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The Digital Erosion of Firm Boundaries: Complementarities between IT Use and Production Chain Organization in US Manufacturing

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Abstract

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PRELIMINARY

The Digital Erosion of Firm Boundaries: Complementarities between IT Use and Production Chain Organization in US Manufacturing*

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1. Introduction

The information age has arrived – but unevenly, and with imperfectly understood consequences. While U.S. firms have invested robustly in information technology over the past few decades[1], their returns have often lagged (Tambe and Hitt 2011) and vary strikingly across organizations (e.g., Aral and Weill 2007). A frontier approach to understanding this variation focuses on potential complementarities between IT adoption and organizational practices. This framework argues that firms adopting a particular set of IT and organizational practices *together* will enjoy greater returns than firms adopting only a subset of these technologies or practices (Milgrom and Roberts, 1990). Consistent with this approach, evidence is slowly mounting that alignment between IT investments and certain aspects of a firm's overall organizational strategy (e.g., internal allocation of decision rights, worker training and selection, compensation policies, etc.) is associated with greater IT-related productivity.[2] However, the best "recipes" for combining IT 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 complementarities literature has focused exclusively on characteristics that are internal to the firm. Yet a growing body of evidence suggests that external linkages to suppliers and customers may be instrumental in determining firm performance[3] as well as fundamental strategy choices such as market entry (Alcacer and Oxley 2012) or innovation (Afuah and Bahram 1995, Tambe et al. 2012, McElheran 2013).

In this paper, we focus on one of the most fundamental firm design choices: where to draw the firm boundary. In particular, we investigate the conditions under which a firm will choose to own the links in its production chain – i.e., whether it will be vertically integrated. Recent work in economics has

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[1]Annual IT-related investment by U.S. firms exceeded $558 billion in 2012 (U.S. Bureau of Economic Analysis, 2013). For further detail, see Jorgenson, Ho, and Stiroh (2005).

[2] See, for example, Bresnahan et al. (2002), Bloom et al. (2011), Aral et al. (2012), Tambe et al. (2012), and Melville and Kraemer (2012).

[3] For evidence on the performance benefits of firm investment in interorganizational systems see, for example, Dong, Zu, and Zhu (2009), Mukhopadhyay and Kekre (2002), Mukhopadhyay, Kekre, and Kalathur (1995), Rai, Patnayakuni, and Seth (2006), Srinivasan, Kekre, and Mukhopadhyay (1994), and Yao and Zhu (2012).

begun to explore the drivers of this firm decision (Atalay et al. 2012). In the information systems literature, externally-focused IT investments have been found to coincide with a range of relationships between firms and their partners within the value chain.[4] However, due to data constraints, there has been little direct empirical testing of how IT-enabled linkages influence the ownership structure of production chain interactions, and none has considered multiple margins of external and internal investment.[5]

The goal of this paper is to provide some unique 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.

We take as a point of departure that firms are embedded in strategic value chain relationships whose performance may be affected by internal organizational decisions such as IT adoption. Drawing upon prior literature, we generate a set of predictions about how different margins of IT use will lower the costs of coordinating with customers and internal supply chain partners through improvements to resource allocation decisions and incentives.[6] Our core hypothesis is that more-transparent and accurate flow-through of information about downstream demand signals *and* upstream supply information will lower the frictions of transacting with external organizations, leading to a lower degree of vertical integration.

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 margins of IT use along important dimensions. Our data combines the non-public micro data from the 1992 Census of Manufacturers (CMF) and the

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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., Dedrick and Kraemer 2010; Bardhan, Mithas, and Lin 2007; Bardhan, Whitaker, and Mithas 2006) 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 2012).

[5] As we describe in further detail below, prior work has examined the relationship between generic IT capital spending and firm size (Brynjolfsson et al. 1994), as well as firm participation in vertically integrated industries (e.g., Hitt 1999, Dewan, Michael, and Min 1998, Ray, Wu, and Konana 2009).

[6] See, for example, Baker and Hubbard (2003, 2004), Forman, Goldfarb, and Greenstein (2005), Forman and Gron (2011), Hubbard (2000).

1999 Annual Survey of Manufactures (ASM), including the Computer Network Use Supplement (CNUS) addendum. The resulting data set brackets the potentially important diffusion of the commercial Internet (circa 1995) and yields observations for roughly 2,500 plants across a wide range of industries.

Our dependent variable is a measure of the value of plant shipments that is transferred to other plants within the same firm, normalized by the total plant shipment value; we label this margin of activity the *percentage of within-firm transfers.* The advantage of this measure is that it directly captures the extent of output that is used for downstream production within the same firm, providing us with a plant-level measure of the extent to which commodity flows are vertically integrated. To our knowledge this variable offers one of the few opportunities to directly measure the extent of vertical integration in production chains across multiple industries.[7] Our source of data on IT investment presents not only on *what* networking technology is in use at a respondent plant but *with whom* the plant shares information – a key requirement of our research design. Using differences-in-differences estimation, we find that externally-focused IT aimed at improving the coordination of *both* downstream and upstream economic activity is associated with a 2-3 percentage point decline in the percentage of within-firm transfers. Relative to a mean percentage of 14.4%,[8] this represents an economically as well as statistically significant impact. These results are robust to the inclusion of a wide range of time-varying controls—including controls for IT investment that lower internal coordination costs—as well as changes to the definitions of our margins of external IT investment, changes to our sample, and changes to the distributional assumptions of our econometric model. We find they are also robust to including a measure of IT investment that reduces internal (i.e., within-firm) coordination costs.

We address the potentially problematic assumption that the IT adoption of interest is exogenous using instrumental variables estimation. Within the constraints of this econometric approach, we find that the general pattern of results holds, consistent with a causal effect of IT on firm boundary decisions.

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[7] For another example of measurement of vertical integration using a different Census plant-level data set, 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).

[8] This surprisingly low level of vertically integrated production in U.S. Manufactures is not unique to our data sample. See Atalay et al. (2013) for further evidence and discussion.

Central to our arguments about complementarities, we delve into the interaction effects between upstream and downstream margins of external IT use. Leveraging prior work in operations management, we argue that improvements in coordinating economic activity with downstream customers arising from IT-enabled links with customers will be more impactful if they are accompanied by adoption of upstream electronic links with suppliers –and vice versa. The adoption of this combination of applications will improve firms' resource allocation decisions by better linking upstream production and inventory information with downstream demand signals. We hypothesize three-way complementarities between customer-focused IT, supplier-focused IT, and reduced vertical integration. We test this hypothesis by examining adoption patterns of the three practices as well as interacting our measure of customer-focused IT with supplier-focused IT in the vertical integration regression. Our results are consistent with the presence of complementarities.

