The Digital Reorganization of Firm Boundaries: IT Use and Vertical Integration in U.S. Manufacturing[*]

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Abstract

We investigate complementarities between external uses of information technology (IT) and firm boundary decisions following the diffusion of the commercial Internet. Using detailed plant-level data covering roughly 2,500 establishments from the U.S. Census of Manufactures, we focus on the decision to allocate production output to either downstream plants within the same firm or to external customers. Using a differences-in-differences design, we find that IT-enabled coordination with external supply chain partners is associated with a significant decline in downstream vertical integration. Our results are robust to extensive time-varying controls for both internal and external downstream demand, as well as instrumental variables estimation. In addition, we find that the upstream and downstream uses of digital coordination are complementary to each other; the magnitude of the effect is greatest when *both* suppliers and customers are granted greater visibility into the focal plant's operations.

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1. Introduction

The information age has arrived – but unevenly, and with consequences that we are still just beginning to understand. While U.S. firms have invested robustly in information technology over the past few decades,[1] the returns on these investments have often lagged (Tambe and Hitt 2012) and vary strikingly across organizations (e.g., Aral and Weill 2007). One approach to understanding this variation focuses on complementarities between IT adoption and organizational practices within firms. This line of research explores the possibility that firms adopting a particular set of IT and organizational practices *together* will enjoy greater returns than those adopting individual practices or technologies in isolation (Milgrom and Roberts 1990; Brynjolfsson and Milgrom 2012). Consistent with the idea that a coordinated system may be greater than the sum of its parts, evidence is mounting that alignment between IT and certain aspects of a firm's organizational strategy (e.g., allocation of decision rights, worker training, or compensation policies) is associated with greater IT-related productivity.[2] However, the best "recipes" for combining IT applications and organizational features remain elusive to practitioners and scholars alike.

We argue that a key missing ingredient is careful consideration of the external interactions between a firm and its value chain partners. With a couple of notable exceptions (Bartel et al. 2007, Tambe et al. 2012), the existing IT complementarities research has focused on characteristics that are internal to the firm. Yet a growing body of evidence indicates that external linkages to suppliers and customers may be instrumental in determining firm performance[3] as well as influencing important strategic decisions such as market entry (Alcacer and Oxley 2012) or product and process innovation (Afuah and Bahram 1995, Tambe et al. 2012, McElheran 2013).

In this paper, we focus on one of the most fundamental organizational design choices: where to draw the firm boundary. In particular, we investigate the conditions under which a firm's choice to keep transfers of intermediate products within the firm – i.e., whether it will be vertically integrated – will be

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[1] Annual IT-related investment by U.S. firms exceeded $558 billion in 2012 (U.S. Bureau of Economic Analysis, 2012). For further detail, see Jorgenson, Ho, and Stiroh (2005).

[2] See, for example, Aral et al. (2012), Tambe et al. (2012), Bloom et al. (2012) and Bresnahan et al. (2002).

[3] For evidence on the performance benefits of firm investment in interorganizational systems see, for example, Dong, Zu, and Zhu (2009), Mukhopadhyay, Kekre, and Kalathur (2002), and Yao and Zhu (2012).

affected by the adoption of externally-focused information technology. In prior work, inter-organizational IT investments (e.g., electronic data interchange, or EDI) have been found to accompany a range of relationships between producers and their partners within the value chain.[4] However, there has been little direct empirical testing of how such IT-enabled linkages influence the ownership structure of production chain activities, and none has considered multiple margins of external and internal IT investment.

The goal of this paper is to provide new empirical evidence on this question, highlighting the role that changes in the costs of both upstream and downstream coordination might play in shaping the organization of production. To that end, we leverage the lens of complementarities and a unique micro-level dataset to investigate how upstream, downstream, and internal IT use may impact firm boundary decisions. In particular, our core hypothesis is that, all else equal, the returns to less vertical integration will be higher in the presence of externally-focused IT.

To test this hypothesis, we exploit a unique data set that allows us to both measure vertical integration at the micro level and disentangle different dimensions of IT investment. We combine non-public establishment-level data from the 1992 Census of Manufacturers (CMF) with the 1999 Annual Survey of Manufactures (ASM), including its Computer Network Use Supplement (CNUS) addendum. This large panel of data brackets the arguably transformative diffusion of the commercial Internet (circa 1995) and yields detailed observations for roughly 2,500 plants across a wide range of industries.

Our dependent variable is the value of plant shipments transferred to other plants within the same firm, normalized by the plant's total value of shipments, i.e., the *percentage of within-firm transfers.* This measure has the advantage of directly capturing – at the plant level – the extent to which output is used for downstream production within the same firm. To our knowledge, this represents one of very few opportunities to directly observe the extent of vertical integration in production chains across multiple

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[4] For example, IT investments have been shown to influence the likelihood that firms will outsource critical business processes (e.g., Bardhan, Mithas, and Lin 2007) and will also influence the optimal number of suppliers (e.g., Aral, Bakos, and Brynjolfsson Forthcoming; Clemons, Reddi, and Row 1993; Dedrick, Xu, and Zhu 2008). Recent work has studied other aspects of interorganizational collaboration such as alliances and other types of external orientation (e.g., Tambe et al. 2012; Tafti, Mithas, and Krishnan 2013).

industries.[5] We also observe not only *what* networking technology is in use at a respondent plant but *with whom* it shares information – an unusual feature of our data and a key requirement of our research design.

We use difference-in-differences estimation to study whether adoption of new-to-the-world Internet-enabled IT that lowers the costs of communicating and coordinating between firms is associated with changes in vertical integration. Our choice of estimation strategy reflects two considerations. As in prior work (e.g., Arora 1996; Novak and Stern 2009), we rely on revealed preferences to test for complementarities without directly estimating the performance implications of organizational choices. This decision is driven by data constraints: while we have rich information on the inputs and outputs of individual plants, some of the benefits and costs of firm boundary decisions may accrue to other, unobserved, units within the firm. Second, we focus on the causal impact of externally-focused IT use for firm boundaries, and not the converse. We exploit the rapid decline in information processing and communications costs during our sample period – in particular, those enabled by the widespread commercialization of the Internet –to explore how the resulting new IT adoption changed the returns to adopting related organizational practices.

We find that externally-focused IT for both downstream and upstream coordination is associated with a 2-3 percentage point decline in the percentage of within-firm transfers. Relative to a mean percentage of 14.4%, this represents an economically as well as statistically significant impact. We further demonstrate that the organizational response to the adoption of external IT is isolated to a particular set of circumstances where the plant adopts IT for coordinating economic activity with *both* suppliers and customers. That is, there exist three-way complementarities between supplier IT, customer IT, and vertical integration. This is consistent with arguments in the operations management literature that the value of IT-enabled information sharing in the value chain will be increasing in the number of linked participants (Lee, Padmanabhan, and Whang 1997).

Our initial results treat IT adoption as an exogenous factor that influences economic outcomes.

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[5] For another example of measurement of vertical integration using Census micro-data, see Atalay, Hortacsu, and Syverson (2013). For examples that use the institutional features of specific industries, see the studies surveyed in Lafontaine and Slade (2007).

Then, we examine the implications of this assumption through a series of additional analyses.[6] First, we control for a range of other plant, firm, and local factors that are believed to shape firm boundary decisions. Second, we show that the timing of organizational changes is consistent with the diffusion of the commercial Internet. Third, we instrument for external IT adoption using variables that will shift the costs of adoption. Our first instrument uses an engineering estimate of the local costs of delivering telecommunications services. Our second two instruments follow recent literature (e.g., Forman, Goldfarb, and Greenstein 2008, 2012; Augereau, Greenstein, and Rysman 2006) by using the IT investment behavior of geographically linked establishments within the same firm and of their competitors as instruments. Fourth, our findings of three-way complementarities circumscribe the way in which unobserved heterogeneity must influence our results. Namely, it would need to appear only in the presence of both customer and supplier IT together, but not when these are adopted separately.

We last extend our findings to examine some of the circumstances under which adoption of external IT has the greatest effect on changes in firm boundaries. We find our results are strongest in large organizations, for which the tradeoff between external and internal costs of exchange may be most relevant. We further show that the impact of external IT is particularly pronounced where supply chains tend to be more complex: e.g., in multi-product plants and in the transportation equipment manufacturing industry. While these cuts of the data are surely not exhaustive, they provide preliminary insight into the underlying heterogeneity in the distribution of these complementarities.

The research contribution of these findings centers on bringing a novel external dimension to the complementarities literature and better understanding how “complementarities explain the specific set of activities that happen inside of firms and those which are outsourced or spun-off” (Brynjolfsson and Milgrom 2012, p.66). However, these findings also shed light on long-standing questions concerning the impact of IT on organizational boundaries. Networked IT investments can reduce the costs of coordinating economic activity inside the firm we well as with outside market participants. Therefore, the

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[6] This empirical approach has been followed by a range of papers that study the implications of IT adoption decisions on organizational outcomes, including Athey and Stern (2002), Bloom et al. (2009), Forman, Goldfarb, and Greenstein (2012), and Aral, Brynjolfsson, and Wu (2012).

ultimate impact will depend upon how specific uses of IT improve external and internal coordination costs– and the relative magnitude of these effects (e.g., Malone, Yates, and Benjamin 1987; Gurbaxani and Whang 1991; Baker and Hubbard 2003). A leading hypothesis has been that generic IT capital spending will be associated with a greater decline in external costs of monitoring than internal ones (e.g., Malone, Yates, and Benjamin 1987; Gurbaxani and Whang 1991), generating the prediction that an increase in general IT capital spending should be associated with smaller (less integrated) firms.

Large-scale multi-industry empirical studies have sought to test this hypothesis either by measuring the extent of vertical integration using average firm size within industries (Brynjolfsson, Malone, Gurbaxani, and Kambil 1994; Hu and Saunders 2012) or by measuring the extent of firm participation in industries that are more or less vertically integrated (Dewan, Michael, and Min 1998; Hitt 1999; Ray, Wu, and Konana 2009). These studies provide important insights into the scope of firm activity, however they are limited in the information they provide on how IT investments have reorganized firm boundaries at discrete points along the production chain and the specific applications of IT that complement organizational change. In contrast, by measuring the effects of specific types of IT-enabled information-sharing on commodity flows within production chains, we can more directly study the microfoundations of this phenomenon.

Our paper also contributes to the operations management literature studying supply chain coordination within and between firms. A long line of work (e.g., Bray and Mendelson 2012; Cachon et al. 2007; Lee, Padmanabhan, and Whang 1997) has argued that investments in information technology will increase the efficiency of supply relationships between heterogeneous partners at multiple points in the value chain. However, the implication that this should increase the benefits of arm’s length transactions relative to vertical integration in equilibrium has not been tested directly to our knowledge.

Finally, the determinants of firm boundary decisions have been central areas of study in both economics and strategy. Understanding what drives the decision to organize economic activity according to the rules of organizations versus those of the market has been deemed “one of the most important issues in economics” (Lafontaine and Slade, 2007, p. 629) and represents a core research question and source of controversy in the strategic management literature (e.g., Argyres and Zenger 2012, *inter alia*).

2. Theoretical Motivation

Because leading theories of the firm center on the costs of gathering, communicating, and verifying information within and between firms (Gibbons 2005, LaFontaine and Slade 2007), information technology has the potential to shift these costs – and therefore the optimal demarcation of the firm (Gurbaxani and Whang 2001). The challenge is that generic IT investment has the potential to shift multiple margins at the same time, requiring care in both generating and testing predictions.

We proceed by detailing the types of incentive and coordination problems that have been argued in prior work to increase the cost of market-based exchange, thereby favoring internal organization of commodity flows. This is not intended to be a comprehensive catalog of the factors influencing firm boundary decisions, which would require far more space than we have here.[7] Rather, we describe some of the more common problems in market-based exchange, with a particular focus on ones that can be addressed with IT. We then provide examples of how externally-focused IT can address these particular transaction costs and develop implications for the distribution of firm boundaries in equilibrium. By focusing on how specific types of externally focused IT will reduce particular costs, our approach differs from prior work that has focused on the implications of generic IT investments for the costs of market versus internal exchange (e.g., Malone, Yates, and Benjamin 1987; Gurbaxani and Whang 2001).

A complete treatment of how IT influences firm boundaries would also address the costs of *internal* organization of commodity flows and how IT might likewise shift this margin (Gibbons 2005). We justify our asymmetric external focus based on our empirical strategy, which separately controls for the use of IT to coordinate economic activity *inside* the firm as well as for a variety of other fixed and time-varying internal characteristics that might otherwise impact firm boundary choices (see Section 3).

2.1 Impact of Externally-Focused IT

2.1.1 Incentive Problems in Supply Chain Relationships

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[7] For reviews of the related literature, see LaFontaine and Slade (2007) and Gibbons and Roberts (2012).

