INFORMATION SYSTEMS RESEARCH
Vol. 00, No. 0, Xxxxx 0000, pp. 000–000
ISSN 1047-7047 | EISSN 1526-5536 | 00 | 0000 | 0001

INFORMS
DOI 10.1287/xxxx.0000.0000

An Internet-Enabled Move to the Market in Logistics

Fengmei Gong
College of Business and Public Management, University of La Verne, CA, USA, fgong@laverne.edu

Barrie R. Nault
Haskayne School of Business, University of Calgary, Calgary, Alberta, Canada, nault@ucalgary.ca

Mohammad S. Rahman
Krannert School of Management, Purdue University, West Lafayette, IN, USA, mrahman@purdue.edu

January 21, 2016

Logistics outsourcing has increased with the commercialization of the Internet, implying a reduction in the corresponding transaction costs. The Internet – with its universal connectivity and open standards – radically enhanced information technology (IT) capabilities, and we hypothesize this has reduced external transaction costs relatively more than internal governance costs. Using transaction cost theory as a lens, we examine whether the commercialization of the Internet coincided with a move to the market in logistics – one of the most connected industries in the economy. We estimate the relationship between IT and outsourced logistics in a production function based on two datasets from 1987 to 2008. We find that the effects of IT on outsourced logistics have changed in the post-Internet era. After the commercialization of the Internet, an industry's own IT investment and outsourced logistics became complements whereas they were not before. It suggests that because of the unique characteristics of the Internet as an enabler, IT reduced external transaction costs relatively more than internal governance costs. Consequently, industries favored the market form of the provision of logistics. We also find similar impacts of customers' IT investments on a focal industry's outsourced logistics. Previous studies argued that IT led to the shift from hierarchies to markets, or provided indirect evidence through measures of firm size or integration. Using a production theory model our study provides systematic empirical evidence to support that the Internet enabled a move to the market in the provision of logistics.

Key words: Information technology (IT); organizational boundaries; hierarchies and markets; logistics outsourcing; IT spillovers; production function framework; input-output tables.

1. Introduction

Logistics is a process of planning, implementing, and controlling the effective and efficient flow of goods, services, and information between the point of origin and the point of consumption (Rutner and Langley Jr. 2000). Its activities typically include inbound and outbound transportation, warehousing, inventory management, etc. It is through logistics that raw materials flow into production and finished goods are delivered to customers. Logistics are costly: in 2011, logistics expenditure was 8.5% of GDP, reaching about $1.28 trillion (Wilson 2012).

Logistics outsourcing, the use of external organizations to perform logistics activities that alternatively could be conducted by firms themselves, plays an important role in logistics management. In recent decades, logistics outsourcing has grown substantially. For example, in U.S. manufacturing industries—one of the largest users of logistics outsourcing, the usage rate of logistics outsourcing remained stable in the early 1990s but increased sharply after the commercialization of the Internet. In a survey of top-500 manufacturing firms in the U.S., 37% of firms used third-party logistics services (3PLs) in 1991 and 38% in 1994, reaching 60% in 1995 and climbing to 80% by 2004 (Lieb and Randall 1996, Ashenbaum et al. 2005). This climb from the mid-1990s to the mid-2000s was reflected in other surveys and was even more pronounced in estimated expenditures on 3PLs moving from under $31B in 1996 to almost $90B in 2004 (Ashenbaum et al. 2005).

The substantial growth of logistics outsourcing starting in 1994/95 suggests that the transaction costs of outsourcing logistics have fallen and the benefits have risen relative to in-house logistics, and consequently the trend has been towards external provision. As we can see from the Transportation Satellite Accounts (TSAs) data in Table 1, for-hire or outsourced logistics accounts for around 80% of transportation costs for manufacturing

Table 1 Transportation Costs of Manufacturing Industries in 1992 and 1996

	1992		1996		% Change ((B-A)/A)
	1992 Nominal Value	1997 Real Value (A)	1996 Nominal Value	1997 Real Value (B)	
Total Transportation Costs	102,054	116,747.45	116,591	119,266.13	2.2%
For-hire	80,248	91,801.88	94,275	96,438.10	5.1%
In-house	21,806	24,945.57	22,316	22,828.03	-8.5%
Total Output	2,951,303		3,666,001		
For-hire/Total Transportation Costs	0.786		0.809		
In-house/Total Transportation Costs	0.214		0.191		
Total Transportation Cost/Total Output	0.035		0.032		
For-hire/Total Output	0.027		0.026		
In-house/Total Output	0.007		0.006		

Notes: (1) Transportation costs and output is from Table 5 and Table 2 of 1996 TSAs (Transportation Satellite Accounts), respectively. (2) For-hire transportation includes railroad and related services, passenger ground transportation, except transit; motor freight transportation and warehousing; water transportation; air transportation; and pipelines, freight forwarders, and related services. In-house transportation includes transportation by truck and bus provided by manufacturing industries for their own use. (3) The values are in millions of dollars at producers' prices. (4) Refer to U.S. Department of Transportation et al. (2011), nominal 1992 dollars and 1996 dollars are adjusted using the current series of consumer price index (CPI) published by the U.S. Bureau of Labor Statistics for all transportation. CPI for all transportation is 140.3, 156.9, and 160.5 in 1992, 1996, and 1997, respectively.

industries in the U.S. Although these transportation costs rose over 2% in real terms between 1992 and 1996, the for-hire component grew by 5% and the in-house component fell by over 8%, consistent with the percentage-using and estimated-expenditures-on 3PLs surveys quoted above.