The research contribution of these findings centers on bringing a novel external dimension to the complementarities literature. However, these findings also shed light on long-standing questions in the much broader literature on the impact of IT on organizations. Networked IT investments can reduce the costs of coordinating economic activity inside the firm boundary we well as with outside market participants. Therefore, the 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) 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 on the scope of firm activity, however they are limited in their ability to provide insights into how IT investments have reorganized the ownership of production chains. In contrast, by measuring the effects of IT investments on commodity flows within production chains, we offer some insights into this question.

Further, in contrast to prior work on IT and firm boundaries, we take advantage of the ability to separately observe specific internal and external uses of IT. This allows us to disentangle and separately measure the competing effects of IT capital spending on internal and external coordination costs. It further allows us to advance recent literature that has sought to test for three-way complementarities between specific margins of IT investment and organizational practices (e.g., Aral, Brynjolfsson, and Wu 2012).

Our paper also contributes to the empirical operations management literature studying production chain coordination within and between firms. A long line of work has argued theoretically (e.g., Aviv 2007; Cachon and Fisher 2000; Chen and Lee 2009, 2011; Lee, Padmanabhan, and Whang 1997) and empirically (Bray and Mendelson Forthcoming; Cachon et al. 2007) that investments in information technology will increase the efficiency of supply relationships between heterogeneous partners. This should increase the benefits of arm's length transactions relative to vertical integration, promoting less integrated production in equilibrium. While a variety of work has asserted this hypothesis, it has not been tested directly to our knowledge.

Finally, the determinants and complements of firm boundary decisions have been central areas of study in both economics and strategy. Understanding what determines firm boundaries and the decision to organize economic activity according to the rules of organizations or those of the market has been deemed "one of the most important issues in economics" (Lafontaine and Slade, 2007). Important streams of research in strategy have also grappled with these issues (e.g., Novak and Stern 2009).

Beyond the broad research implications, our results also have important and surprising implications for management practice. Complementarities between upstream and downstream coordination imply that firms interested in pursuing more market-based downstream activity aided by sophisticated IT coordination will be more successful if they include upstream supply coordination in their business strategies. A laser focus on customers and customer needs that ignores the potentially more important upstream margin of coordination could significantly reduce the returns to IT and complementary organizational investment.

2. Theoretical Motivation (under revision)

We examine the factors influencing a firm's decision to retain the output of one of its establishments for use in the firm's internal value chain or to sell the output outside of the firm boundary. We label this problem the *within-firm sales* decision. 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 in question allocated to internal use. Outside of this boundary case, remaining productive capacity at the plant may be used to produce output for sale on the external market.

How much of that capacity is allocated to external sales will depend upon a range of internal and external supply and demand conditions. We focus on the factors that are most likely to be influenced by the introduction of Internet-enabled information technology (IT) applications. We follow prior research by focusing primarily on factors external to the firm. We justify this approach with the observation that, while internal factors are almost surely instrumental in the firm boundary decision they are a) typically unobserved with precision in large data sets and b) addressed in our econometric estimation.

An important external factor is the productivity of the establishment in question relative to others in the same industry. While the firm may choose to retain a relatively unproductive establishment to conserve on transaction costs or maintain a stable source of supply, such an unproductive establishment may find it challenging to compete in an external market if its production costs are higher than those of competitors.[9] Specifically, if the costs of production at the plant are higher than other plants within the

[9] However, see Hortacsu and Syverson (2009) for evidence that vertically integrated firms may be more productive if they have better management.

same industry, this will decrease the propensity to sell externally.

The decision of where to allocate sales will also be influenced by the non-production costs of coordinating economic activity with firms in the external market. These costs can include the costs of opportunistic behavior as well as the costs of coordinating resource allocation decisions between firms. We explore the source of each of these costs below.[10]

2.1 Incentive Problems in Supply Chain Relationships

Supply chain relationships between independently owned firms are subject to a range of potential incentive problems that may give rise to opportunistic behavior by customers and suppliers. These risks have been documented extensively elsewhere (e.g., Clemons and Row 1992; Lee, Padmanabhan, and Whang 1997a; Lee and Whang 2000), so we describe them only briefly here. One potential risk is downstream customers misstating delivery performance, claiming late or incomplete delivery when goods have in fact been received on-time and in full.[11] Another common problem is order rationing by suppliers in times of shortages that may lead downstream partners to overstate their orders and forecasts (e.g., Lee, Padmanabhan, and Whang 1997a). The risks of opportunistic behavior are not confined to customers, however. In the absence of real-time information, suppliers may misstate order status to customers, hoping to make up any unreported delays through expedited production or shipping.

2.2 Coordination Problems in Supply Chain Relationships

Another factor influencing the extent of within-firm sales will be the cost of coordinating economic activity within and between firms.[12] The implications of imperfect information flows for coordination costs and resource allocation decisions have been explored in the literature on supply chain

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[10] Of course, there is a long literature on the risks of opportunism in cross-firm transactions, which we will not attempt to summarize here. For summaries see, for example, Williamson (1985) or Hart (1995). For a specific discussion about the role of these costs in supply chain relationships and how they can be influenced by IT investments see, for example, Clemons and Row (1992).

[11] For one example, see Langer et al. (2007)

[12] As Hubbard (2000) notes, analysis of the value of information in these contexts arises from decision theory (e.g., Raiffa and Schlaifer (1961), Raiffa (1968), and DeGroot (1970)). However, issues surrounding the costs of information in supply chains have played a prominent role in the operations management literature, perhaps most prominently in work on the bullwhip effect (e.g., Lee, Padmanabhan, and Whang 1997a, 1997b).

management.[13] In particular, one common problem arises when upstream suppliers observe only orders and not final demand and when demand signals are correlated. In this case, when there is a demand shock and downstream firms issue large orders based on their updated forecasts, there is a distortion of demand information that increases the farther one moves up the supply chain. The demand information received by the downstream firm is transmitted in an exaggerated firm to the upstream supplier. This leads to the well-known "bullwhip effect"—the variance in orders is strictly larger than that of sales and distortion in demand signals increases the farther up one moves through the supply chain. This inefficiency typically hurts 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 coordination costs have other implications. In particular, the costs of transacting with external partners often lead to order batching that likewise contributes to increases in order variability (Lee, Padmanabhan, and Whang 1997a). Similarly, high-low pricing will lead to order clustering as customers attempt to take advantage of price discounts. These increases in order variability will contribute to higher inventory and order-fulfillment costs (Aviv 2007; Chen and Lee 2009, 2011).