Exchange relationships between independently owned firms are subject to a range of incentive problems that may give rise to opportunistic behavior by customers and suppliers, thereby increasing the costs of market-based exchange. The transaction cost economics (TCE) literature emphasizes how incomplete contracts can expose parties to costly renegotiation after relationship-specific investments have been made (e.g., Williamson 1975). It is widely believed that such investments can be significant in production chain relationships (e.g., Clemons and Row 1992) and provide firms strong incentives to extract quasi-rents from less-powerful partners once these investments have been made.[8]

Other incentive problems among production chain partners are the focus of a sizeable literature in operations management (e.g., Lee and Whang 1999) and are particularly salient in our setting. For instance, downstream customers may misstate delivery performance, claiming late or incomplete delivery when goods have in fact been received on-time and in full (Langer et al. 2007). Order rationing by suppliers during shortages can lead downstream firms to strategically overstate their orders and forecasts (Lee, Padmanabhan, and Whang 1997). Suppliers can also exhibit opportunistic behavior: in the absence of real-time information, they may purposefully misstate order status information, hoping to make up unreported delays through expedited production or shipping. We argue that these behaviors generate external transaction costs that will encourage internal organization of the production chain, all else equal.

2.1.2 Coordination Problems in Supply Chain Relationships

Abstracting away from incentive misalignment among supply chain partners, the costs and effectiveness of coordination among firms will also influence the optimal mix of internal and external commodity flows. Again, the supply chain management literature provides useful motivation. In particular, one common problem arises when demand signals are correlated and upstream suppliers observe only orders and not final demand. In such cases, if there is a demand shock, downstream firms may make large changes to their orders based on their updated forecasts. As a result, the demand information that was received by the downstream firm is transmitted in an exaggerated form to the

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[8] The potential for these costs to favor vertical integration of production activities has received considerable attention from TCE scholars. For a review, see Shelanski et al. (1995)

upstream supplier, and so on, up the value chain. This leads to the well-known “bullwhip effect.” Inefficiencies created by the bullwhip effect typically hurt all participants in the supply chain in the form of excess raw materials inventory, unplanned purchases of supplies, inefficient asset utilization and overtime, excess warehousing expenses, and premium shipping costs (Lee and Whang 2000).

High external coordination costs have other efficiency implications. For example, the information-gathering and communication costs of transacting with external partners often contribute to order batching. This, in turn, exacerbates order variability (Lee, Padmanabhan, and Whang 1997) and contributes to higher inventory and order-fulfillment costs (e.g., Chen and Lee 2009). Failure to coordinate supply with demand typically leads to stock-outs and/or additional inventory carrying costs.

2.1.2. The Implications of External IT

Many externally-focused applications of IT are specifically designed to reduce the costs of market-based exchange described above. Consider two examples of how external IT may reduce costs arising from incentive conflicts. First, by making information both more readily available and verifiable, external IT can increase the range of activities on which firms can explicitly contract. For instance, it can enable parties to contract on shipment dates rather than the dates on which goods are received, preventing upstream firms from taking noncontractible actions that delay shipment and then blaming the delays on transportation and logistics partners. Second, by sharing information such as order status, production schedules, and inventory data with downstream customers, the latter may face less supply uncertainty – a central driver of strategic ordering behavior (Lee, Padmanabhan, and Whang 1997).

The first-order reduction in the costs of sharing information due to digital communications is believed to have enhanced production coordination across a range of settings and activities.[9] In particular, sharing frequently updated demand data with upstream suppliers helps them produce better forecasts and formulate better production plans. This, in turn, can reduce input shortages at downstream plants, reduce inventory holding costs related to buffer stocks (for all supply chain partners), and alleviate other

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[9] See for example, Malone, Yates, and Benjamin (1989), Gurbaxani and Whang (1991), Clemons and Row (1992) and, more recently, Baker and Hubbard (2003) and Ray, Wu, and Konana (2009).

problems commonly associated with the bullwhip effect (Lee and Whang 2000). Lee et al. (2000) have quantified the value of such information-sharing in an analytical two-level supply chain model, showing that it can provide significant inventory reduction and cost savings to a downstream manufacturer.

It is worth emphasizing that, in a multi-level supply chain, information-sharing with *upstream* suppliers can influence a plant's costs of transacting with *downstream* customers. This is because the overall value to the supply chain of information-sharing is increasing in the number of electronically linked participants (Lee and Whang 2000, Leng and Parlor 2009). That is, the benefits of information-sharing are greatest when a plant shares *both* with suppliers and customers. As chain-wide costs decline, some of the benefits will accrue to the focal plant (Lee and Whang 2000, Leng and Parlor 2009).[10]

The discussion above only touches on a handful of examples and cannot do justice to the importance of information sharing and coordination in supply chain management. However, it motivates our argument that, all else equal, the effects of external IT will reduce an array of costs associated with market-based exchange, increasing the net value of transacting with external customers for firms that have adopted the technology. In equilibrium, this complementarity will tend to promote less vertical integration among firms adopting external IT. Moreover, we expect that the shift to market transactions will be greatest when upstream and downstream IT are adopted jointly.

3. Empirical Approach to Testing Complementarities

The theory of organizational complementarities was formalized by Milgrom and Roberts (1990, 1995), who argue that there may be important nonconvexities in the returns to combined systems of organizational practices and provide a framework for addressing the possibility that marginal returns to one organizational choice are increasing in the levels of the other choices. Their prediction is that dramatic productivity differences will naturally arise between firms that adopt an integrated system of complementary practices versus those that adopt only certain practices in isolation.

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[10] Leng and Parlor (2009) demonstrate in a three echelon supply chain that total supply chain profits are increasing in the number of linked participants. Using cooperative game theory, they then devise a scheme for allocating the payoffs among supply chain participants.

The two basic statistical tests used to detect complementarities have been 1) correlations in adoption or demand and 2) evidence of systematic performance differences, usually productivity (Arora 1996, Athey and Stern 1998, Novak and Stern 2009, Brynjolfsson and Milgrom 2012). The first determines if a cluster of practices are in fact adopted jointly more often than they are adopted separately; optimizing firms ought to understand the complementarities and adopt accordingly. The second tests whether the combination of practices actually generates greater productivity than the separate components (Milgrom and Roberts 1990, Ichniowski et al 1997, Bresnahan et al. 2002).

As noted above, the location of firm boundaries will influence a range of benefits and costs, some of which may accrue to economic agents beyond the focal establishment. Given our focus on the establishment as the unit of analysis and our incomplete data on firm components in some (non-Census) years of our data, it is difficult for us to directly test for the productivity or profitability implications of vertical integration, which would be more appropriately addressed in a firm-level analysis. Instead, we rely on a revealed preference argument that only requires the firm (and not the econometrician) to know about the returns to vertical integration across its constituent establishments. Assuming that firms are optimally choosing combinations of organizational boundaries and IT, then if the returns to less vertical integration are higher when external IT is in place at a given plant, then there should be a lower observed level of vertical integration amongst adopting plants compared to non-adopters. In essence, this is a form of the correlation test, with the addition of a robust set of controls. Moreover, we also explore the causal relationship between the complementary variables (see below).

We motivate our empirical analyses using a behavioral model developed in prior work on complementarities among organizational decisions (Novak and Stern 2009).[11] Suppose that there is an observable binary firm boundary choice, *ORG*, and an observable externally-focused technology choice, *ExternalIT*, with separable net benefits to the firm denoted by β_i, $i = (ORG, ExternalIT)$. Both the firm and the econometrician observe choice-specific drivers Z_i with marginal returns to the firm of those

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[11] For closely related approaches see Arora (1996), and Athey and Stern (2002).

choices δ_i . Choice-specific mean-zero shocks η_{ij} are observed by the firm but not the econometrician. These choice-specific shocks may be correlated; in particular, there may be a firm-level shock for firm *j*, ξ_j, that simultaneously decreases the level of vertical integration and increases investment in external IT. Thus for choice *i* at each firm *j*, the random shock can be decomposed into a firm-level and choice-level effect: $\eta_{ij} = \xi_j + \varepsilon_{ij}$. Assuming that firms will adopt a practice whose net benefits are positive, the typical adoption condition for the organizational choice in the absence of complementarities would be:

$$ORG_j = 1 \text{ if } \xi_j + \beta_{ORG} + \delta_{ORG} Z_{ORG_j} + \varepsilon_{ORG_j} > 0 \, , \qquad (1)$$

with an analogous condition for the *ExternalIT* decision. We note that prior to the appearance of Internet-enabled external IT, condition (1) determined whether vertical integration would be selected.

However, the returns to each choice may be interdependent: following the arguments detailed in the previous section, the marginal returns to less vertical integration ought to depend on whether external IT has been adopted, and vice versa. For simplicity, assume that the parameter of interdependence, λ , is common across all firms. Thus, the adoption condition for each practice becomes:

$$ORG_j = 1 \text{ if } \lambda ExternalIT_j + \xi_j + \beta_{ORG} + \delta_{ORG} Z_{ORG_j} + \varepsilon_{ORG_j} > 0$$

$$ExternalIT_j = 1\ if\ \lambda ORG_j + \xi_j + \beta_{ExternalIT} + \delta_{ExternalITj} Z_{ExternalITj} + \varepsilon_{ExternalITj} > 0 \qquad (2)$$

Thus, the firm's organizational or technology choice depends on the complementary decision, the observable choice-specific drivers, Z_{ij} , and the stochastic components ξ_j and ε_{ij} .The parameter λ captures the degree of complementarity (assuming $\lambda > 0$, else this would be the degree of substitutability) between the two practices and is the object of the econometric analysis.

In our setting, we measure *ORG* using the percentage of within-firm transfers, *WFT*. Specifically, given some existing short-run production capacity at the focal plant, the parent firm has the choice to allocate all or some fraction of this capacity to internal downstream customers. At one extreme is complete forward integration, with 100% of the output allocated to internal use. Outside of this boundary case, productive capacity at the plant not used internally may be sold on the external market.

How much of a plant's existing capacity is allocated to external sales will define the firm boundary in a fundamental way. While this definition differs from the common "make or buy" question concerning asset ownership (e.g., Williamson 1975, Grossman and Hart 1986; Gibbons 2005, *inter alia*), it is consistent not only with Coase's seminal (1937) article but also with more recent work taking transactions as the fundamental unit of analysis (e.g., Masten 1984, Oxley 1997, Novak and Stern 2009). Following prior empirical work addressing organizational design choices (e.g., Hubbard 2000, Bresnahan et al. 2002, Aral et al. 2012) we assume that ownership is a longer-run decision that is quasi-fixed when firms make short-term decisions – in this case, how best to allocate their existing production output.

Consider the following linear probability model:

$$WFT_j = \alpha_{WFT} + \lambda ExternalIT_j + \delta_{WFT} Z_{WFTj} + \eta_{WFTj} \tag{3}$$

Estimation of equation (3) using OLS will lead to biased coefficient estimates of λ. One fundamental challenge is that WFT will be increasing in the firm-level component of η_{WFT_j} , ξ_j, so a cross-sectional estimation using ordinary least squares (OLS) will be biased due to the omitted variable and may provide a positive coefficient on the IT variable where no complementarities, in fact, exist.

We use two sources of variation in our data to identify the effects of external IT on firm boundaries. First, as described above, our data straddle the diffusion of the commercial Internet, so the option to adopt $ExternalIT_j$ prior to then does not exist. We use differences in establishment decisions to adopt $ExternalIT_j$ after its initial appearance to identify its affects on the ORG_j decision.

This empirical strategy has two implications. First, it allows us to extend equation (3) to allow for time series variation, allowing for changes over time in *WFT* and the later appearance of *ExternalIT*. That is, we estimate the following:

$$WFT_{jt} = \alpha + \lambda ExternalIT_{jt} + \delta Z_{jt} + \mu_j + \tau_t + \eta_{jt} \tag{4}$$

where we now suppress the *WFT* subscripts on our parameters to simplify notation. We estimate this model over two periods, 1992 and 1999. Thus, our primary approach uses difference-in-difference linear regression, comparing the percentage of within-firm transfers prior to adoption of IT to the percentage after adoption.[12] It is worth noting that we use the firm's short-run decision to adopt a new technology shortly after its appearance as a source of variation that identifies a change in communications costs that will shift the benefits of WFT. As a result of this approach, we do not study the converse effect of WFT on IT adoption (as would be common in other studies of complementarities).

The regression above assumes that unobserved factors can be decomposed into an additively separable time-invariant component and a time-varying component that is constant across establishments (Athey and Stern 2002). However, there remains the possibility that time-varying factors may simultaneously boost the adoption of certain organizational practices and IT, creating the appearance of complementarities where none actually exist.

We use several features of our empirical setting to probe whether our regression results indicate a causal relationship. First, we include a variety of controls related to the productivity of the plant, the demand for its output from both local establishments and other establishments within the same firm, and competition from other plants in the same industry and location.