Our premise is that the commercialization of the Internet changed the relationship between IT and outsourced logistics, leading to an increase in outsourced logistics. The predominant IT innovation in logistics in the pre-Internet era was electronic data interchange (EDI), which could not meaningfully support logistics outsourcing.[1] The post-Internet era

[1] "The objective of EDI was to standardize the content of a reasonably complete commercial transaction set—the set of documents required to execute a variety of business transactions.... Thus, EDI is an initial step in the use of IT in transportation, automating the exchange of business documents (Nault 1998, p.248-249)." Moreover, EDI was not implementable in all business relationships (Brousseau 1994). The Internet, in contrast, enabled a variety of new logistics strategies that generated value beyond that available from EDI. These strategies included vendor-managed inventory, merge-in-transit policy, time-definite delivery, and freeze-point delay (Rabah and Mahmassani 2002).

logistics strategies are often combined in a modern integrated collaborative planning, forecasting and replenishment (CPFR) solution, and some of the most sophisticated technologies include Internet-based solutions. Internet-based CPFR include web-based collaboration for information sharing about forecasts, POS data, inventory and visibility-in-transit logistics; event management and analysis highlighting exceptions and consequent options; and real-time tracking and reporting against plan (Danese 2006).

1.1. Logistics Sourcing, the Internet, and Transaction Costs

The decision to outsource logistics depends on the transaction costs of market versus in-house (internal) provision. IT has reduced both market transaction costs and internal governance costs (Malone et al. 1987, Gurbaxani and Whang 1991). We argue that in the case of logistics the Internet has reduced market transaction costs relatively more than internal governance costs. Transaction costs depend on bounded rationality and opportunism—two assumptions about decision-makers' behaviors, and on asset specificity, uncertainty, and frequency—three dimensions of transactions (Williamson 1981).[2]

In the context of logistics, the Internet loosens bounded rationality and reduces the potential for opportunism. The Internet reduces buyer search costs (Bakos 1997), so that buyers of 3PL services can access information about price, capacity, and services at low cost. In addition, it can be costly or even impossible to check shipment records through traditional EDI for a manufacturer that has many shipments delivered by a variety of carriers because of the low diffusion of EDI and its limited implementation. However, using visibility-in-transit enabled by the Internet, a manufacturer can track and trace shipments real-time and check the records of all carriers' on-time delivery performance.

The Internet also reduces asset specificity of 3PL providers by facilitating an online logistics market that helps match logistics capacity and demand, and resource sharing among

[2] Our online supplement discusses these assumptions and dimensions in the context of logistics outsourcing.

3PL providers (e.g., Nault and Dexter 2006). Online brokers can match carrier capacity and shipping demand, enabling 3PL providers to redeploy their human- and physical-specific assets over more users and uses to achieve economies of scale and scope. By outsourcing logistics, firms avoid holding transportation and warehousing assets, allowing 3PL providers to hold those assets because they have lower asset specificity as they can redeploy those assets to other customers. At the same time, firms can obtain additional efficiency by exploiting logistics expertise of 3PL providers (Deepen 2007).

Information sharing among supply chain partners facilitated by Internet-based CPFR reduces uncertainty by improving supply chain visibility and enabling firms to adaptively control logistics activities. When a shipment is delayed or lost, an event management system can notify shippers or customers, and both can adapt to minimize or prevent potential problems. Finally, the Internet reduces the cost and technological barriers that restricted EDI adoption: the Internet supports a range of transaction frequency at low communication costs, which reduces costs across transactions.

Previous studies suggest that IT shaped the change in organizational boundaries. Some studies argue theoretically that IT led to the shift from hierarchies to markets by reducing transaction costs (Malone et al. 1987, Gurbaxani and Whang 1991, Clemons et al. 1993). Brynjolfsson et al. (1994) find that IT was associated with smaller firm size which the authors suggested was a shift to externally provided services by reducing external coordination costs relative to internal. Hitt (1999) find that IT was associated with the decrease in vertical integration, which suggested that the increase in IT was related to the change in organizational structure towards less in-house making. These studies provide important initial insights regarding the impact of nascent IT on organizational boundaries, and the commercialization of the Internet radically enhanced IT capabilities which, in turn, fundamentally redefined the role of IT in organizations (Zhu and Kraemer 2002, Zhu 2004).