2.3 The Implications of IT

In this previous section we discussed how incentive and coordination problems increased the costs associated with transacting in arm's length supply chain relationships. In this section, we discuss the potential for IT to reduce each of these costs, thereby potentially influencing the net benefits of such arm's length relationships relative to vertical integration and increasing the propensity to sell outside of the firm.

Customer-focused IT. We label the first type of IT we study as customer-focused IT. As has been highlighted above and elsewhere in the literature, customer-focused IT has the potential to reduce

[13] Prior work on the implications of IT for firm boundaries has also explored these issues. For further details, see Gurbaxani and Whang (1991), Clemons and Row (1992), and Clemons, Reddi, and Row (1993).

both the costs of coordinating operational activity among firms and the risks of opportunistic behavior. We detail each of these mechanisms briefly below.

Customer-focused IT can enable the sharing of information to customers such as design specifications, product descriptions or catalogs, order status, production schedules, and inventory data. It can also facilitate transactions with customers by facilitating ordering and payment by customers. This heterogeneity in applications and uses means that investment in customer IT can give rise to a variety of different implications for the costs of transacting in supply chain relationships. Below we discuss how we measure the effects of customer IT given this heterogeneity in use; here we focus upon the implications of a generic decline in the costs of information flows that are enabled by IT investments.

Adoption of this kind of IT can reduce the costs of coordinating economic activity between firms. For example, customer-focused IT can reduce customers' search costs of identifying a trading partner. Customer-focused IT investments can also reduce many coordination costs in the supply chain that engender increases in order variability. For example, if downstream customers share demand data with manufacturers, the latter can better forecast demand and make better production plans. Lee et al. (2000) have quantified the value of this information-sharing in an analytical model of a two-level supply chain, showing that information-sharing can provide significant inventory reduction and cost savings to a manufacturer. By reducing the costs of transacting with supply chain partners, customer-focused IT will also decrease incentives for order batching. The value of such declines in order batching have been quantified by Cachon and Fisher (2000), who show that cutting batch sizes in half can reduce supply chain costs by over 20%.

By facilitating monitoring of the focal establishment's operations, customer-focused IT also has the potential to reduce the risks of opportunism and hold-up. For example, by sharing information such as order status, production schedules, and inventory data with customers, the latter can more easily monitor the focal establishment's adherence to contracted production schedules. Further, the risks that customers will overstate their orders will be less if suppliers can observe customer demand and inventory. Last, electronic monitoring of the supply chain can verify delivery performance, reducing the risks that customers may claim late or incomplete delivery of goods that have been received on-time and in full. [14]

In short, the discussion above suggests that, if anything, adoption of customer IT will decrease the percentage of production allocated to within-firm sales.

Supplier-focused IT. The other margin of IT investment that we investigate in-depth is supplier-focused IT. Supplier-focused IT includes the sharing of information such as design specifications, order status, production schedules, and inventory data with suppliers. It can include automated ordering from and payment to vendors, vendor-managed inventory, and the use of electronic marketplaces. Supplier-focused IT has the potential to reduce the costs of transacting with external suppliers. However, as noted earlier, we do not study the implications of IT investment for the make-or-buy decision due to data constraints. Rather, we focus on the indirect effects that supplier IT will have on the intensity of external downstream sales.

By sharing information with suppliers such as order status, production schedules, inventory data, and logistics, supplier IT has the potential to reduce not only the coordination costs of transacting with external suppliers but also those of transacting with external customers. The information-sharing enabled by supplier-focused IT will be particularly important in reducing the costs associated with inaccurate demand signals. As noted above, when downstream customers share only order information with suppliers, the distortion in demand signals becomes greater the farther one moves up the supply chain (Lee, Padmanabhan, and Whang 1997). Lack of information-sharing between the focal establishment and upstream suppliers hurts all participants in the supply chain in the form of excess raw material inventory, unplanned purchases of supplies, inefficient utilization and overtimes, excess warehousing expenses, and premium shipping costs (Lee and Whang 2000). Sharing performance metrics such as product quality data, lead times, and service performance will therefore help not only the focal establishment but also its

[14] We note that customer IT can potentially reduce the costs of producing output in several ways. For example, by automating customers' ordering and payment customer IT will reduce the costs of the sales order process. Further, because customers will have better information about the focal establishment's production and inventory, they are less likely to make large orders for buffer stocks (e.g., Lee and Whang 2000) which will lower the focal establishment's inventory holding costs. However, we classify these benefits as reflecting the value of lower external coordination costs. This reflects our classification of costs. We classify production costs as those that influence production regardless of the final customer for the product, internal or external.

downstream customers (Lee and Whang 2000). For example, inaccurate demand signals from the focal establishment to its supplier will lead the latter to hold excess inventories, increasing its costs and lower its service levels in ways that will affect downstream firms.

Thus, improved information-sharing between the focal establishment and upstream suppliers can also improve service levels and costs between for the focal establishment's downstream customers. The value of upstream information-sharing to downstream customers will be even greater when used in conjunction with customer-focused IT. In this latter case, the flow-through of information will be greatest, benefiting all supply chain participants. Further, downstream customers will be able to benefit more directly from information-sharing with the focal establishment's upstream suppliers. In other words, the improvement in demand signal-processing that arises from better flow-through of information will be greatest when both customers and suppliers are linked electronically.

Thus, like customer-focused IT, supplier-focused IT has the potential to reduce the coordination costs between the focal establishment and downstream customers. Because of these efficiencies, we expect that adoption of supplier-focused IT will also be associated with an increase in external sales relative to internal sales. However, while supplier-focused IT will reduce the coordination costs between the focal establishment and downstream customers, there is no comparable effect on **incentive** costs of transacting downstream. In other words, while supplier-focused IT will decrease the incentive costs of transactions between the focal establishment and ***upstream*** suppliers—such as those arising from shortage gaming on the part of the focal establishment—there is no mechanism through which this decrease in incentive-based frictions will influence the costs of ***downstream*** external sales relative to downstream internal sales. That is, we do not expect that ex ante improvements to incentives between the focal establishment and upstream supplier arising from supplier IT will influence the downstream within-firm sales decision.

3 **Empirical Approach**

We lean on revealed preference arguments (Athey and Stern 1998; Bocquet, Brossard et al. 2007)) to motivate our analysis. Although we do not directly model the productivity impacts of these practices (either separately or in combination), we leverage the pattern of adoption to make inferences about the joint returns to the practices. Under the assumption that firms are optimally making their IT and organizational choices, then the presence of complementarities will generate clustering in the adoption pattern, which can be readily observed.

