that reason, we see the results of our formal test of

Hypothesis 6 as merely suggestive evidence for the role of holdup in our theoretical model. A more ideal approach to this analysis might be, for instance, to collect firm-level panel data on complementary investments in human and physical capital and to employ firm and time fixed effects to control for unobserved heterogeneity that may explain the differences that we observe. We certainly hope to see more specific research on this topic in future work.

Another important limitation of our work is that our empirical analysis is primarily based on cross-sectional data. This limits our ability to understand trends over time (other than those that are self-reported) and precludes the use of panel data techniques. Furthermore, like all survey-based empirical work, variables could be operationalized in different ways and respondents may misinterpret the questions, fail to answer some questions, or provide inaccurate data, though the results are robust to several different specifications and tests for bias. The primary variables we observed in terms of susceptibility to holdup were asset specificity and the intensity of human versus physical capital. Other industry- or firm-level variables could also affect susceptibility to holdup, however, and future research should investigate this and whether our findings are robust to different operationalizations. The repeated interaction with IT suppliers may also be driven by concerns about compatibility, which would be specific to our industry setting and thus might limit the generalizability of our results; if this is the case, however, we believe it would likely affect all firms in a comparable way and thus would not affect the comparative statics among the variables we consider, neither theoretically nor empirically. While our data are from a variety of types of firms in 12 different countries, they cannot capture the full span of potential or actual supplier relationships. Though our results likely generalize well to IT supply, they may not generalize as well to the supply of auto parts, for instance, or other materials. More research is needed on how similar supply relationships are across different contexts. Given the nature of our data, we cannot rule out the possibility that some of our results are driven by unobserved heterogeneity (i.e., differences in variables that we didn't measure). Finally, while our instrumental variables techniques are designed to address endogeneity, they cannot fully eliminate the potential for this type of bias.

6. Conclusion

In some ways, empirical investigations of the IT-supply base relationship have been reminiscent of the story of the blind men examining an elephant. Studies have examined different theories and perspectives on the subject in isolation, focusing on search and coordination, transaction cost economics, or incomplete contracts theory alone. Taken individually, each of these theories is sensible. However, collectively they have supported contradictory predictions about when firms are likely to work with more or fewer suppliers or when they are likely to "move to the middle." What's more, while theories abound, there has been a relative dearth of large-scale empirical work on IT and supplier relations outside of manufacturing industries.

Our work attempts not only to bridge and integrate these theoretical perspectives but also to test alternative theories about the relationship between IT and supply base size using what we believe is the largest global survey of IT procurement and governance conducted to date. Our integrated model incorporates, formalizes, and extends the key features of earlier theories and makes testable predictions, as summarized in Tables 2 and 4. Our data were specifically gathered with these theories in mind, explicitly distinguishing among different types of IT and asking about codifiability, asset specificity, repetition, and other factors. Our data set covers the IT sourcing decisions of 1,355 firms in 12 countries, providing the breadth of coverage and statistical power to distinguish among hypotheses.

Our theory and data address three questions that are central to the understanding of IT and supplier relations: (1) Does IT reduce coordination and search costs, or does it increase lock-in? (2) Is a reduction in the number of suppliers associated with an increase in repeated relationships, potentially mitigating the holdup problems associated with asset specificity? Additionally, (3) how does the role of human and nonhuman assets mediate supply chain governance? While an empirical test of any one of these questions in isolation might give contradictory or ambiguous results, by examining them simultaneously, we can better understand the relevant trade-offs and interactions. For example, we find that IT does not have a universal effect on coordination and search costs, but rather, the effect depends on the type of IT used. Our empirical results regarding incomplete contracts theory also highlight the importance of contingencies, including the industry setting. When there are large investments in nonhuman assets, holdup is more of an issue. Furthermore, we find evidence that reducing the supply base can foster repetition and, in turn, repetition may mitigate some of the problems that arise when assets are specific to a bilateral relationship.

The unified framework we develop can also help to guide managers to address their IT sourcing relationships. Considering sourcing decisions in context, determining the need to provide investment incentives to suppliers, the relative importance of trust and repetition in different industries and understanding the variable impact of different types of IT on supply relationships can help managers to decide when and how to increase or decrease supply base size. Apple's decision to increase their supply base is a fundamental supply strategy decision. Our work sheds theoretical and empirical light on these decisions, highlighting for managers the dimensions of firm and industry context that should shape these decisions.

Our understanding of IT and supplier relationships depends on improved theory and better data. Given the plethora of theories, our main theoretical contribution is to integrate prior work and, in particular, to formalize the role of repeated interactions, as suggested by casework and interviews. Ultimately, empirical evidence is the standard by which any theory must be assessed. The large new data set we introduce, which includes key metrics of interest, seeks to help the field to advance on this front as well.