Second, we present instrumental variables regressions that use local telecommunications costs, adoption of external IT by plants in competing firms, and the IT capabilities of other plants within the same firm as instruments. As explained in detail below, changes in these instruments should affect the likelihood of adopting external IT but should not affect the extent of within-firm transfers. Third, we can use the sudden and rapid diffusion of the commercial Internet to run a falsification exercise. No affiliation between external IT and changes in firm boundaries should be observed prior to when this began in 1995. The absence such "false positives" can be taken as additional support for our identification assumptions.

4. Data

We match data on IT use from the Census Bureau's 1999 Computer Network Use Supplement (CNUS)[13] to plant-level data on production, shipments, and internal transfers from the Annual Survey of

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[12] We estimate equation (4) using robust, clustered standard errors so the approach will give identical results to a cross-sectional two-period difference regression.

[13] The CNUS was a one-time survey focused on plant use of networked computers that accompanied the Annual Survey of Manufactures in 1999.

Manufacturers (ASM) and the Census of Manufacturing (CMF), which is conducted every five years. The sample for the annual survey targets roughly 50,000 of the over 300,000 establishments in the U.S. manufacturing sector. It is generated from five-year rotating sample frames that begin in years ending with "4" or "9" and end in years ending with "8" or "3." The ASM sample over-weights large plants because it is intended to generate representative annual coverage of the manufacturing sector.[14]

As noted above, we use a two period difference-in-difference model to compare within-firm transfers from a period before Internet-enabled coordination technologies diffused to a period after their diffusion. We take 1999 as our second period because it is the earliest year in which Census collected data on Internet-related IT use, though we also explore how results change over a longer difference. We take 1992 as our first period for two reasons. First, it precedes the diffusion of the commercial Internet, which is typically estimated to begin around 1995. [15] Thus, no plants in our sample will have adopted Internet-enabled coordinating technologies by 1992. Second, it is a complete Census year, enabling us to maximize the coverage of our sample. Our results are robust to a variety of changes in the base year and assumptions about the timing of Internet diffusion, which we discuss in detail in section 5.3.

We place several restrictions on our sample. First, the two-period difference-in-difference model requires plants be in our data for both years. Thus, our results should be understood to examine the variance in within-firm transfers among plants who survived from 1992 to 1999. In addition, we take steps to reduce the likelihood that our results would be biased by the inclusion of establishments that would not, *under any circumstances*, transfer output to other units within the same firm. First, we remove all plants that constituted single-establishment firms in either 1992 or 1999. Second, following Atalay et al. (2013) we include only plants that produce products that are used downstream within the firm as part of a substantial link in the vertical production chain. Our definition of these linked plants is motivated by

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[14] Plants with over 2,500 employees are sampled with certainty; the likelihood of sampling is lower but increasing with size for all plants below this threshold.

[15] In particular, as noted in Forman, Goldfarb, and Greenstein (2012), few well-known events provide useful benchmarks for understanding why Internet investment did not begin prior to 1995. The first nonbeta version of the Netscape browser became available in early 1995, followed by the firm's IPO in August 1995. Bill Gates' internal memo about Microsoft's change in direction ("The Internet Tidal Wave") is dated May 1995.

that used in Atalay et al. (2013): a substantial vertical link exists between an industry A and an industry B when industry A produces a commodity which constitutes at least five percent of the intermediate materials purchased by firms in industry B according to the BEA's 2002 Benchmark Input-Output (IO) tables. We do not define a substantial link to have occurred for two plants in the same industry. For example, if two plants within a firm are both in industry A, we would not define a substantial vertical link to exist. This is to account for the possibility that one plant may not further transform the other's output, and vice versa (e.g., if transfers of the same product are made for shipping or inventory management purposes). However, as a robustness check, we have experimented with allowing the existence of a substantial vertical link in these same-industry cases and our results do not substantively change.

Third, we exclude plants for which the value of our dependent variable was either 0 or above the 95th percentile for three years prior to our estimation sample.[16] We do this to account for production technologies that may preclude transfers between plants (e.g., continuous manufacturing processes such as glass production) as well as captive plants whose output allocation may be determined for reasons unrelated to transactions costs (e.g., restricting outside access to sensitive intellectual property). Last, we exclude a small number of outliers with values for within-firm transfers that exceed total value shipped by more than a factor of two.

As a result of these restrictions, our final sample includes approximately 2,500 establishments.[17] However, our findings are robust to relaxing these restrictions, including removing the requirement of a substantial vertical link and the requirement that the dependent variable not be at the tails of the distribution prior to 1992. Table 1a provides a set of descriptive statistics from 1999 for the main variables in our models. The table indicates that plants in our sample are large: the average ships approximately $221 million in value per year. For comparison, in the Appendix we present descriptive statistics for the entire 1999 ASM sample. The average plant in the ASM ships only $4.8 million in value

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[16] The ASM sample frame is selected at 5-year intervals beginning in the second year subsequent to the Economic Census; in our case, the sample frame was set in 1989 and again in 1994, so we only have three years prior to 1992 with complete data on all the plants in our sample.

[17] We do not report exact sample sizes throughout this draft manuscript in order to avoid inadvertent disclosure of confidential firm data that could arise if the sample size shifts in later revisions.

per year, but this masks huge variation; the standard deviation is over $175 million.

External IT data. Information on external IT adoption comes from the Computer Network Use Supplement (CNUS) of the ASM, which contains detailed information on plant-level adoption of a variety of networked technologies that facilitate information sharing with value chain partners. Moreover, it separately asks whether information exchange is taking place with external suppliers, external customers, or other internal company units. The types of information that are explicitly explored in the survey are: design specifications, product descriptions or catalog, demand projections, order status, production schedules, inventory data, and logistics or transportation.[18] Because it surveys plants on specific types of information-sharing rather than on the adoption of applications (which may include multiple types of information-sharing), the survey offers an unusual opportunity to measure more precisely how business process transformation can reduce costs in the value chain.

To facilitate interpretation and analysis, we aggregate the heterogeneous components of information-sharing into three categories that we label *customer IT*, *supplier IT*, and *internal IT*. To define these variables we proceed in two steps. First, we use the CNUS to identify whether the establishment has engaged in at least one type of information sharing with each of customers, suppliers, or internal units. Then, we add the condition that the information-sharing must be conducted using Internet technology. For example, for an establishment in our sample to be included as adopting customer IT, it must both be involved in digitized information-sharing with customers and be using Internet technology at the plant.

We add the latter condition because older networked technologies for cross-establishment and cross-firm interaction such as (pre-Internet) EDI may be batch-oriented and limited in the types of information that they can share (Lee and Whang 2000). Moreover, they often require significant relationship-specific investment in private networks; thus adoption was often driven by a customer with market power sufficient to both demand the investment and dictate the standards governing data transfer, which could dramatically impact the firm boundary decision according to the logic of the TCE literature

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[18] The survey instrument can be found at https://www.census.gov.edgekey.net/econ/estats/1999/manufinal/MA-1000(EC).pdf

(see section 2). We separately explore the impact of EDI technology in section 5.4. Within our sample, 35.6% of establishments adopted customer IT by 1999, 44.2% adopted supplier IT, and 62.7% adopted internal IT. These percentages are somewhat higher than recent studies that have examined adoption of Internet-enabled enterprise IT over a similar time period.[19] This may be due to the fact that the average plant in our sample is large; in general, adoption of new technologies is increasing in plant size and Internet is no exception (e.g., Forman, Goldfarb, and Greenstein 2008).

As discussed above, there are compelling reasons to believe that customer IT and supplier IT may better reduce coordination costs when adopted together. If so, then there should be clustering in their adoption (Brynjolfsson and Milgrom 2012). As shown in Table 1b, this is indeed what we see in the data. The majority of plants in our sample adopt the combination of customer IT and supplier IT (27.2%) or neither (47.4%). To simplify our analysis, we combine both variables into a single *external IT* measure for most specifications. In later analyses, we decompose external IT into its constituent parts to identify whether the effects are, in fact, greatest when customer and supplier IT are adopted together. Table 1a and 1b illustrate another feature of our data: most plants adopting external IT have also adopted internal IT. In particular, Table 1b shows that only 8.3% (3.5%) of establishments in our sample adopt supplier IT (customer IT) without also adopting internal IT. This likely reflects the widespread belief that the value of adopting information-sharing with external partners is greater once an organization has already adopted internal information-sharing (e.g., Barki and Pinsonneault 2005).

Within-firm transfers. Our main dependent variable is the percentage of total shipments that are transferred internally within the firm. This variable is equal to the dollar value of within-firm transfers divided by the dollar value of total shipments.[20] The average value of this measure in our sample is 14.4%

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[19] For example, McElheran (2013), also using the 1999 CNUS, finds 14.6% of U.S. manufacturing establishments engaged in e-selling and 21.3% engaged in e-buying. Forman, Goldfarb, and Greenstein (2005), using 2000 data from the Harte Hanks Market Intelligence CI Technology database, find 12.6% of establishments have adopted Internet applications that facilitate enhancement of business processes.

[20] Specifically, the question on total value shipped asks for “Total value of products shipped and other receipts.” The survey then asks respondents to report on “Market value of products shipped to other domestic plants of your company for further assembly, fabrication, or manufacturing” and specifies that it is a break-out of the previously reported shipment value.

in 1999 (Table 1a). Even with the sampling restrictions described above, this average includes a large mass of establishments with 0% within-firm transfers in that year and another (much smaller) mass near 100%. Atalay et al. (2013) construct a similar measure and explore it at length. While their primary data source is different (the U.S. Census Bureau's Commodity Flow Survey), as is their sample period, they report a distribution quite similar to what we observe –e.g., the weighted mean of the percent of within-firm transfers in their paper is 16.0% and is robust to a large number of robustness checks. This similarity increases our confidence that our measure captures the relevant variance in input flows within and between firms. Finally, we observe large cross-industry differences in the extent to which establishment outputs are transferred within firms, which we document in the Appendix.

Controls. We include in our regression models a variety of controls using data from the CMF and ASM. To control for the possibility that firms may increase external sales to dispose of excess buffer stock, we include the log of the dollar value of current inventories. To control for the skill mix of workers at the plant, we include the ratio of production to nonproduction worker wages (e.g., Atrostic and Nguyen 2005). To control for variation in a plant's external market opportunities due to varying productivity, we include a measure of total factor productivity at the establishment computed following Cooper et al. (1999).[21] Last, we compute the log of the total number of products produced by the plant in case the propensity to vertically integrate also varies with supply chain complexity.

We also control for demand for the focal plant's output both within the firm and in the local external market. First, we identify the set of "downstream" plants within the same firm using the vertical linkages algorithm described above. For each plant in this set, we weight its total inbound materials consumption (measured in dollars) by the industry-level percentage of inputs coming from the focal establishment's industry. This weighting percentage comes from the Detailed Use Tables of the BEA's 2002 Benchmark Input/Output tables. We then sum the value of this variable across all related plants to estimate the downstream internal demand for the focal plant's output. Because this variable requires the

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[21] This is essentially the residual of a three-factor log-linear production function controlling for capital, labor, and material inputs, where capital stocks are accounted for and deflated following Cooper, Haltiwanger, and Power (1999).

complete universe of establishments, it must be constructed using Census years – e.g., 1992 and 1997. Thus, we impute a value for the second year of our sample (1999) using 1997 values.

We also compute a proxy for local external demand for the plant's output. While goods in our sample are tradable, much trade among manufacturing establishments in the U.S. is geographically proximate (Hillberry and Hummels 2008). Thus, local demand is likely to influence a plant's decision to trade with external partners. To compute local demand for the plant's output, we first identify the establishments in the local county with a substantial vertical linkage. As with downstream internal demand, we multiply the value of materials consumption for these local "linked" plants by their industries' percentage of inputs from the focal plant's primary industry using the Benchmark Input/Output tables. We then sum these values across all related plants in the county.

In addition, we include two controls for the presence of competition in the plant's primary industry. First, we include an indicator of whether there are any competitors in the same three-digit NAICS code in the same county. Second, using the total value of shipments for each plant, we compute a plant-level Herfindahl index for the three-digit NAICS industry and county.

In some specifications we have also included firm size controls such as total manufacturing employment.[22] Because this may be related to within-firm transfers, we omit it from our baseline model.

5. Estimation Results

We proceed in several steps. First, we estimate the overall effects of external IT on within-firm transfers. Second, we demonstrate that it is the combination of supplier and customer IT, rather than any one IT practice, that is associated with a decline in within-firm transfers. Next, we explore robustness and identification of our main results through a variety of further tests. Finally, we explore some particular circumstances under which external IT may have a particularly strong impact on within-firm transfers.