The key challenge to correct inference, as emphasized by Arora (1996) and Athey and Stern (1998) is the potential for omitted factors (e.g., managerial skill) to simultaneously boost the adoption of certain organizational practices and IT, creating the appearance of complementarities where none actually exist. Our approach to this challenge is threefold. First, we use fixed effects panel data models to account for unobserved time-invariant characteristics of plants that could confound our results. Second, we employ a rich set of time-varying controls to address key factors that are likely influence firm boundary decisions (such as changes in downstream demand for production output), in hopes of identifying the IT-related effect. Third, we explore the use of instrumental variables estimation to account for potential endogeneity in the IT adoption decision.

Thus, we begin with a difference-in-difference approach, comparing the percentage of within-firm transfers prior to adoption of customer- and supplier-focused IT to the percentage after adoption. In particular, we estimate:

$$WFT_{it} = \alpha X_{it} + \beta External - IT_{it} + \mu_i + \tau_t + \varepsilon_{it} \quad (1)$$

Here WFT_{it} is the percentage of total shipments that are transferred internally within the firm. $External - IT_{it}$ is a dummy variable that measures whether the establishment has adopted Internet-enabled IT that facilitates coordination with both suppliers and customers by time *t*. Internet technology had not diffused among firms prior to 1995 except in very rare cases, so the value of this variable will be equal to zero prior to this date. The variable X_{it} includes a constant term and a set of time-varying establishment-level controls for factors that may influence the propensity of an establishment to sell outside the firm. We estimate our model using two periods of data, 1992 and 1999. We expect that adoption of external IT will be associated with a decline in the percentage of within-firm transfers, i.e. $\beta < 0$.

There are several things to note about our estimating equation. First, our estimation approach is equivalent to a two-period difference-in-difference model. We estimate the above equation using robust, clustered standard errors so the approach above will give identical results to a cross-sectional two-period difference regression. Second, as noted above our differencing approach will remove industry-based time-invariant cross-sectional differences across establishments that may influence the propensity to engage in inter-firm sales.[15]

Third, the regression equation above is a linear model although our dependent variable is a percentage and so bounded between 0 and 1. Thus, our estimating approach shares similar shortcomings to that of the linear probability model: namely, our model can predict values outside of the 0/1 range and the errors in the model will be heteroskedastic. We choose 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.[16]

Fourth, 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). This assumption will be violated if, for example, there exists reverse causality: for example, if changes in the intensity of within-firm transfers cause IT adoption. Prior work has identified a relationship between the extent of vertical integration and investment spending in information technology (e.g., Dewan, Michael, and Min 1996; Hitt 1999). We have chosen not to examine this relationship directly because of the nature of our investigation. Specifically, while prior

[15] For a discussion of how product characteristics can influence transactions costs and optimal supply chain structure, see Fisher (1997). For empirical tests of this hypothesis, see Randall and Ulrich (2001) and Randall, Morgan, and Morton (2003).

[16] 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)), this method is unattractive given that our data have significant mass points at both 0 and 1. For further details, see Papke and Wooldridge (1996). Our results are robust to a fractional probit estimation (results pending Census disclosure review).

work has examined the equilibrium relationship between IT and vertical integration, our focus is to study the short-run change in the extent of vertical integration that arises from the adoption of new IT. More broadly, our results may be influenced not only by reverse causality but also other unobserved factors that may be correlated both with IT investment and the extent of vertical integration.

We address these concerns in several ways. First, we include a variety of controls related to the productivity of the establishment, the demand for the establishment's output from local establishments and other establishments within the same firm, and competition from other establishments in the focal establishments industry and location. In later regressions we will control for alternative margins of IT use, so if unobservable factors are influencing within-firm transfers they must be specific to external IT.

Second, we present instrumental variables regressions that use local telecommunications costs, adoption of external IT by establishments in competing firms, and the IT capabilities of other establishments within the same firm as instruments. As we explain in further detail below, changes in these instruments should affect the likelihood of adopting external IT but should not affect the extent of within-firm transfers.

4 Data

We use data from a variety of data sources to examine how IT adoption influences the intensity of inter-firm sales. In particular, we match data from the 1999 Computer Network Use (CNUS) supplement to data from the 1999 Annual Survey of Manufacturers and the 1992 Census of Manufacturers. We describe each of these data sources below.

IT data. The dependent variables capturing the uses of new internet technology by firms come from the Computer Network Use Supplement (CNUS) included in the US Census Bureau's 1999 Annual Survey of Manufacturers. The approximately 35,000 plants in the sample accounted for more than 50% of manufacturing employment and output in the US at the time. They belonged to more than 20,000 firms in 86 different manufacturing industries, providing data across a wide range of market contexts.

The CNUS contains detailed information on establishment-level adoption of a variety of networked technologies. We group the responses into two categories that we label *customer-focused IT* and *supplier-focused IT*. These margins of IT investment identify changes in coordination costs between the establishment and its external customers and between the establishment and its upstream suppliers. To define these variables we proceed in two steps. First, we identify questions in the CNUS survey that specifically ask about sharing information over computer networks with external customers and external suppliers, and identify establishments involved in each of these practices.[17] [18] Once we identify establishments that are engaged in information-sharing with each of the groups, 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-focused IT, it must both be involved in digitized information-sharing with customers and be using internet technology. We add the latter condition because older networked technologies for cross-establishment and cross-firm interaction like EDI have significant limitations such as multiple industry-specific standards, may be batch-oriented, and have severe limitations for information-sharing (Lee and Whang 2000). However, our results are robust to relaxing this condition.

As noted above, we believe that adoption of *customer-focused IT*, *supplier-focused IT*, and declines in the extent of vertical integration form a system of complements. In other words, the value of adopting any one practice increases when adoption in conjunction with the others. If customer-focused IT and supplier-focused IT are complements, then we should observe that there adoption is clustered. This is what we see in the data. The majority of establishments in our sample adopt the combination of customer-

[17] To identify customer-focused IT, question 6 on the CNUS survey asks if the establishment shares any of the following with external customers, external suppliers, or other company units: design specifications; product descriptions or catalog; demand projections; order status; production schedules; inventory data; or logistics and transportation. Further question 7(b) asks if the establishment has currently computer networked any of the following business processes: access to your products or catalog; ordering by your customers; payment by your customers; management of your customer's inventory; or customer support. We identify establishments as practicing customer-focused IT if it answers yes to any of these questions.