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Endnotes

[1] We use the term "holdup" to refer to the ability of any party to appropriate greater value in bargaining over ex post surplus. We use "lock-in" to refer to switching costs created by adopting specific technology or processes that require specific investments.

[2] A few notable studies examine different theories in isolation, focusing on search and coordination, transaction cost economics, or incomplete contracts theory separately in single firms (e.g., Levina and Su 2008, Levina and Vaast 2008, Levina and Ross 2003, Craighead et al. 2007, Dyer 1997), manufacturing (Helper et al. 2000, Helper and Levine 1992, Helper 1991, Dedrick et al. 2008), or differences between the United States and Japan (Cusumano and Takeishi 1991).

[3] For instance, firm needs may evolve from period to period, and suppliers are ex ante equivalent in their ability to target their product offerings to anticipated firm requirements.

[4] For instance, α may scale the fit cost, which could be given by αx or αx^2.

[5] In most real-world settings, this type of supplier investment would only be responsible for part of the value generated by the firm. For instance a software supplier's investment may involve customizing its product to the firm's needs and providing appropriate training. Some part of that investment will be contractible (e.g., installation of the software and trainer time spent at customer premises), and that part will allow the firm to generate some value even if the supplier completely shirks the noncontractible part (e.g., to assign high-quality developers and trainers who invest the effort to understand the firm's needs and to meet unanticipated changes in the firm's requirements after the contract is signed). Since the contractible supplier investment does not present the incentive problems that drive our analysis, we normalize the setting so that investment X is entirely noncontractible and in its absence the firm generates zero value.

[6] Since all suppliers are ex ante identical, the expected surplus $\hat{f}(\alpha, n)$ from a specific supplier also provides a measure of that supplier's fit; a higher $\hat{f}(\alpha, n)$ value would correspond to a better fit.

[7] The folk theorem provides that there will be a multiplicity of equilibria, with punishments less severe than the "grim strategy" indicated above; however this is a reasonable focal strategy as it provides the strongest incentives for cooperation. Since there is no uncertainty in the outcome from investing (or not investing), grim outcomes (supplier firings) only occur off the equilibrium path and thus will not be observed at equilibrium. Also, Brown et al. (2004) find in an experimental setting that low effort or bad quality are penalized by termination of the relationship. A less grim strategy toward defecting suppliers would not change the qualitative nature of our results if the punishment were sufficient; other things being equal, it would reduce the optimal number of suppliers as it would reduce the cost of defection, and thus the firm would need to increase the benefit from cooperation.

[8] The selected supplier may be able to appropriate an even higher payoff due to its bargaining power as one of a limited number of long-term suppliers. Since the coordination cost of κn is sunk, the firm and its suppliers generate expected incremental surplus of $f(\alpha, n) - X$. Following Hart and Moore (1990), we can apportion this surplus based on each participant's Shapley value, so that the firm will appropriate $(f(\alpha, n) - X)n/(n+1)$ and each supplier will appropriate $(f(\alpha, n) - X)/n(n+1)$. If each period the selected supplier receives the entire supplier share of the surplus, its payoff will be $\max((f(\alpha, n) - X)/(n+1) + X, X\delta^{-n})$, a portion $\beta f(\alpha, n)$ of which will be captured in ex post bargaining, with a resulting profit of $\max((f(\alpha, n) - X)/(n+1), X(\delta^{-n} - 1))$. The firm's corresponding period profit is $\Pi(n) = \min((n-1)/(n+1) f(\alpha, n) - \kappa n - \nu K - (2n)/(n+1)X, (1-\beta) f(\alpha, n) - \kappa n - \nu K - \delta^{-n}(X - \beta f(\alpha, n)))$. This scenario is similar to Bakos and Brynjolfsson (1993a) in the sense that the value appropriated by the suppliers is based on their Shapley value bargaining power. The Shapley value share of $1/n(n+1)$ for each supplier rapidly decreases as the number of suppliers increases; thus we simplify our analysis by assuming that the Shapley value does not provide adequate incentives to the supplier. This does not involve much loss of generality and focuses on the case where repetition enables outcomes that would otherwise be unattainable.

[9] f increases with n as the distance x of the best-fitting product offering, which is the minimum of the n draws, decreases. This decreases the expected improvement in the next draw, and thus $\partial^2 f(\alpha, n)/\partial n^2 < 0$.

[10] While firms may employ hundreds or thousands of suppliers in total (e.g., see Dedrick et al. 2008), supplier incentives are determined by the number of alternative suppliers for a particular product or service, as modeled in our setting.

[11] For a recent description of the marked increase in vendors' poaching of the corporate IT staff of their clients, see King 2011.