5.1 Baseline Results

Figure 1 reports the results of a nonparametric difference-in-difference analysis of the percentage

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[22] Controlling for total number of manufacturing plants in the firm yielded qualitatively similar results.

of within-firm transfers between 1992 and 1999 according to the adoption of external IT. The results show that for both years, the percentage of within-firm transfers is lower for plants adopting external IT than for those that do not, highlighting the need to control for time-invariant differences in our data (which we do in subsequent analyses). The percentage of within-firm transfers declined by a statistically significant 2.9 percentage points among plants that did not adopt external IT, but fell by an even greater 6.4 percentage points among those that did adopt. In other words, the percentage of within-firm transfers fell by 3.5 percentage points more among adopters of external IT, a difference that is statistically significant at the one-percent level.

In table 2 we use the regression model in equation (4) to explore this relationship. The within R-squared values in the table are fairly low, which is consistent with prior work using dependent variables bounded between zero and one (e.g., Athey and Stern 2002). Column 1 shows the correlation between supplier IT and the percentage of within-firm transfers with no controls. Column 2 adds a variety of controls for establishment inventories, productivity, worker skill mix, and demand for the plant's output. Column 3 includes controls for local competition and is our baseline specification. In this column, the coefficient on external IT is -0.029; in other words, adopting external IT is associated with a 2.9 percentage point decline in the percentage of within-firm transfers. Recall that across the entire sample, the average percentage of within-firm transfers is approximately 14.4%, so in percentage terms this represents over a 20% change. Column 4 shows these results to be robust when controlling for firm size. Because some of our controls may be determined by a process that simultaneously affects within-firm transfers, in column 5 we re-estimate our model replacing our time-varying controls with a model that interacts the 1992 values of our controls with a time dummy for 1999. That is, we estimate

$$WFT_{jt} = \alpha + \lambda ExternalIT_{jt} + \delta Z_j \tau_t + \mu_j + \tau_t + \eta_{jt} \tag{5}$$

Our basic findings are robust to all of these changes.

The remaining columns show that the results are robust to a variety of changes in both the sample and the construction of key variables. In column 6 we relax the requirement that a plant's percentage of within-firm transfers be consistently greater than zero and less than the 95th percentile prior to our sample period. In column 7 we further exclude the requirement of a substantial vertical link with other plants in the firm. Statistically, the results are not significantly different. In column 8 we explore the impact of external IT on the **extensive** margin of within-firm transfers: i.e., whether the plant transfers any product within the firm at all. We estimate this model over the sample used in column 6; because we are focused on the decision of whether to transfer any output within the firm, we do not exclude establishments for whom the percentage of within-firm transfers has been consistently near zero or one. The results, which are statistically significant at the 10% level, suggest that adoption of external IT is associated with a 3.9 percentage point decline in the likelihood of transferring any output within the firm.

5.2 Disaggregating the impact of external IT

In Table 3, we show the results of a series of regressions that disaggregate the impact of external IT and show that it is the combination of supplier IT and customer IT together that gives rise to the change in within-firm transfers. That is, we estimate the following regression

$$WFT_{jt} = \alpha + \lambda ExternalIT_{jt} + \gamma_1 SupplierIT_{jt} + \gamma_2 CustomerIT_{jt} + \delta Z_{jt} + \mu_j + \tau_t + \eta_{jt} \quad (6)$$

where $ExternalIT_{jt} = SupplierIT_{jt} \times CustomerIT_{jt}$. If the effects of customer and supplier IT are greatest when they are adopted together, then we expect $\lambda < 0$. That is, the goal of this analysis is to identify the joint effect of coordinating electronically with suppliers and customers while controlling for their independent effects. Our identification assumption here is somewhat weaker than for equation (4) in that we require only no differential trend in unobservables that are correlated with WFT when supplier IT and customer IT appear *together*.

Following the baseline results reported again in column 1, columns 2 and 3 report the estimated effects of supplier IT and customer IT on the percentage of within-firm transfers. Column 2 shows that adopters of supplier IT experience a 3.2 percentage point decline in within-firm transfers relative to non-adopters; in contrast, adoption of customer IT on its own is not associated with any change (column 3). Column 4 shows that these results are robust when supplier IT and customer IT are included in the same regression. Column 5 shows the main result of this table; it includes supplier and customer IT separately and then interacted together, as in equation (6). According to these estimates, supplier IT and customer IT are associated with a decline in within-firm transfers only when they are adopted together. When this happens, the percentage of within-firm transfers declines an additional (statistically significant) 5.6 percentage points relative to when they are adopted separately. In contrast, when supplier IT is adopted alone there is no significant effect on within-firm transfers, and when customer IT is adopted alone there is actually a significant *increase* in within-firm transfers.

The increase in WFT that is associated with adoption of customer IT without accompanying supplier IT is surprising. We offer one potential explanation. As noted by McElheran (2013), adoption of customer IT over this period was particularly challenging. Relative to supplier IT, customer IT was a less mature technology, which is reflected in its lower adoption rate in Table 1a. McElheran documents how adoption of customer IT required complementary investments by downstream partners who were frequently unprepared to make these investments. As noted by Clemons, Reddi, and Row (1993), when such complementary investments are required, the number of supply chain partners may fall. Thus, this result may reflect a temporary outcome as firms adjust to a new technology. Further exploration of our data provides some support for this hypothesis; as shown in column (6) rerunning regression model (6) using 2002 as the second period (by which time firms have had longer to adjust) shows the positive effect of customer-facing IT declines and its effect is no longer statistically significant.[23]

In columns 7 and 8 we show that IT for information-sharing within the firm has no effect on the extent of within-firm transfers. Last, in column 9 we add controls for variation in the intensity of investment. In particular, we add indicators of whether the plant has adopted three or more supplier IT applications or three or more customer IT applications; we label these additional margins of investment "Advanced Supplier IT" and "Advanced Customer IT". Again, the results do not qualitatively change. Collectively, columns 7 through 9 provide additional evidence that the incremental benefits of adopting supplier IT and customer IT together do not proxy for the benefits of incremental investments in generic

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[23] A complete set of results in which we disaggregate complementarities over the 1992-2002 sample period is available in Appendix Table 4. Note that we use 2002 because it is a Census of Manufacturers year, which allows us to retain all of the observations in our sample (use of 2000 or 2001 would result in a loss of data).

IT spending. Overall, the results in Table 3 provide evidence that there is something particular about the adoption of supplier IT and customer IT together that influences the extent of within-firm transfers. Thus, the remainder of this paper restricts attention to the combined external IT measure.

5.3 Further Robustness and Identification

In Table 4 we probe the robustness of our results. In columns 1 and 2 we rerun regression equation 1 but also add the interaction of MSA (column 1) and MSA and three-digit NAICS (column 2) dummies with a 1999 time dummy. These regressions control for differential time trends across industries and locations.[24] It is encouraging that the results do not change much between column 3 of Table 2 and columns 1 and 2 of Table 4, suggesting that the impact of unobservables would have to be large relative to that of observables to have a sizeable influence on our results (Altonji, Elder, and Taber 2005).

We next subject our findings to a timing falsification exercise. While we do not observe the precise timing of external IT adoption, the Internet's sudden deployment nevertheless provides an opportunity to see if the benefits of external IT have the "right" timing. If our assumptions about the nature of unobservables in our model are correct, we should not see any affiliation between external IT adoption and within-firm transfers prior to 1995.[25] To test this hypothesis, we use the ASM data panel to rerun a version of regression equation (1) over the period 1992-1999. The regression equation takes the following form:

$$\begin{aligned} WFT_{jt} = \alpha + \lambda_1 ExternalIT_{jt} + \lambda_2 EarlyExternalIT_{jt} + \gamma_1 InternalIT_{jt} \\ + \gamma_2 EarlyInternalIT_{jt} + \theta_1 NAICS_j t + \theta_2 MSA_l t + \delta Z_{jt} + \mu_j + \tau_t + \eta_{jt} \end{aligned} \qquad (7)$$

where $ExternalIT_{it}$ and $InternalIT_{it}$ are equal to zero prior to 1995 and 1 thereafter, and $EarlyExternalIT_{it}$ and $EarlyInternalIT_{it}$ are set equal to one during the period 1991-1994 and zero otherwise. Z_{jt} includes the same controls for inventories, skill mix, productivity, and number of products as in equation (4) but excludes controls for downstream firm demand, local demand, and local

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[24] In the case of establishments that are not located in MSAs, we construct "phantom MSAs" that are defined by the area of a state excluding its MSAs.

[25] In this sense, our test is similar to that employed by Forman, Goldfarb, and Greenstein (2012) in their examination of the effects of business Internet investment on local wage growth.

competition as these are constructed using the Census of Manufacturers and so do not vary across all of the years in the ASM-based panel. The coefficients of the vectors θ_1 and θ_2 capture the effects of MSA and 3-digit NAICS time trends. We include $InternalIT_{jt}$ and $EarlyInternalIT_{jt}$ to control for the effects of other IT investments over this period, and to show the contrast between their differential effects.

Column 3 shows the results of estimating regression equation (7) excluding the terms $EarlyExternalIT_{jt}$ and $EarlyInternalIT_{jt}$, to facilitate a comparison of the results of this model with our earlier results. The qualitative effects of external IT are similar, if somewhat smaller, possibly reflecting the increased measurement error due to assuming that external IT was adopted in all years after 1994 among those reporting adoption in the 1999 CNUS survey. Column 4 shows the results of estimating regression equation (7). Adoption of external IT is associated with a statistically significant (at the 5% level) 2.7 percentage point decline in the percentage of within-firm transfers after 1994 but has no effect on within-firm transfers prior to that period. The coefficients for external IT adoption and early external IT adoption are also statistically different from one another at the 10% level. Figure 2 shows an adaptation of regression equation (7) in which we estimate the marginal effect of external IT adoption year by year. While the coefficient estimates do have some year-to-year variation, the results show that external IT adoption has a statistically significant negative effect on the percentage of within-firm transfers beginning in 1995 but no effect prior to then,[26] while internal IT has no effect during any time over our sample period. In short, the difference between the effects of internal IT and external IT on within-firm transfers has the "correct" timing according to our assumptions.

In all of our regressions thus far, we have estimated linear probability models. We chose this approach because it facilitates the use of establishment-level fixed effects and a more straightforward interpretation of the implied marginal effects from our model.[27] In column 5 we show that our results are robust to using the fractional probit model described in Papke and Wooldridge (2008).

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[26] The coefficients are statistically significant at the 5% or 10% level for all years with the exception of 1997, where the p-value is 0.102.

[27] An alternative approach would be to model the log-odds ratio as a linear function. However, this function is not defined for values of 0 and 1. While adjustments are possible using the Berkson's minimum chi-square method (detailed in Maddala 1983), it is unattractive given that our data have significant mass points at both 0 and 1.

In columns 6 and 7 we run separate regressions for the values of within firm transfers and total value shipped. This allows us to see whether the decline in the percent of within firm transfers among external IT adopters is caused by an increase in the value of total value shipped, a decline in the value of within-firm transfers, or both. Our results show that both within-firm transfers decline and total value shipped increases, but in percentage terms, the magnitude of the change in within-firm transfers is greater. Within-firm transfers decline by 50.1% for adopters of external IT. These results must be viewed with some care because of the mass of plants for whom the value of within firm transfers is equal to zero (we use the log(1 + x) transformation). However, they suggest that the direction of change in the value of within-firm transfers is both negative and sizeable. Column 7 also shows that the value of total value shipped increases by a smaller 7.7% for adopters of external IT.

In columns 5 and 6 we examine whether our results differ for establishments that had adopted electronic data interchange (EDI). As noted above, EDI was an earlier technology used to automate certain types of exchange between supply chain partners. We expect that the effects of external IT adoption will be lower among firms who were adopters of EDI for a variety of reasons. First of all, EDI substituted for certain Internet-based interactions with customers (McElheran 2013), so EDI users adopting external IT may not have been as far down the adoption curve as firms without this alternative means of inter-firm communication. Or, they may have already made the organizational and business process adjustments necessary to enjoy the returns to both types of investments prior to our sample period. In addition, firms with EDI might face disproportionate barriers to shifting the composition of their downstream customer base. For instance, the use of proprietary EDI systems would tend to increase the switching costs involved in coordinating with new customers via different standards. Moreover, to the extent that customers with power may drive EDI adoption, they may also hinder their suppliers' pursuit of new customers. Unfortunately, we observe EDI adoption only using the 1999 CNUS survey, so we are unable to identify the timing of EDI adoption and the dynamics of how prior investments in EDI influenced the returns to adopting the new generation of technology, as has been done in prior studies (e.g., Bresnahan and Greenstein 1996). However, we can still observe whether the organizational change in response to external IT adoption is lower when the establishment reports having adopted EDI. The results are consistent with our predictions: non-adopters of EDI experience a statistically significant 4.7 percentage point decline in within-firm transfers when they adopt external IT, while adopters of EDI experience no such change from external IT adoption. This result is also informative about identification in our analysis: if our results are shaped by changes to unobserved factors that are correlated with external IT and within-firm transfers, they must be specific to establishments that have not adopted EDI.