[18] To identify supplier-focused IT, we again use the items in question 6 that correspond to information sharing with suppliers. We augment this with responses to question 7(a) that asks if the establishment has computer networked any of the following business processes: access to vendor products or catalogs; ordering from vendors; payment to vendors; vendor management of your inventory; online bidding; or using electronic marketplaces linking specialized business buyers and sellers. We identify establishments as practicing supplier-focused IT if it answers yes to any of these questions.

focused IT and supplier-focused IT (27.2%) or neither kind of external IT (47.4%). As a result, to simplify our analysis we combine both variables into a single measure of IT that facilitates coordination with suppliers and customers, which we label *external IT*. In later analyses, we decompose *external IT* into its constituent parts to formally identify complementarities between *customer IT* and *supplier IT*.

Within-firm transfers. The 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. These variables are from the 1992 Census of Manufacturers (CMF) and the 1999 Annual Survey of Manufacturers (ASM). Due to the nature of our study, we place a number of restrictions on our estimation sample. This is 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 establishments from single-establishment firms. Second, following Atalay, et al. (2013) we include only establishments that produce products that are used downstream within the firm as part of a substantial link in the vertical production chain. We also follow Atalay, et al. (2013) in defining these establishments: specifically, a substantial vertical link exists between an industry A and an industry B when industry A produces a commodity which industry B buys at least five percent of for its intermediate materials, according to the BEA's 2002 Benchmark Input-Output tables. Our results are robust to excluding this condition.

Third, we exclude establishments for which the value of our dependent variable was either 0 or above the 95th percentile for multiple years prior to our estimation sample. We do this to account for the possibility of production technologies that are resistant to any sort of within-firm transfer (e.g. glass production) as well as captive plants whose output allocation may be determined for reasons unrelated to transaction costs (e.g. restricting outside access to sensitive intellectual property). It turns out that our results are robust to relaxing these conditions as well. Fourth, because of our difference-in-difference identification strategy, we only include establishments that are present in both years of our sample, 1992 and 1999. Last, we exclude a small number of outliers where the value of within-firm transfers exceeded the value of total shipments at the establishment by more than a factor of two.

We include several controls using the CMF and ASM data for our analyses. To control for how differences in inventory levels may influence the propensity to sell outside the firm– in particular, the possibility that firms may increase external sales in order to dispose of excess inventory, we include a control for the log of the dollar value of the current stock of inventories. To control for the skill mix of workers in the firm, we include a control for the ratio of production to nonproduction workers. Further, as noted above, more productive plants are likely to be more successful in selling externally. To control for variation in a plant's external market opportunities as a result of varying productivity, we include a measure of total factor productivity at the establishment computed following Cooper et al (1999).[19] Last, we compute the log of the total number of products produced by the establishment.

We also include controls for demand for the focal establishment's output both within the firm and locally. To control for downstream demand for the focal plant's output, we first identify the set of "downstream" establishments within the same firm using the algorithm described above. For this set of establishments, we next take the product of the value of the establishment's total materials consumption with the percentage of inputs used from the focal establishment's industry using the Detailed Use Tables from the 2002 Benchmark Input/Output tables. We last sum the value of this variable across all related establishments.

To compute local demand for the establishment's output, we similarly identified the establishments in the local county that use the focal establishment's output as a significant input (i.e., those establishments where a substantial vertical link exists using the definition of Atalay, Hortacsu and Syverson (2013)). As we did for downstream firm demand, we multiplied the value of materials consumption for these local establishments by the percentage of inputs used from the focal establishment's industry using the Benchmark Input/Output tables. We then summed these values across all related establishments in the county.

We include two variables to control for the presence of competition in the establishment's

[19] 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 following Cooper, Haltiwanger, and Powell (1999).

primary three-digit NAICS industry. First, we include a dummy variable that indicates whether there exist any competitors in the same three-digit NAICS and in the same county. Second, using the total value of shipments for each establishment, we compute an establishment-level Herfindahl index for the three-digit NAICS industry and county.

Table 1a provides some descriptive statistics for our estimation sample as of 1999, then second year in our sample. The average percentage of shipments that are transferred internally is approximately 14.4%. Table 1b shows the average percentage of within-firm transfers across three-digit NAICS in our sample. The table demonstrates that there is significant variance in the intensity of WFT across industries. The average industry percentage WFT ranges from 3.7% in petroleum and coal products manufacturing to 26.2% in textile mills. We will attempt to control for this variance using establishment-level fixed effects in our estimation.

Table 1a displays the remainder of the descriptive statistics as of 1999. 44.2% of the establishments have supplier-focused IT in our sample, while 35.6% have customer-focused IT and 27.2% have both supplier-focused and customer-focused IT. The lower fraction of customer-focused IT likely reflects the additional difficulties of coordinating externally with customers during this time period, as detailed in McElheran (2013).

5 Results

We examine the relationship between external IT and the percentage of interplant transfers. We show that these results are robust to a variety of changes in sample, changes to the IT variables, and estimation approach. Next we show that our results are due to both a decline in WFT and an increase in total value shipped, and that our results are strongest among establishments who had not adopted earlier generations of coordinating IT such as EDI. We next explore the robustness of our results to the use of instrumental variables. Last, we disaggregate external IT into its component margins of IT investment, to better understand how external IT is influencing firm boundaries.

5.1 Baseline Results

Figure 1 reports the results of a nonparametric difference-in-difference analysis of the percentage of within-firm transfers between 1992 and 1999 and according to the adoption of external IT. The results first show that for both years, the percentage of within-firm transfers is lower for establishments receiving the IT treatment than for those who do not, highlighting the need to control for time-invariant differences in our data. As a result, we focus on differences in within-firm transfers for adopters and non-adopters of external IT. The percentage of within-firm transfers declined by a statistically significant 2.9 percentage points among establishments who did not adopt external IT, but fell by an even greater (and statistically significant) 6.4 percentage points among those who adopted external IT. 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. This is the core result of our paper. Throughout the remainder of the paper, we study whether this result is robust to a variety of robustness checks, including the inclusion of controls and instrumental variables analysis.