[12] We asked respondents about their IT contracting and vendor selection responsibilities: 88% of respondents were authorized to select vendors, 81% were authorized to select brands, 81% were tasked with determining IT needs, 72% were responsible for creating IT strategy, 67% were responsible for authorizing purchases, 73% were responsible for managing vendor contracts and relationships, and 71% were responsible for the design and architecture of approved IT solutions. The average respondent was responsible for 5.3 of these 7 responsibilities. Of all respondents, 55% were IT managers and 45% were senior business managers.

[13] We surveyed a stratified sample of global firms to capture firms of representative sizes in the United States, Europe, the Asia Pacific region, and in emerging markets. We sampled 250 firms from the United States and 100 firms each from France, Germany, the United Kingdom, Australia, China, India, Korea, Japan, Brazil, Mexico, and India.

[14] The sample was stratified to include 25% small enterprises (between 20 and 100 employees), 25% medium-sized enterprises (between 100 and 999 employees in the United States and between 100 and 499 employees in the rest of the world), and 50% large enterprises (more than 1,000 employees in the United States and more than 500 employees in the rest of the world). The resulting sample included 333 firms with fewer than 100 employees (25%), 470 firms with between 100 and 999 employees (35%), 528 firms with more than 1,000 employees (40%) (mean number of employees = 10,463, SD = 39,705.56, min = 20, max = 500,000), for a total of 1,331 firms

(24 respondents did not provide data on the number of employees). The data were collected through a web survey dynamically adapted to satisfy the stratification constraints and while we were able to control for observable characteristics such as firm size or geographic location, we are not able to calculate an exact response rate or bias. Thus there is a risk that the firms we analyze in our sample differ from the universe of firms in the economy in ways we did not observe.

[15] We note that, while these instruments can help to address firm-specific simultaneity, they could influence the number of suppliers and fraction of repeated relationships by means other than the firm-level variables they are instrumenting; for example, they can influence the competition and availability of suppliers in the industry, which could in turn affect the dependent variables.

[16] The average adjusted R^2 in the first-stage regressions is 0.67 across the six endogenous variables and all instrument coefficients and F-statistics are all highly significant, demonstrating the strength of these instruments in each of the six first-stage regressions (see the online appendix).

[17] We apply the correlational marker technique (CM) instead of other techniques such as the confirmatory factor analysis marker technique, the unmeasured latent method construct technique, and Harman's single-factor test because CM has been found to have the highest true positive rate (Richardson et al. 2009).

[18] It should be noted that this relationship is not tautological; for instance it is possible for a firm to reduce the number of suppliers while at the same time reducing their tenure; the result would be fewer suppliers, but more frequent changes and a reduced fraction of repeated relationships.

[19] We define human capital-intensive industries as including professional services, software, education, healthcare, nonprofit, finance, insurance, and real estate management. This subsample consists of 272 firms. We define physical capital-intensive industries as including manufacturing, construction, energy, telecommunications, and transportation. This subsample consists of 244 firms. We exclude federal and state and local Government, retail, wholesale, and other. However, inclusion of these industries with government in human capital and retail and wholesale in physical capital industries produces similar results.

[20] This result also reinforces the validity of our second finding by excluding alternative explanations for repeated interaction (such as suppliers learning how to fulfill a firm's needs) or serial correlation in firm needs and supplier offerings (the suppliers that best satisfy the firm's needs in one period are likely to do so in the following period(s)).

[21] While our theoretical model does not make predictions about the direction or magnitude of other parameters in the split-sample analysis, some other results may warrant further investigation in future work. Vendor-specific IT creates lock-in and supply base reduction in physical capital-intensive industries but has no affect in human capital-intensive industries. This could be due to a greater need to create incentives for suppliers to make noncontractible investments in physical capital-intensive industries caused by differences in asset ownership and bargaining power as previously discussed. Total IT investments and coordination IT are more strongly associated with use of more suppliers in physical capital-intensive industries than in human capital-intensive industries. This could be because IT use increases measurability, which is associated with increases in supply base size (Hypothesis 5). If work in human capital-intensive industries is inherently less measurable, this could explain why these effects are less pronounced in human capital-intensive industries. In our sample, there is a positive and statistically significant correlation between IT spending and codifiability ($p < 0.01$), and codifiability, monitorability, and measurability are all higher in physical capital-intensive industries than in human capital-intensive industries (t-test significance for codifiability, $p < 0.05$; monitorability, $p < 0.10$; measurability, $p < 0.10$), which may lend credence to this argument.

[22] It should be noted that this relationship is not tautological; for instance, it is possible for a firm to reduce the number of suppliers while at the same time reducing their tenure; the result would be fewer suppliers, but more frequent changes and a reduced fraction of repeated relationships.

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