5.4 Justifying a causal interpretation

To further investigate how potential reverse causality and omitted variable bias may influence our findings, in Table 5 we present the results of instrumental variables estimates. Two of our instruments capture cross-sectional variance in the costs to Internet adoption. Our first instrument indicates an estimate of the cost of delivering telecom services to a region based on the FCC's Hybrid Cost Proxy Model (HCPM). The HCPM is an economic engineering model that computes the local cost of providing telecommunications services, given a location's geographic terrain and subscriber density. Thus, we expect increases in local proxy costs to be associated with higher operating costs for Internet service providers, which should translate into higher Internet adoption costs or lower service quality for firms. The HCPM is computed from wire centers; we follow Prieger's (2003) matching of wire centers to ZIP code areas and then match to establishments using their ZIP codes.[28]

Our second instrument uses certain types of firm-level IT capabilities to instrument for external IT adoption. Forman, Goldfarb, and Greenstein (2008) show that establishments that are part of firms with IT capabilities in other locations adopted Internet-enabled applications more quickly (even if there were few capabilities at the local establishment). They argue for a causal interpretation, because the capabilities were developed for reasons unrelated to Internet investment. In other words, IT expertise elsewhere in the firm makes adoption of external IT at the focal plant more likely; depending on the type

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[28] We think Jim Prieger for providing these data for us. Proxy costs are not available from the model for about one third of the wire centers; we follow Prieger (2003) in using the proxy cost of the nearest wire center. Further, not all zip codes in our data had a matching zip code with a proxy cost; we use the proxy cost of the closest zip code.

of IT, these capabilities should also be uncorrelated with organizational decisions at the focal plant such as the extent of within-firm transfers. We capture IT expertise fitting this description using the adoption of CAD/CAE (computer aided design and computer aided engineering) at other establishments within the same firm, using data from the CNUS survey. As noted in Astebro (2002), adoption of CAD requires significant noncapital adjustment costs such as learning how to use and program a CAD package, as well as significant costs to adjusting an organization's business operations, routines, authority, and span of control. These are the same types of adjustment costs that are required in other forms of general purpose IT investments (e.g., Bresnahan and Greenstein 1996; Bresnahan, Brynjolfsson, and Hitt 2002). Thus, CAD/CAE adoption should be a useful proxy for general IT capabilities. However, adoption of this technology elsewhere in the firm should not directly improve the focal plant's ability to exchange with external partners. We compute the percentage of other establishments within the same firm that have adopted CAD/CAE.

Our last instrument uses the adoption of external IT by competing firms in the same three-digit NAICS industry in other locations where the focal firm has establishments. This instrument is similar to ones used in Forman, Goldfarb, and Greenstein (2008) and Augereau, Greenstein, and Rysman (2008). The identification assumption is that adoption by competing establishments in other geographic markets will increase the likelihood of external IT adoption by establishments in the same firm in those other geographic markets. This will decrease the costs of external IT adoption by the focal plant but should not influence its decision to sell its output outside of the firm.

The top portion of Table 5 presents the first stage results of our LIML instrumental variable regressions. We present only the coefficient estimates from the exclusion restrictions; the full set of coefficient estimates is available in the Appendix. Column 1 includes only the instrument for competitor adoption, column 2 includes only the instrument for adoption of CAD/CAE within the firm, column 3 includes the instrument using the hybrid cost proxy model, and column 4 presents all instruments together. As expected, increases in competitor adoption of external IT and increases in adoption of CAD/CAE within the firm are both correlated with an increase in the likelihood of adopting external IT at the focal plant. Further, increases in the local costs of providing telecommunications services are negatively correlated with the likelihood of adopting external IT. The F-statistics for the first stage range from 11.39 to 40.43, above the commonly used threshold of 10 and, with the exception of the proxy cost instrument in column 3, above the Stock and Yogo (2005) critical threshold for weak instruments using the criteria of maximal LIML size > 10%.

The bottom portion of Table 5 presents the second stage results. Although the direction of the estimated effect of external IT is stable across specifications, the magnitude and significance of the coefficient estimates differ. Further, the coefficient estimates of the instrumental variable regressions in columns 1 through 4 are generally larger in magnitude (more negative) than the baseline regression results from the comparable OLS regression in column 3 of Table 2. For example, the coefficient estimate for external IT using the combined set of instruments is -0.1909 compared to -0.0291 in column 3 of Table 2, though the standard error on the former estimate is fairly large despite its statistical significance at the 5% level (0.0902). A Hausman test does not reject the null hypothesis of equality of coefficients across the two specifications, though this is in part because of the similarity in estimates for the control variables. We speculate that the difference in coefficient estimates across the two models may be because of heterogeneous effects of external IT on within-firm transfers; that is, overall, the local average treatment effect for external IT may be largest for establishments that are most influenced by competitor adoption, capabilities within the firm, and the local costs of delivering telecommunications services. In sum, our instrumental variable results provide additional evidence in support of a causal interpretation that adoption of external IT will lead to a decline in the percentage of within-firm transfers.

5.5 Examining Where the Effects Occur

Thus far, we have investigated the average effect of external IT on the percentage of within-firm transfers. In this section, we examine the circumstances under which adoption of external IT will have the greatest impact on vertical integration. We consider three sources of firm heterogeneity: firm size, supply chain complexity, and whether the establishment operates in the transportation equipment manufacturing industry (where vertical integration has been studied most often in prior work). We estimate our model across each subset of data and compare results. In general, we find that our results are strongest in large firms, plants producing multiple products, and those in the transportation equipment manufacturing industry. The results are reported in Table 6. As elsewhere in the paper, we first estimate OLS models and then explore robustness to instrumental variables estimation.

In columns 1 through 4 of Table 6 we examine whether the effects of external IT are stronger in large firms. Large firms may have systematically different organizational responses to external IT for several reasons. First, they are more likely to engage in within-firm value chain transfers (Atalay, et al. 2013). Thus, external IT may have a greater impact on the margin of activity that we study. Further, large firms may be differentially effective at implementing enterprise IT. For example, large firms may be able to apply greater expertise to enterprise IT implementations (e.g., Forman, Goldfarb, and Greenstein 2008) but may also have legacy investments and organizational structures that could make the necessary technological and organizational adaptations more difficult (e.g., Bresnahan and Greenstein 1996).

In the face of these contrary predictions, we investigate how firm size shapes the organizational response to new external IT investment by first computing the number of manufacturing establishments within the same firm. To identify a break point for small and large firms, we compute a measure of central tendency for the distribution of firm plants by splitting the sample into 10 percentiles and then computing the average between the 50th and 60th percentiles.[29] While external IT has no statistically significant effect on the percentage of within-firm transfers among plants in smaller firms, it does affect within-firm transfers in larger firms: Adoption of external IT in large firms (those above the central tendency) is associated with a 3.3 percentage point decline in the percentage of within-firm transfers. The average within firm transfers is 19.2% for large firms and 17.8% for small firms, so this translates into a 17.4% decrease in within-firm transfers for large firms versus a (statistically insignificant) 13.1% decrease for small firms. However the difference in the marginal effects for small and large firms is not

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[29] We do not use the median for disclosure avoidance purposes, as splitting the sample based upon the median of the distribution may reveal confidential information about the median firm.

statistically significant. Columns 3 and 4 show the results of a similar analysis using firm-wide (i.e., not just manufacturing) employment as the measure of firm size. The results in this case are qualitatively similar though less statistically significant.

Next we investigate whether the marginal effect of external IT is influenced by variance in product variety managed within the manufacturing establishments. Increases in product variety increase market mediation costs such as variety-related inventory holding costs, markdown costs when supply exceeds demand, and the opportunity costs of lost sales when demand exceeds supply (Randall and Ulrich 2001; Fisher 1997). That is, in these environments of greater supply chain complexity, IT investments that reduce market mediation costs are expected to be particularly valuable. We measure product variety using product-level data from the ASM and CMF and split the sample based upon whether the plant produces more than one product (defined at the 7-digit NAICS level). Columns 5 and 6 show that manufacturing plants producing more than one product see a statistically significant (at the 5% level) 2.9 percentage point decline in WFT when adopting external IT. Focused plants see a 3.1 percentage point decline; however, because of large standard errors this estimate is not statistically significant. Moreover, the differences between the two subgroups are not statistically significant at conventional levels.

We next specifically examine the implications of external IT adoption for the production of transportation equipment. We study transportation equipment manufacturing industries for two reasons. First, because of the presence of high and (highly variable) coordination costs and contracting costs within and between subassemblies in the manufacturing of transportation equipment, these industries are among those where vertical integration decisions have been most intensely studied.[30] Second, recent evidence suggests that IT investments have been useful in reducing some of these coordination costs (e.g., Mukhopadhyay and Kekre 2002; Argyres 1999). Column 4 shows that among establishments in the transportation industries, adoption of network IT is associated with an 11.5 percentage point decline in the

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[30] For example, studies of vertical integration in automobile manufacturing extend back to the classic GM-Fisher body integration choice (e.g., Coase 1937; Monteverde and Teece 1982) and have continued to the present day (e.g., Novak and Stern 2009). Vertical integration has also been intensely studied in aerospace manufacturing (e.g., Masten 1984; Argyres 1999).

percentage of within-firm transfers. This decline is both large and statistically different (at the 10 percent level) from the average effect across all other industries in our sample. In fact, the average treatment effect across all other industries is a statistically insignificant 1.6 percentage point decline, i.e. lower than our baseline result in Table 2 and with a similar standard error. This insignificant result masks considerable variation around the mean; however, the effects in transportation are notable both because of the size of the effect and the importance of the industry.

In Table 7 we present LIML instrumental variable results for the models in Table 6. In each column, we use the complete set of three instruments from table 5 column 4. In general, the instruments have power in explaining variation in external IT adoption among plants in large firms, multi-product plants, and outside the transportation industry. The first-stage F-statistic in these subsamples range from 13.79 to 22.55. Outside these settings, the instruments are quite weak, and the F-statistics range from 0.19 to 4.72. Despite the weakness of the first stage, it is encouraging that the second stage regression results shown in Table 7 are consistent with the OLS results. In general, the second stage results show a negative and statistically significant impact of external IT on within firm transfers in plants with a large number of firm sites, with large firm employment, and in multi-product plants. The second stage coefficient for external IT for transportation equipment manufacturing is very large (-2.2485) but imprecisely measured, likely reflecting the small subsample size and weakness of the instruments.

6. Discussion and Conclusion

Our results show that adoption of IT that facilitates coordination with suppliers and customers has an economically and statistically significant negative impact on the percentage of within-firm transfers – our measure of vertical integration. Adoption has the largest impact on within-firm transfers when the upstream and downstream margins of digital coordination are adopted together. This finding is robust to extensive time-varying controls, a falsification exercise, as well as instrumental variables estimation. We find these effects are strongest in particular circumstances, namely in large firms and in complex supply chains such as transportation equipment manufacturing.

Our findings contribute to growing research on the complementarities between IT investments and organizational practices. While early research in this area focused on the implications of IT capital spending for clusters of management choices, our research contributes to a growing stream of work that explores specific margins of IT use and narrowly defined organizational practices that combine to form efficient, integrated systems of management (e.g., Aral, Brynjolfsson, and Wu 2012; Bartel, Ichniowski, and Shaw 2007; Bloom et al. 2009). We extend this line of research to study organizational practices that define the boundary of the firm, an area where there has so far been little research.[31]

Our findings sharpen and extend the conclusions of prior research on IT and firm boundaries in several ways. Our focus on complementarities is important because nonconvexities can exist in a firm's decision to adopt any or all of a set of organizational practices– i.e., adoption "may not be a marginal decision" (Milgrom and Roberts 1990). In practical terms, this suggests that the striking variance in firm response to digital communication and growing information processing capability will not even out in the near term – and may actually increase – even as more firms come to rely on these new technologies.

In our setting, changes to firm boundaries occur only when supplier IT and customer IT are adopted together. These findings add nuance and precision to the predictions of prior work that the net impact of IT capital spending will tend to pull in firm boundaries (e.g., Malone, Yates, and Benjamin 1987, Gurbaxani and Wang 1991, Hitt 1999, Ray, Wu, and Konana 1999). We confirm that intuition, but highlight the need for particular combinations of investments for this organizational change to occur.

Evidence for the complementary role of digital coordination with customers has important implications for how production chain organization is likely to evolve beyond the period we study. Namely, as has been noted elsewhere, coordination with customers was more difficult than with suppliers during our sample period (McElheran 2013). In particular, adoption of customer-facing IT required significant change to internal business processes to align them with both the needs of the new software and the needs of business partners. This suggests that customer-facing coordination may be the limiting factor in the diffusion of this complementary system of organization practices. If so, the distribution of

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[31] Tambe, Hitt, and Brynjolfsson (2012) is one notable exception.

organizational change will tend to reflect *ex ante* differences in firm capabilities with respect to adopting and adapting new forms of inter-firm digital technologies. As the nature of these costs evolve, the patterns of adoption and organizational adjustment we observe in our data—in particular, the differences in firm size and transportation equipment manufacturing—may change over time.