In table 2 we use the regression model in equation (1) to examine the implications of external IT for the percentage of within-firm transfers. Column 1 shows the correlation between supplier-focused IT and the percentage of within-firm transfers. Column 2 adds a variety of controls for establishment inventories, productivity, worker skill mix, and demand for the establishment'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, if an establishment adopts supplier-focused IT this translates into a 2.9 percentage point decline in the percentage of within-firm transfers (or, equivalently a 2.9 percentage point increase in inter-firm transfers). Recall that across the entire sample the average percentage of within-firm transfers is approximately 14.4%, so this is economically a very significant impact. The rest of the columns show that the results are robust to a variety of changes in the sample and construction of key dependent and independent variables. In column 4 we relax the requirement that an establishment's percentage of within-firm transfers be greater than zero and less than the 95th percentile prior to our sample period. In column 5 we further exclude the condition that there be a substantial vertical link in the production chain of the firm. The results remain robust to both of these changes. In column 6 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 4; i.e., 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.

In Table 3 we conduct additional analyses to probe the robustness of our results. In columns 1 and 2 we run separate regressions for within firm transfers and total value shipped. This allows 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, but in percentage terms the magnitude of the change in within-firm transfers is greater. Our results show that 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 establishments for whom the value of within firm transfers is equal to zero. However, they do suggest that direction of change in the value of within-firm transfers is negative and sizeable. Column 2 also shows that the value of total value shipped increases by 7.7% for adopters of external IT.

Columns 3 and 4 of Table 3 show the results of our main models when we add MSA and MSA and three-digit NAICS time trends. In these regressions, we interact each MSA—and, in column 4, three-digit NAICS—with a 1999 time dummy. For establishments in locations outside of a MSA, we define a "phantom" MSA that is defined by the state excluding any MSAs in the state. These additional controls control for potential unobserved time-varying industry and location factors that may be correlated both with adoption of external IT and within-firm transfers. Are results are robust to the inclusion of these controls.

In columns 5 and 6 we examine if our results differ for establishments that had adopted electronic data interchange (EDI). EDI was an earlier technology that had been used to improve coordination with suppliers and customers. It was a text-based system that involved communications over a proprietary network, and usually did not involve the dynamic flows of information that later occurred over Internet-based systems that facilitated coordination in production chains. We expect that the effects of external IT adoption will be lower among firms who were adopters of EDI, as it will enable much of the same functionality. Establishments that had adopted EDI are likely to have already made many of organizational adjustments that we observe upon adoption of external IT. 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; Forman 2005; McElheran 2013). However, we can still observe whether the organizational change in response to external IT adoption is lower when the establishment had adopted EDI. This is exactly what we find: 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 our identification strategy: if our results are shaped by changes to unobserved factors that are correlated with external IT and the within-firm transfers, they must be specific to establishments that have not adopted EDI.

5.2 Justifying a causal link

To address concerns about reverse causality and omitted variable bias, in Table 4 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 will be associated with higher operating costs for Internet service providers, which should translate into higher Internet adoption costs 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.[20]

Our second instrument uses 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 are 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, in our setting, IT expertise elsewhere in the firm makes adoption of external IT more likely. It should also be uncorrelated with other organizational decisions such as the extent of within-firm transfers. We measure IT expertise using the percentage of other establishments within the same firm that have adopted CAD/CAE (computer aided design and computer aided engineering).

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 establishment but should not influence its decision to sell its output outside of the firm.

Table 4a presents the first stage results of our LIML instrumental variable regressions. 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 establishment. Further, increase in the local costs of providing telecommunications services are negatively correlated with the likelihood of adopting external

[20] 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.

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%.

Table 4b 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 2 through 5 are generally larger in magnitude (more negative) than the baseline regression results that are reproduced in column 1. We speculate that this 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. The model in column 5 is overidentified, and the p-value for the overidentification statistics is 0.1944.

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.

5.3 Complementarities: Disaggregating the impact of external IT

In Table 5 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 that gives rise to the change in within-firm transfers. After presenting the baseline results again in column 1, in columns 2 and 3 we present the results of supplier IT and customer IT separately on the percentage of within-firm transfers. The results in column 2 show that adopters of external IT experience a 3.2 percentage point decline in within-firm transfers relative to non-adopters; in contrast, column 3 shows that on its own adoption of customer IT is not associated with any change in within-firm transfers. Column 4 shows that these results are robust when supplier IT and customer IT are included together in the same regression. Column 5 shows this main results of this table; it includes supplier and customer IT separately and then interacted together. The results show that adoption of supplier and customer IT is associated with a decline in within-firm transfers only when they are adopted together. When both supplier and customer IT are adopted together, the percentage of within-firm transfers declines a statistically significant 2.8 percentage points. 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.

Last, in columns 6 and 7 we explore whether the complementarity observed between supplier IT and customer IT may be proxying for other kinds of IT investment. Column 6 shows that the results in column 5 do not qualitatively change when we add an additional control for adoption of IT that allows for coordination of economic activity within the firm. This variable has no effect on within-firm transfers. In column 7 we add controls for additional investment in supplier IT and customer IT. In particular, we add controls indicating whether the establishment has adopted in three or more supplier IT applications or three of more customer IT applications. We do this to control for the possibility that the combination of supplier and customer IT does not reflect complementarities but instead reflects the benefits of additional investment in IT more generally. Again, the results do not qualitatively change.

6 Discussion and Conclusion (under revision)

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 downstream within-firm transfers. This finding is robust to extensive time-varying controls for both internal and external downstream demand, as well as instrumental variables estimation. Furthermore, we find that the adoption has the largest impact on within-firm transfers when the upstream and downstream margins of digital coordination are adopted together.

We focus on the implications of IT investment for the short run decision to sell a plant's output internally or externally, taking the supply chain of the firm as fixed. This focus reflects the nature of our setting and research design: the short-run response of a manufacturing plant to a decline in communication costs that was enabled by the commercialization of the Internet. However, our results are also suggestive about the implications of supplier IT for the extensive margin of within-firm transfers,--whether the plant sells its output internally at all. This suggests that these same IT investments will also have implications for the long run configuration of a firm's supply chain. We leave exploration of this question for future work.

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Figure 1: Percent Within-firm Transfers by Year and Whether Treated by the Combination of Supplier-Focused IT and Customer-Focused IT

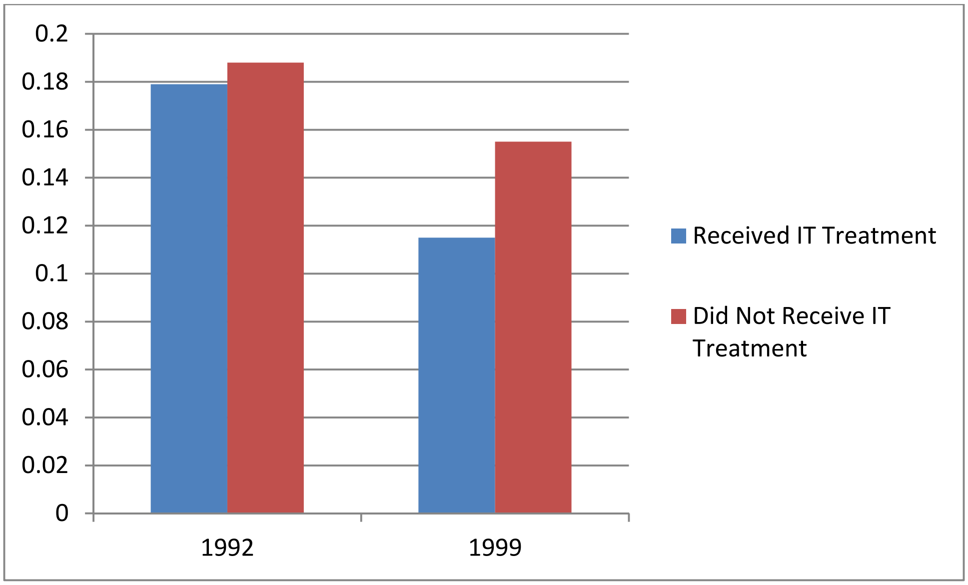

Table 1a: Descriptive Statistics, 1999

	Mean	Standard Deviation	Number of observations
Percent within-firm transfers	0.144	0.267	~2500
Total within-firm transfers (Thousands)	~38800	~148000	~2500
Total value shipped (Thousands)	~221000	~481300	~2500
Supplier- and customer-focused IT	0.272	0.445	~2500
Supplier-focused IT	0.442	0.497	~2500
Customer-focused IT	0.356	0.479	~2500
Advanced supplier-focused IT	0.162	0.368	~2500
Advanced customer-focused IT	0.109	0.312	~2500
Internal company-focused IT	0.627	0.484	~2500
Log(inventories)	6.56	3.10	~2500
Production to nonproduction workers	0.303	0.170	~2500
Log(Total factor productivity)	1.62	0.582	~2500
Log of downstream firm demand	8.77	4.25	~2500
Log of local demand	5.71	4.83	~2500
Dummy for competitors in local area	0.931	0.252	~2500
Local competition Herfindahl	0.427	0.316	~2500
Log(number of establishment products)	1.17	0.783	~2500

Table 1b: 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, 324, and 337 were omitted for disclosure purposes. Descriptive statistics computed over establishments in baseline sample in 1999.

Table 1c: Correlation Matrix, 1999

		1	2	3	4	5	6	7	8	9	10	11	12
1	Percent within-firm transfers	1.0000											
2	Supplier-focused IT	-0.1377	1.0000										
3	Customer-focused IT	-0.0114	0.4818	1.0000									
4	Supplier- and customer-focused IT	-0.0672	0.6863	0.8223	1.0000								
5	Log(inventories)	-0.2655	0.0796	0.0471	0.0593	1.0000							
6	Production to nonproduction workers	-0.1864	0.1091	0.0944	0.0873	0.1430	1.0000						
7	Log(Total factor productivity)	-0.0068	0.1142	0.0222	0.0820	-0.1741	0.0269	1.0000					
8	Log of downstream firm demand	0.2806	-0.0674	0.0457	-0.0054	-0.0683	-0.1177	-0.1039	1.0000				
9	Log of local demand	0.0624	0.0313	0.0070	0.0176	0.0705	0.0665	-0.1435	0.1849	1.0000			
10	Dummy for competitors in local	-0.0211	0.0078	0.0055	0.0237	0.0099	0.0414	-0.0207	-0.0280	0.2473	1.0000		
11	Local competition Herfindahl	0.0310	0.0197	0.0308	0.0106	0.0652	-0.1066	0.0038	0.0616	-0.4611	-0.4901	1.0000	
12	Log(number of establishment products)	-0.1139	0.0446	0.0963	0.0733	0.2111	0.0321	-0.1938	0.0479	-0.0125	-0.0089	0.0755	1.0000

Descriptive statistics computed over establishments in baseline sample in 1999.

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

	(1)	(2)	(3)	(4)	(5)	(6)
	No controls	Includes all controls but competition	Includes controls	Exclude prior year sample conditioning	Exclude prior year and substantial vertical link conditioning	Any IPT - Extensive margin
Adoption of external IT	-0.0313	-0.0290	-0.0291	-0.0235	-0.0110	-0.0391
	(0.0123)*	(0.0123)*	(0.0123)*	(0.0092)*	(0.0041)**	(0.0211)+
Log(inventories)		-0.0089	-0.0089	-0.0087	-0.0044	-0.0092
		(0.0034)*	(0.0034)**	(0.0028)**	(0.0012)**	(0.0042)*
Share of workers in white collar employment		-0.0265	-0.0267	-0.0278	-0.0349	-0.0391
		(0.0453)	(0.0454)	(0.0286)	(0.0119)**	(0.0654)
Log of TFP		-0.0309	-0.0306	-0.0322	-0.0138	-0.0212
		(0.0162)+	(0.0162)+	(0.0115)**	(0.0059)*	(0.0219)
Log of downstream firm demand		0.0027	0.0027	0.0020	0.0017	0.0093
		(0.0012)*	(0.0012)*	(0.0009)*	(0.0009)*	(0.0021)**
Log of local demand		-0.0017	-0.0019	-0.0026	-0.0012	-0.0101
		(0.0020)	(0.0020)	(0.0014)+	(0.0009)	(0.0036)**
Log of number of products		-0.0054	-0.0056	-0.0046	-0.0017	0.0548
		(0.0106)	(0.0106)	(0.0077)	(0.0032)	(0.0161)**
Dummy indicating local industry competitors			-0.0044	0.0039	-0.0119	0.0069
			(0.0277)	(0.0210)	(0.0108)	(0.0413)
Industry-country Herfindahl			-0.0503	-0.0519	-0.0215	0.0795
			(0.0475)	(0.0359)	(0.0166)	(0.0727)
1999 Year Dummy	-0.0329	-0.0317	-0.0336	-0.0174	-0.0052	-0.0318
	(0.0067)**	(0.0070)**	(0.0072)**	(0.0050)**	(0.0023)*	(0.0109)**
Constant	0.1856	0.2922	0.3210	0.2803	0.1609	0.4408
	(0.0028)**	(0.0408)**	(0.0568)**	(0.0428)**	(0.0199)**	(0.0817)**
Observations	~4500	~4500	~4500	~7500	~24000	~7500
Establishments	~2500	~2500	~2500	~3500	~12000	~3500
R-squared	0.03	0.04	0.04	0.02	0.01	0.02