Our results can also help to improve our understanding of how externalities can shape patterns of production chain reorganization. The changes we document require complementary – and typically uncompensated – investments by partners upstream and downstream in the value chain, whose decisions will similarly be shaped by their ability to undertake the costly technological and organizational adjustments. This will have important implications for where and when we observe production chain reorganization.

Beyond these broad research implications, our results also have important and somewhat surprising implications for management practice. Complementarities between upstream and downstream coordination imply that a firm interested in pursuing more market-based downstream activity aided by sophisticated IT will be more successful if it includes upstream supply coordination in its overall business strategy. A narrow focus on customers and customer needs that ignores the critical upstream margin of coordination could significantly reduce the returns to IT and complementary organizational investments.

Certain limitations of our study are worth bearing in mind. To begin, our econometric approach and limitations of the data (in particular the timing of complete Census years) require that establishments be observed in both periods over a seven-year difference. This may impose a survivor bias on our findings, suggesting care in assuming that these effects hold equally for struggling or otherwise less-established firms. For instance, our findings related to firm size and supply chain complexity suggest that start-up firms, which tend to be smaller and less diversified, will be less subject to the effects we find. However, a rigorous test of this conjecture is left to future research. In addition, our empirical setting is confined to the manufacturing sector and to a particular point in time when the diffusion of Internet-based IT was quite rapid. The extent to which these findings generalize to other sectors and other generations of technology warrants additional study.

Our findings point to other potential opportunities for future research to explore how IT investments can complement production chain reorganization. In this paper, we focus on the implications of IT investment for the short-run decision to sell a plant's output internally vs. externally, taking the broader supply chain of the firm as fixed. However, the same IT investments ought to influence the long-run configuration of a firm's value chain by impacting the costs of owning and acquiring productive assets in different locations and industries across time. Through their ability to reduce geographic and other frictions, these sorts of IT investments may have important implications for the spatial organization and horizontal diversification of production chains. We hope that our research will encourage future work in these important areas.

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Figure 1: Percent Within-firm Transfers by Year and Whether Adopt External IT

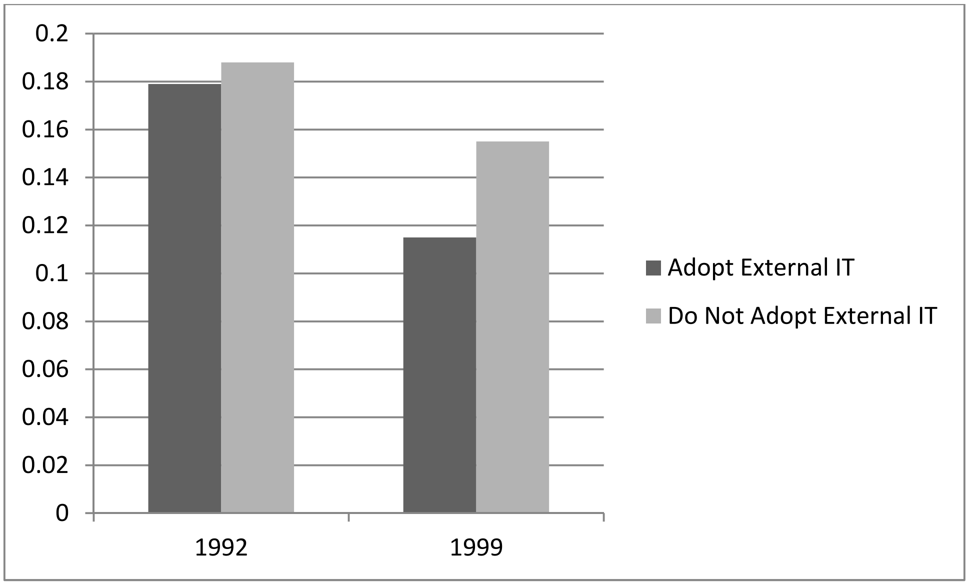
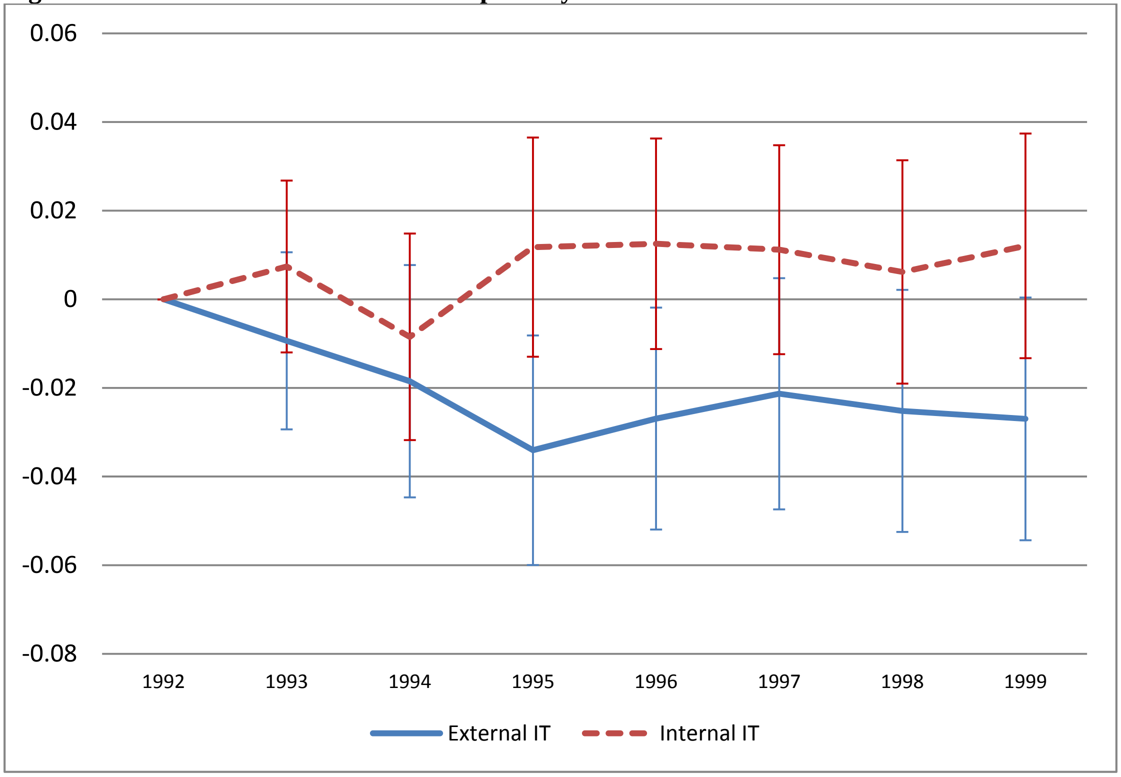


Figure 2: Coefficients on External IT Adoption by Year



Error bars show 95% confidence intervals.

Table 1a: Descriptive Statistics, 1999

	Mean	Standard Deviation
Percent within-firm transfers	0.144	0.267
Total within-firm transfers ($ Thousands)	~38,800	~148,000
Total value shipped ($ Thousands)	~221,000	~481,300
External IT	0.272	0.445
Supplier IT	0.442	0.497
Customer IT	0.356	0.479
Advanced supplier IT	0.162	0.368
Advanced customer IT	0.109	0.312
Internal IT	0.627	0.484
Log(inventories)	6.56	3.10
Production to nonproduction workers	0.303	0.170
Log(Total factor productivity)	1.62	0.582
Log of downstream firm demand	8.77	4.25
Log of local demand	5.71	4.83
Dummy for competitors in local area	0.931	0.252
Local competition Herfindahl	0.427	0.316
Log(number of establishment products)	1.17	0.783
Log(number of manufacturing sites)	3.81	1.21
Log(manufacturing employment)	9.26	1.42

Number of observations is approximately 2,500.

Table 1b: Percentage of establishments adopting pairwise combinations of IT applications

		Customer IT		**Internal IT**	
		0	**1**	**0**	**1**
Supplier IT	**0**	**47.4**	**8.4**	**29.0**	**26.8**
	1	**17.0**	**27.2**	**8.3**	**35.9**
Internal IT	**0**	**33.8**	**3.5**	**--**	**--**
	1	**30.6**	**32.1**	**--**	**--**

Each cell shows the percentage of establishments adopting the particular pairwise combination of IT applications in our baseline sample of approximately 2,500 establishments. 0 indicates that the establishment does not adopt and 1 indicates that the establishment adopts. For example, the table shows that 47.4% of establishments in our sample adopt neither customer IT nor supplier IT, while 27.2% adopt both customer IT and supplier IT.

Table 2: Is Adoption of External IT Associated with a Decline in Within-firm Transfers?

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	No controls	Includes all controls but competition	Includes controls	Includes Controls for Manuf Employment in Other Locations	Interacts 1992 controls with time trends	Exclude prior 3-year sample conditioning	Exclude prior 3-year and substantial vertical link conditioning	Any IPT - Extensive margin
External IT	-0.0313	-0.0290	-0.0291	-0.0268	-0.0332	-0.0235	-0.0110	-0.0391
	(0.0123)*	(0.0123)*	(0.0123)*	(0.0112)*	(0.0125)**	(0.0092)*	(0.0041)**	(0.0211)+
Log(inventories)		-0.0089	-0.0089	-0.0099		-0.0087	-0.0044	-0.0092
		(0.0034)*	(0.0034)**	(0.0034)**		(0.0028)**	(0.0012)**	(0.0042)*
Share of workers in white collar employment		-0.0265	-0.0267	-0.0311		-0.0278	-0.0349	-0.0391
		(0.0453)	(0.0454)	(0.0456)		(0.0286)	(0.0119)**	(0.0654)
Log of TFP		-0.0309	-0.0306	-0.0339		-0.0322	-0.0138	-0.0212
		(0.0162)+	(0.0162)+	(0.0162)*		(0.0115)**	(0.0059)*	(0.0219)
Log of downstream firm demand		0.0027	0.0027	0.0005		0.0020	0.0017	0.0093
		(0.0012)*	(0.0012)*	(0.0012)		(0.0009)*	(0.0009)*	(0.0021)**
Log of local demand		-0.0017	-0.0019	-0.0009		-0.0026	-0.0012	-0.0101
		(0.0020)	(0.0020)	(0.0019)		(0.0014)+	(0.0009)	(0.0036)**
Log of number of products		-0.0054	-0.0056	-0.0049		-0.0046	-0.0017	0.0548
		(0.0106)	(0.0106)	(0.0106)		(0.0077)	(0.0032)	(0.0161)**
Dummy indicating local industry competitors			-0.0044	-0.0033		0.0039	-0.0119	0.0069
			(0.0277)	(0.0278)		(0.0210)	(0.0108)	(0.0413)
Industry-country Herfindahl			-0.0503	-0.0458		-0.0519	-0.0215	0.0795
			(0.0475)	(0.0476)		(0.0359)	(0.0166)	(0.0727)
Log(firm manufacturing employment)				0.0314				
				(0.0065)**				
Observations	~4500	~4500	~4500	~4500	~4500	~7500	~24000	~7500
Establishments	~2500	~2500	~2500	~2500	~2500	~3500	~12000	~3500
R-squared	0.03	0.04	0.04	0.08	0.03	0.02	0.01	0.02

Unit of observation is an establishment-year. Sample includes annual data from 1992 and 1999. Regressions include establishment-specific fixed effects, differenced out at means, and 1999 year fixed effects. Robust standard errors, clustered by establishment, in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%

Table 3: Disaggregating Complementarities Among IT Applications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Baseline	Supplier IT	Customer IT	Supplier and Customer IT	Supplier and Customer IT Separately and Together	Supplier and Customer IT Separately and Together, 1992-2002	Internal IT	Supplier Customer and Internal IT	Supplier, Customer, and Internal IT controlling for additional IT investment
External IT	-0.0291				-0.0560	-0.0543		-0.0554	-0.0523
	(0.0123)*				(0.0271)*	(0.0292)+		(0.0274)*	(0.0278)+
Supplier IT		-0.0323		-0.039	-0.0201	-0.0013		-0.0209	-0.0143
		(0.0111)**		(0.0124)**	(0.0145)	(0.0156)		(0.0147)	(0.0146)
Customer IT			-0.0050	0.0144	0.0477	0.0168		0.0462	0.0445
			(0.0117)	(0.0130)	(0.0222)*	(0.0236)		(0.0237)+	(0.0217)*
Internal IT							-0.0032	0.0035	
							(0.0117)	(0.0135)	
Advanced Supplier IT									-0.0263
									(0.0178)
Advanced Customer IT									0.0169
									(0.0229)
Combined effects of external IT	-0.0291				-0.0284	-0.0388		-0.0301	-0.0221
	(0.0123)*				(0.0135)*	(0.0156)*		(0.0152)*	(0.0162)
Observations	~4500	~4500	~4500	~4500	~4500	~4500	~4500	~4500	~4500
Establishments	~2500	~2500	~2500	~2500	~2500	~2500	~2500	~2500	~2500
R-squared	0.04	0.04	0.03	0.04	0.04		0.03	0.04	0.04