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

Table 3: Robustness: Within-firm transfers and total value shipped separately, Falsification Exercises

	(1)	(2)	(3)	(4)	(5)	(6)
	Log(WFT)	Log(TVS)	MSA Time Trends	MSA + Industry Time Trends	Baseline no EDI	Baseline has EDI
Adoption of external IT	-0.5014	0.0768	-0.0267	-0.0221	-0.0471	0.0031
	(0.2434)*	(0.0257)**	(0.0130)*	(0.0130)+	(0.0155)**	(0.0206)
Log(inventories)	-0.0646	0.0369	-0.0095	-0.0092	-0.0079	-0.0102
	(0.0493)	(0.0073)**	(0.0034)**	(0.0034)**	(0.0042)+	(0.0057)+
Share of workers in white collar employment	-0.6970	-0.3359	-0.0167	-0.0141	-0.0212	-0.0352
	(0.8064)	(0.1466)*	(0.0476)	(0.0477)	(0.0558)	(0.0791)
Log of TFP	-0.1791	0.3359	-0.0355	-0.0324	-0.0336	-0.0251
	(0.2572)	(0.0399)**	(0.0150)*	(0.0155)*	(0.0171)*	(0.0357)
Log of downstream firm demand	0.0936	0.0047	0.0035	0.0035	0.0021	0.0037
	(0.0240)**	(0.0030)	(0.0014)*	(0.0014)*	(0.0013)+	(0.0023)
Log of local demand	-0.1093	-0.0040	-0.0030	-0.0033	-0.0015	-0.0024
	(0.0402)**	(0.0047)	(0.0021)	(0.0021)	(0.0027)	(0.0028)
Dummy indicating local industry competitors	0.2725	0.0483	-0.0295	-0.0202	-0.0145	0.0170
	(0.4888)	(0.0469)	(0.0287)	(0.0290)	(0.0361)	(0.0445)
Industry-country Herfindahl	0.5084	0.3210	-0.0513	-0.0453	-0.0657	-0.0310
	(0.7817)	(0.1118)**	(0.0496)	(0.0490)	(0.0602)	(0.0767)
Log of number of products	0.4359	0.1110	-0.0113	-0.0125	-0.0030	-0.0105
	(0.1866)*	(0.0342)**	(0.0105)	(0.0104)	(0.0132)	(0.0178)
Observations	~4500	~4500	~4500	~4500	~3000	~1500
Establishments	~2500	~2500	~2500	~2500	~1500	~1000
R-squared	0.07	0.32	0.04	0.06	0.04	0.11

Robust standard errors, clustered by establishment, in parentheses. Column (1) uses total within-firm transfers and column (2) uses total value shipped; all other columns use the ratio of within firm transfers and total value shipped. All columns include a constant term and year dummies. + significant at 10%; * significant at 5%; ** significant at 1%

Table 4a: Second Stage of Instrumental Variable Estimates of Table 3 Column 3

	(2)	(3)	(4)	(5)
	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

First stage dependent variable is an indicator for whether the establishment has supplier and customer IT. All regressions include time dummies. 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%

Table 4b: Second Stage of Instrumental Variable Estimates of Table 3 Column 3

	(1)	(2)	(3)	(4)	(5)
	Baseline, no IV	Competitor Adoption of Networked IT	Other Firm Adopters of CAD/CAE	Log of proxy cost	All instruments
Adoption of external IT	-0.0291	-0.1917	-0.0526	-0.4367	-0.1909
	(0.0123)*	(0.1038)+	(0.0987)	(0.2077)*	(0.0902)*
Log(inventories)	-0.0089	-0.0083	-0.0088	-0.0061	-0.0073
	(0.0034)**	(0.0035)*	(0.0035)*	(0.0039)	(0.0036)*
Share of workers in white collar employment	-0.0267	-0.0425	-0.0290	-0.1204	-0.0875
	(0.0454)	(0.0491)	(0.0462)	(0.0632)+	(0.0495)+
Log of TFP	-0.0306	-0.0309	-0.0306	-0.0346	-0.0373
	(0.0162)+	(0.0165)+	(0.0162)+	(0.0170)*	(0.0147)*
Log of downstream firm demand	0.0027	0.0021	0.0026	0.0011	0.0018
	(0.0012)*	(0.0013)	(0.0012)*	(0.0016)	(0.0013)
Log of local demand	-0.0019	-0.0005	-0.0017	0.0035	0.0010
	(0.0020)	(0.0022)	(0.0021)	(0.0031)	(0.0022)
Dummy indicating local industry competitors	-0.0044	-0.0094	-0.0051	-0.0151	-0.0096
	(0.0277)	(0.0282)	(0.0278)	(0.0322)	(0.0282)
Industry-country Herfindahl	-0.0503	-0.0528	-0.0507	-0.0634	-0.0646
	(0.0475)	(0.0488)	(0.0475)	(0.0583)	(0.0507)
Log of number of products	-0.0056	0.0023	-0.0045	0.0172	0.0045
	(0.0106)	(0.0118)	(0.0113)	(0.0167)	(0.0118)
Observations	~4500	~4500	~4500	~4500	~4500
Establishments	~2500	~2500	~2500	~2000	~2000
Overidentification test (p-value)	--	--	--	--	0.1944
Hausman test (p-value)	--	0.9991	1.0000		0.0925

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

Table 5: Disaggregating Complementarities

	(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	Complementarities controlling for additional IT investment
Adoption of external IT	-0.0291				-0.0560	-0.0554	-0.0523
	(0.0123)*				(0.0271)*	(0.0274)*	(0.0278)+
Adoption of supplier-facing IT		-0.0323		-0.039	-0.0201	-0.0209	-0.0143
		(0.0111)**		(0.0124)**	(0.0145)	(0.0147)	(0.0146)
Adoption of customer-facing IT			-0.005	0.0144	0.0477	0.0462	0.0445
			(0.0117)	(0.0130)	(0.0222)*	(0.0237)+	(0.0217)*
External Suppliers Deep IT							-0.0263
							(0.0178)
External Customers Deep IT							0.0169
							(0.0229)
Adoption of internal company IT						0.0035	
						(0.0135)	
Observations	~4500	~4500	~4500	~4500	~4500	~4500	~4500
Establishments	~2500	~2500	~2500	~2500	~2500	~2500	~2500
R-squared	0.04	0.04	0.03	0.04	0.04	0.04	0.04

Robust standard errors, clustered by establishment, in parentheses. * p<0.05, ** p<0.01, *** p<0.001