Unit of observation is an establishment-year. Sample includes annual data from 1992 and 1999. Regressions include establishment-specific fixed effects, differenced out at means. All regressions include controls used in column 3 of Table 2. Robust standard errors, clustered by establishment, in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%

Table 4: Additional Robustness

	(1) MSA Time Trends	(2) MSA + Industry Time Trends	(3) Panel	(4) Panel including early adoption of IT	(5) Fractional Probit Model	(6) Log(WFT)	(7) Log(TVS)	(8) Baseline no EDI	(9) Baseline has EDI
External IT	-0.0267	-0.0221	-0.0176	-0.0271	-0.1457	-0.5014	0.0768	-0.0471	0.0031
	(0.0130)*	(0.0130)+	(0.0079)*	(0.0115)*	(0.0558)**	(0.2434)*	(0.0257)**	(0.0155)**	(0.0206)
Internal IT			0.0113	0.0112					
			(0.0073)	(0.0105)					
Early adoption of external IT				-0.0139					
				(0.0103)					
Early adoption of internal IT				-0.0001					
				(0.0096)					
Observations	~4500	~4500	~18000	~18000	~4500	~4500	~4500	~3000	~1500
Establishments	~2500	~2500	~2500	~2500	~2500	~2500	~2500	~1500	~1000
R-squared	0.04	0.06	0.06	0.06		0.07	0.32	0.03	0.05

Robust standard errors, clustered by establishment, in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%

Columns (1)-(2): Unit of observation is an establishment-year. Sample includes annual data from 1992 and 1999. Regressions include establishment-specific fixed effects, differenced out at means. All regressions include controls used in column (3) of Table 2. Column (1) includes MSA time trends and column (2) includes MSA and three-digit NAICS time trends. Dependent variable is percentage of within-firm transfers.

Columns (3)-(4): Unit of observation is an establishment-year. Sample includes annual data from 1992 through 1999. Regressions include establishment-specific fixed effects, differenced out at means. Regressions include time dummies, MSA and three-digit NAICS time trends, and controls for log(inventories), share of workers in white collar employment, log of TFP, and log of number of products. Dependent variable is percentage of within-firm transfers.

Column (5)-(9): Unit of observation is an establishment-year. Sample includes annual data from 1992 and 1999. Regressions include establishment-specific fixed effects, differenced out at means. Includes controls used in column (3) of Table 2. Dependent variable in column (6) is the log of within-firm transfers; dependent variable in column (7) is the log of total value shipped. Dependent variables in columns (5), (8), and (9) is percentage of within-firm transfers.

Table 5: Instrumental Variable Estimates of Table 2 Column 3

	(1)	(2)	(3)	(4)
	Competitor Adoption of Networked IT	Other Firm Adopters of CAD/CAE	Log of proxy cost	All instruments
First Stage: Dependent Variable is External IT				
Competitor Adoption of External IT	0.5152			0.3738
	(0.0880)**			(0.0957)**
Other Firm Adopters of CAD/CAE		0.2433		0.1542
		(0.0383)**		(0.0424)**
Log of proxy cost			-0.0778	-0.0570
			(0.0231)**	(0.0231)*
F-statistic	34.26	40.43	11.39	17.53
Stock-Yogo (2005) critical values	16.38	16.38	16.38	6.46
Second Stage: Dependent Variable is Percent Within-Firm Transfers				
External IT	-0.1917	-0.0526	-0.4367	-0.1909
	(0.1038)+	(0.0987)	(0.2077)*	(0.0902)*
Observations	~4500	~4500	~4500	~4500
Establishments	~2500	~2500	~2000	~2000
Overidentification test (p-value)	--	--	--	0.1944

Unit of observation is an establishment-year. Sample includes annual data from 1992 and 1999. Regressions include establishment-specific fixed effects, differenced out at means, and 1999 year fixed effects. First stage dependent variable is an indicator for whether the establishment has external IT. Stock and Yogo (2005) critical values are reported for maximal LIML size > 10%, respectively. Overidentification test uses Hansen J statistic. Robust standard errors, clustered by establishment, in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%

Table 6: Examining Where the Effects Occur: Splitting the Sample by Firm Size, Number of Establishment Products, and Industry

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Small Number of Sites	Large Number of Sites	Small Employment	Large Employment	Focused Plants	Multi-product plants	Excluding Transportation	Transportation
External IT	-0.0233	-0.0334	-0.0241	-0.0326	-0.0311	-0.0289	-0.0164	-0.1154
	(0.0179)	(0.0170)*	(0.0176)	(0.0170)+	(0.0410)	(0.0123)*	0.0124	(0.0454)*
Log(inventories)	-0.0056	-0.0112	-0.0048	-0.0116	-0.022	-0.0059	-0.0129	0.0064
	(0.0047)	(0.0049)*	(0.0053)	(0.0045)**	(0.0095)*	(0.0036)	(0.0038)**	(0.0076)
Share of workers in white collar employment	-0.0874	0.0475	-0.0208	-0.0451	-0.0141	-0.0219	-0.0264	-0.0441
	(0.0603)	(0.0683)	(0.0596)	(0.0673)	(0.1098)	(0.0472)	(0.0460)	(0.2325)
Log of TFP	-0.0320	-0.0317	-0.0065	-0.0479	-0.0042	-0.0436	-0.0295	-0.0451
	(0.0209)	(0.0245)	(0.0199)	(0.0236)*	(0.0453)	(0.0146)**	(0.0167)+	(0.0648)
Log of downstream firm demand	0.0003	0.0047	0.0014	0.0038	0.0032	0.0027	0.002	0.0089
	(0.0013)	(0.0021)*	(0.0013)	(0.0020)+	(0.0035)	(0.0013)*	(0.0012)+	(0.0056)
Log of local demand	-0.0002	-0.0027	-0.0009	-0.0022	-0.0005	-0.0018	-0.0015	-0.0046
	(0.0031)	(0.0025)	(0.0025)	(0.0030)	(0.0054)	(0.0020)	(0.0021)	(0.0063)
Log of number of products	-0.0055	-0.004	-0.0155	0.0045	0.0381	-0.0182	-0.0062	-0.0057
	(0.0139)	(0.0161)	(0.0142)	(0.0156)	(0.0309)	(0.0119)	(0.0107)	(0.0462)
1999 dummy	-0.0286	-0.0321	-0.0295	-0.0332	-0.0372	-0.0358	-0.0331	0.0034
	(0.0104)**	(0.0095)**	(0.0099)**	(0.0099)**	0.0247	(0.0074)**	(0.0071)**	0.0302
Constant	0.301	0.273	0.2137	0.3472	0.3094	0.3102	0.3074	0.341
	(0.0568)**	(0.0597)**	(0.0559)**	(0.0590)**	(0.1064)**	(0.0421)**	(0.0444)**	(0.1183)**
Observations	~2000	~2500	~2000	~2500	~1000	~4000	~4000	~500
"Number of LBD Number (Version C201002)"	~1000	~1500	~1000	~1500	~500	~2000	~2000	~200
R-squared	0.03	0.05	0.02	0.05	0.04	0.04	0.04	0.07

Unit of observation is an establishment-year. Sample includes annual data from 1992 and 1999. Regressions include establishment-specific fixed effects, differenced out at means. All regressions include controls used in column 3 of Table 2. Robust standard errors, clustered by establishment, in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%

Table 7: Instrumental Variables Regressions on Split Samples

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Small Number of Sites	Large Number of Sites	Small Employment	Large Employment	Focused Plants	Not Focused Plants	Excluding Transportation	Transportation
First Stage: Dependent Variable is External IT								
Competitor Adoption of External IT	0.1579	0.8804	0.1849	0.5924	0.4137	0.3884	0.3582	-0.0082
	(0.1135)	(0.1580)**	(0.1169)	(0.1500)**	(0.2008)*	(0.1083)**	(0.0989)**	(0.4215)
Other Firm Adopters of CAD/CAE	0.0840	0.2624	0.0738	0.2568	0.1091	0.1598	0.1383	0.1371
	(0.0529)	(0.0672)**	(0.0530)	(0.0719)	(0.0931)	(0.0473)**	(0.0436)**	(0.1918)
Log of proxy cost	-0.0909	-0.0235	-0.0536	-0.0458	-0.1000	-0.0508	-0.0618	0.0054
	(0.0354)**	(0.0303)	(0.0332)	(0.0323)	(0.0539)+	(0.0252)**	(0.0235)**	(0.0936)
F-statistic	4.72	22.55	3.01	18.12	3.34	15.35	13.79	0.19
Stock-Yogo (2005) critical values	6.46	6.46	6.46	6.46	6.46	6.46	6.46	6.46
Second Stage: Dependent Variable is Percent Within-Firm Transfers								
External IT	0.0658	-0.2669	0.1647	-0.3246	0.17	-0.2643	-0.151	-2.2485
	(0.1692)	(0.0922)**	(0.2482)	(0.1043)**	(0.2666)	(0.0943)**	(0.0956)	(5.7712)
Observations	~2000	~2500	~2000	~2500	~1000	~4000	~4000	~500
Establishments	~1000	~1000	~1000	~1000	~500	~2000	~2000	~200
Overidentification Test (p-value)	0.8870	0.0181	0.3833	0.1835	0.3500	0.2520	0.2497	0.9240

Unit of observation is an establishment-year. Sample includes annual data from 1992 and 1999. Regressions include establishment-specific fixed effects, differenced out at means. All regressions include controls used in column 3 of Table 2. First stage dependent variable is an indicator for whether the establishment has external IT. Stock and Yogo (2005) critical values are reported for maximal LIML size > 10%, respectively. Overidentification test uses Hansen J statistic. Robust standard errors, clustered by establishment, in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%

Appendix: Not Intended for Publication

Appendix Table 1: Percent Within-firm Transfers by 3-Digit Industry, 1999

Industry	Frequency	Average Percent Within-firm Transfers
Food Manufacturing (311)	~250	0.086
Textile Mills, Textile Product Mills, Apparel Manufacturing, and Leather and Allied Product Manufacturing (313-316)	~150	0.262
Wood Product Manufacturing (321)	~175	0.140
Paper Manufacturing (322)	~275	0.180
Petroleum and Coal Products Manufacturing (324)	~50	0.037
Chemical Manufacturing (325)	~375	0.117
Plastics and Rubber Products Manufacturing (326)	~150	0.108
Nonmetallic Mineral Product Manufacturing (327)	~75	0.146
Primary Metal Manufacturing (331)	~200	0.131
Fabricated Metal Product Manufacturing (332)	~100	0.092
Machinery Manufacturing (333)	~50	0.181
Computer and Electronic Product Manufacturing (334)	~75	0.066
Electrical Equipment, Appliance, and Component Manufacturing (335)	~100	0.065
Transportation Equipment Manufacturing (336)	~200	0.302
Miscellaneous Manufacturing (339)	~50	0.067

Note: NAICS 312, 323, and 337 were omitted for disclosure purposes. Descriptive statistics computed over establishments in baseline sample in 1999.

Appendix Table 2: Descriptive Statistics for complete ASM sample, 1999

	Mean	Standard Deviation
Percent within-firm transfers	0.043	1.827
Total within-firm transfers ($ Thousands)	~4,750	~175,200
Total value shipped ($ Thousands)	~50,600	~268,900
Log(inventories)	3.899	3.409
Production to nonproduction workers	0.367	0.202
Log(number of establishment products)	1.683	1.322
Log(Total factor productivity)	1.62	0.582

Number of observations is approximately 65,000.

Appendix Table 3: Correlation Matrix, 1999

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Percent within-firm transfers	1.0000													
2	Supplier IT	-0.1373	1.0000												
3	Customer IT	-0.0110	0.4811	1.0000											
4	External IT	-0.0670	0.6871	0.8214	1.0000										
5	Log(inventories)	-0.2667	0.0814	0.0496	0.0613	1.0000									
6	Production to nonproduction workers	-0.1888	0.1089	0.0955	0.0883	0.1431	1.0000								
7	Log(Total factor productivity)	-0.0056	0.1127	0.0202	0.0809	-0.1729	0.0270	1.0000							
8	Log of downstream firm demand	0.2807	-0.0671	0.0473	-0.0043	-0.0709	-0.1190	-0.1021	1.0000						
9	Log of local demand	0.0601	0.0325	0.0086	0.0190	0.0690	0.0645	-0.1404	0.1835	1.0000					
10	Dummy for competitors in local area	-0.0221	0.0041	0.0030	0.0218	0.0117	0.0429	-0.0205	-0.0265	0.2440	1.0000				
11	Local competition Herfindahl	0.0333	0.0229	0.0334	0.0128	0.0643	-0.1053	0.0030	0.0618	-0.4595	-0.4887	1.0000			
12	Log(number of establishment products)	-0.1136	0.0501	0.1000	0.0762	0.2102	0.0349	-0.1921	0.0439	-0.0125	-0.0026	0.0706	1.0000		
13	Log(number of manufacturing sites)	0.0555	-0.0648	-0.0117	-0.0333	-0.1000	-0.1181	0.0009	0.2050	-0.0966	-0.0144	0.0274	0.0871	1.0000	
14	Log(manufacturing employment)	0.1774	-0.0070	0.0735	0.0494	-0.1689	-0.1398	0.0758	0.3120	-0.0893	-0.0134	0.0780	0.1025	0.8431	1.0000

Descriptive statistics computed over establishments in baseline sample in 1999.

Appendix Table 4: Disaggregating Complementarities Among IT Applications, 1992-2002

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Baseline	Supplier IT	Customer IT	Supplier and Customer IT	Supplier and Customer IT Separately and Together	Supplier Customer and Internal IT	Supplier, Customer, and Internal IT controlling for additional IT investment
External IT	-0.0404				-0.0543	-0.0543	-0.0438
	(0.0142)**				(0.0292)+	(0.0293)+	(0.0301)
Supplier IT		-0.0269		-0.0197	-0.0013	-0.0014	0.0036
		(0.0126)*		(0.0133)	(0.0156)	(0.0162)	(0.0156)
Customer IT			-0.0253	-0.0155	0.0168	0.0168	0.0236
			(0.0132)+	(0.0140)	(0.0236)	(0.0247)	(0.0238)
Internal IT						0.0001	
						(0.0150)	
Advanced Supplier IT							-0.0225
							(0.0200)
Advanced Customer IT							-0.0345
							(0.0242)
Observations	~4500	~4500	~4500	~4500	~4500	~4500	~4500
Establishments	~2500	~2500	~2500	~2500	~2500	~2500	~2500
R-squared	0.01	0.01	0.01	0.01	0.02	0.02	0.02

Unit of observation is an establishment-year. Sample includes annual data from 1992 and 2002.
Regressions include establishment-specific fixed effects, differenced out at means. All regressions include controls used in column 3 of Table 2. Robust standard errors, clustered by establishment, in parentheses.
+ significant at 10%; * significant at 5%; ** significant at 1%

Appendix Table 5a: First Stage of Instrumental Variable Estimates of Table 2 Column 3

	(1)	(2)	(3)	(4)
	Competitor Adoption of Networked IT	Other Firm Adopters of CAD/CAE	Log of proxy cost	All instruments
Competitor Adoption of External IT	0.5152			0.3738
	(0.0880)**			(0.0957)**
Other Firm Adopters of CAD/CAE		0.2433		0.1542
		(0.0383)**		(0.0424)**
Log of proxy cost			-0.0778	-0.0570
			(0.0231)**	(0.0231)*
Log(inventories)	0.0033	0.0040	0.0060	0.0060
	(0.0042)	(0.0043)	(0.0045)	(0.0044)
Share of workers in white collar employment	-0.0700	-0.0911	-0.1300	-0.1031
	(0.0725)	(0.0717)	(0.0763)+	(0.0763)
Log of TFP	-0.0019	-0.0034	0.0106	0.0095
	(0.0183)	(0.0184)	(0.0203)	(0.0198)
Log of downstream firm demand	-0.0045	-0.0044	-0.0029	-0.0042
	(0.0021)*	(0.0021)*	(0.0022)	(0.0022)+
Log of local demand	0.0076	0.0076	0.0098	0.0090
	(0.0035)*	(0.0036)*	(0.0037)**	(0.0038)*
Dummy indicating local industry competitors	-0.0270	-0.0164	-0.0086	0.0001
	(0.0418)	(0.0417)	(0.0428)	(0.0423)
Industry-country Herfindahl	-0.0115	-0.0206	0.0084	0.0026
	(0.0742)	(0.0740)	(0.0769)	(0.0753)
Log of number of products	0.0486	0.0488	0.0520	0.0512
	(0.0167)**	(0.0166)**	(0.0174)**	(0.0173)**
Observations	~4500	~4500	~4500	~4500
Establishments	~2500	~2500	~2500	~2500
F-statistic	34.26	40.43	11.39	17.53
Stock-Yogo (2005) critical values	16.38	16.38	16.38	6.46

Unit of observation is an establishment-year. Sample includes annual data from 1992 and 1999. Regressions include establishment-specific fixed effects, differenced out at means, and 1999 year fixed effects. First stage dependent variable is an indicator for whether the establishment has external IT. Stock and Yogo (2005) critical values are reported for maximal LIML size > 10%, respectively. Robust standard errors, clustered by establishment, in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%

Appendix Table 5b: Second Stage of Instrumental Variable Estimates of Table 2 Column 3

	(1)	(2)	(3)	(4)
	Competitor Adoption of Networked IT	Other Firm Adopters of CAD/CAE	Log of proxy cost	All instruments
External IT	-0.1917	-0.0526	-0.4367	-0.1909
	(0.1038)+	(0.0987)	(0.2077)*	(0.0902)*
Log(inventories)	-0.0083	-0.0088	-0.0061	-0.0073
	(0.0035)*	(0.0035)*	(0.0039)	(0.0036)*
Share of workers in white collar employment	-0.0425	-0.0290	-0.1204	-0.0875
	(0.0491)	(0.0462)	(0.0632)+	(0.0495)+
Log of TFP	-0.0309	-0.0306	-0.0346	-0.0373
	(0.0165)+	(0.0162)+	(0.0170)*	(0.0147)*
Log of downstream firm demand	0.0021	0.0026	0.0011	0.0018
	(0.0013)	(0.0012)*	(0.0016)	(0.0013)
Log of local demand	-0.0005	-0.0017	0.0035	0.0010
	(0.0022)	(0.0021)	(0.0031)	(0.0022)
Dummy indicating local industry competitors	-0.0094	-0.0051	-0.0151	-0.0096
	(0.0282)	(0.0278)	(0.0322)	(0.0282)
Industry-country Herfindahl	-0.0528	-0.0507	-0.0634	-0.0646
	(0.0488)	(0.0475)	(0.0583)	(0.0507)
Log of number of products	0.0023	-0.0045	0.0172	0.0045
	(0.0118)	(0.0113)	(0.0167)	(0.0118)
Observations	~4500	~4500	~4500	~4500
Establishments	~2500	~2500	~2000	~2000
Overidentification test (p-value)	--	--	--	0.1944

Unit of observation is an establishment-year. Sample includes annual data from 1992 and 1999. Regressions include establishment-specific fixed effects, differenced out at means, and 1999 year fixed effects. Robust standard errors, clustered by establishment, in parentheses. Overidentification test uses Hansen J statistic. + significant at 10%; * significant at 5%; ** significant at 1%

Appendix Table 6a: First Stage of Instrumental Variables Regressions on Split Samples

	(1) Small Number of Sites	(2) Large Number of Sites	(3) Small Employment	(4) Large Employment	(5) Focused Plants	(6) Not Focused Plants	(7) Excluding Transportation	(8) Transportation
Competitor Adoption of External IT	0.1579	0.8804	0.1849	0.5924	0.4137	0.3884	0.3582	-0.0082
	(0.1135)	(0.1580)**	(0.1169)	(0.1500)**	(0.2008)*	(0.1083)**	(0.0989)**	(0.4215)
Other Firm Adopters of CAD/CAE	0.0840	0.2624	0.0738	0.2568	0.1091	0.1598	0.1383	0.1371
	(0.0529)	(0.0672)**	(0.0530)	(0.0719)	(0.0931)	(0.0473)**	(0.0436)**	(0.1918)
Log of proxy cost	-0.0909	-0.0235	-0.0536	-0.0458	-0.1000	-0.0508	-0.0618	0.0054
	(0.0354)**	(0.0303)	(0.0332)	(0.0323)	(0.0539)+	(0.0252)**	(0.0235)**	(0.0936)
Log(inventories)	0.0072	0.0065	0.0099	0.0051	0.0014	0.0070	0.0074	0.0018
	(0.0063)	(0.0060)	(0.0065)	(0.0058)	(0.0094)	(0.0049)	(0.0049)	(0.0108)
Share of workers in white collar employment	-0.0519	-0.1247	-0.0897	-0.0961	0.1988	-0.2211	-0.1114	-0.0607
	(0.0989)	(0.1146)	(0.1033)	(0.1102)	(0.1311)	(0.0887)*	(0.0780)	(0.3391)
Log of TFP	0.0292	-0.0076	0.0450	-0.0135	0.0478	-0.0024	0.0063	0.0475
	(0.0292)	(0.0264)	(0.0295)	(0.0261)	(0.0465)	(0.0216)	(0.0204)	(0.0776)
Log of downstream firm demand	-0.0014	-0.0081	-0.0017	-0.0064	0.0079	-0.0070	-0.0043	-0.0031
	(0.0031)	(0.0031)**	(0.0031)	(0.0031)*	(0.0053)	(0.0024)**	(0.0023)+	(0.0078)
Log of local demand	0.0031	0.0159	0.0067	0.0116	-0.0023	0.0113	0.0085	0.0153
	(0.0055)	(0.0049)**	(0.0052)	(0.0052)*	(0.0078)	(0.0041)**	(0.0039)*	(0.0122)
Log of number of products	0.1069	-0.0057	0.0840	0.0198	0.0803	0.0687	0.0487	0.0796
	(0.0236)**	(0.0240)	(0.0238)**	(0.0240)	(0.0426)+	(0.0204)**	(0.0181)**	(0.0577)
Observations	~2000	~2500	~2000	~2500	~1000	~4000	~4000	~500
Establishments	~1000	~1000	~1000	~1000	~500	~2000	~2000	~200
F-statistic	4.72	22.55	3.01	18.12	3.34	15.35	13.79	0.19
Stock-Yogo (2005) critical values	6.46	6.46	6.46	6.46	6.46	6.46	6.46	6.46

Unit of observation is an establishment-year. Sample includes annual data from 1992 and 1999. Regressions include establishment-specific fixed effects, differenced out at means. All regressions include controls used in column 3 of Table 2. Robust standard errors, clustered by establishment, in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%

Appendix Table 6b: Second Stage of Instrumental Variables on Split Samples

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Small Number of Sites	Large Number of Sites	Small Employment	Large Employment	Focused Plants	Not Focused Plants	Excluding Transportation	Transportation
External IT	0.0658	-0.2669	0.1647	-0.3246	0.17	-0.2643	-0.151	-2.2485
	(0.1692)	(0.0922)**	(0.2482)	(0.1043)**	(0.2666)	(0.0943)**	(0.0956)	(5.7712)
Log(inventories)	-0.0071	-0.0084	-0.0064	-0.0099	-0.0211	-0.004	-0.0105	0.0081
	(0.0049)	(0.0053)	(0.0059)	(0.0049)*	(0.0100)*	(0.0038)	(0.0039)**	(0.0238)
Share of workers in white collar employment	-0.1184	-0.0403	-0.0305	-0.1433	-0.1576	-0.0925	-0.0832	-0.247
	(0.0605)+	(0.0781)	(0.0628)	(0.0802)+	(0.1160)	(0.0617)	(0.0495)+	(0.8944)
Log of TFP	-0.0327	-0.0515	-0.0223	-0.0649	-0.0262	-0.0506	-0.0357	0.0398
	(0.0215)	(0.0210)*	(0.0257)	(0.0207)**	(0.0419)	(0.0159)**	(0.0146)*	(0.3347)
Log of downstream firm demand	0.0002	0.0028	0.0011	0.0022	0.0013	0.001	0.001	0.0049
	(0.0014)	(0.0023)	(0.0013)	(0.0023)	(0.0044)	(0.0015)	0.0013	(0.0249)
Log of local demand	0.0013	0.0016	-0.0011	0.0026	-0.001	0.0029	0.0009	0.033
	(0.0031)	(0.0031)	(0.0031)	(0.0036)	(0.0057)	(0.0025)	(0.0023)	(0.0947)
Log of number of products	-0.0147	-0.002	-0.0265	0.0111	0.035	-0.0019	0.003	0.1681
	(0.0220)	(0.0169)	(0.0257)	(0.0174)	(0.0361)	(0.0141)	(0.0117)	(0.4609)
Observations	~2000	~2500	~2000	~2500	~1000	~4000	~4000	~500
Establishments	~1000	~1000	~1000	~1000	~500	~2000	~2000	~200
Overidentification Test (p-value)	0.8870	0.0181	0.3833	0.1835	0.3500	0.2520	0.2497	0.9240

Unit of observation is an establishment-year. Sample includes annual data from 1992 and 1999. Regressions include establishment-specific fixed effects, differenced out at means. All regressions include controls used in column 3 of Table 2. Robust standard errors, clustered by establishment, in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%