Given this, we juxtapose the impact of IT on organizational boundaries in the pre- and post-Internet eras. Our study examines whether the commercialization of the Internet—with its universal connectivity and open standards—coincided with a move to the market in logistics: one of the most connected industries in the economy. The contribution of our work is systematic economy-wide empirical evidence that IT in its most interconnected instance—the Internet—favors a market form of the provision of logistics.

To show evidence of this move to the market, we take a novel approach using production theory—an approach that allows us to model the production of output in terms of capital, labor, and intermediate inputs: purchased goods and services from the market rather than generated within the organization. A production function specifies outputs as a function of inputs and these inputs include capital (IT and non-IT), labor, and intermediate inputs. The latter are goods and services purchased on the market and used in the production process to produce output—one might think of these as "materials" that go into the production process. These are not only the goods and services that go into the production process—some are made or provided by the firm itself. Consequently, a firm chooses whether to make these materials or purchase them from the market. If a firm chooses to make the materials, then they make them with capital and labor, thus the inputs are capital and labor rather than intermediate inputs. Alternatively, if a firm chooses to purchase certain goods and services from the market rather than make or provide them, then they are intermediate inputs.

We separate logistics inputs from the rest of the intermediate inputs, and within a production model are able to determine if more or less logistics inputs are purchased from the market over time. In this way, the production function approach is ideal. We adopt the lens of transaction cost economics in interpreting the results because that provides the basis for whether goods and services should be provided within the firm or purchased as intermediate inputs.

We create two datasets by employing the input-output (I-O) tables and industry productivity data: one for Standard Industrial Classification (SIC)-defined manufacturing industries from 1987 to 1999, and the other for North American Industrial Classification System (NAICS)-defined manufacturing industries from 2000 to 2008. We estimate the relationship between an industry's own IT investment and outsourced logistics, and simultaneously estimate the relationship between the given industry's customers' IT investments and outsourced logistics, in the pre- and post-Internet eras. We find that the relationship between IT investments and outsourced logistics changed in the post-Internet era: as measured through our variable coefficient model, IT investments and outsourced logistics became complements only after the Internet was widely used. Together with the growth in the percent of firms using 3PLs, the growth of expenditures in 3PLs, the move from in-house logistics to for-hire logistics, and the fact that there were no substantial regulatory or transportation-related technological changes, this suggests that the Internet is responsible for the shift to the market in the context of logistics. We recognize that we use secondary data that does not directly measure Internet usage and, while we have time precedence and a theory-based explanation, we cannot directly attribute causality to the Internet in interpreting our results. We do, however, consider and negate many plausible alternative explanations in our online supplement.

The next section provides our conceptual and mathematical models. Section 3 presents the estimation, including a description of the data, variables, econometric adjustments, and results. Section 4 discusses our contributions, implications, and limitations.

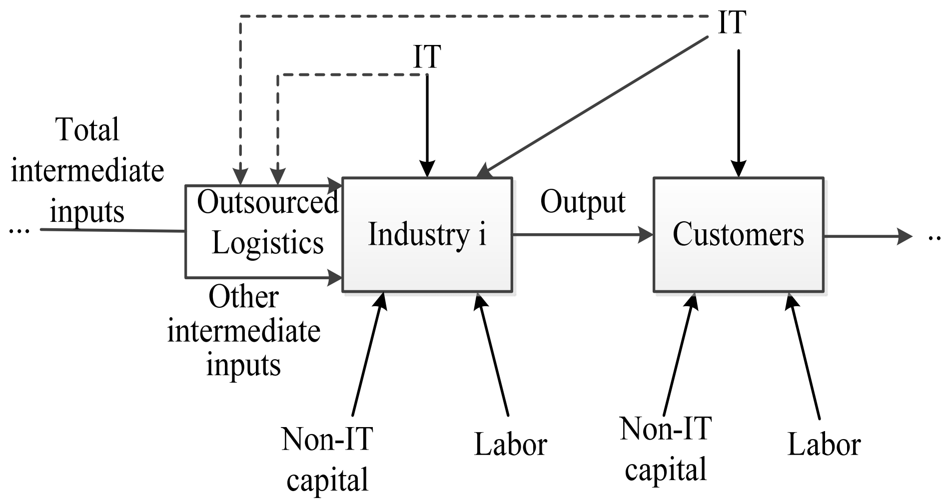

Figure 1 **The Model of IT, Outsourced Logistics, and Output**

2. Our Model of IT, Outsourced Logistics, and Output

Figure 1 is our conceptual model of productivity along a supply chain. To generate output that is supplied to customers, an industry uses non-IT capital, labor, IT capital, and intermediate inputs from the market. Intermediate inputs consist of purchased (outsourced) logistics, and other purchased goods and services. An industry benefits from the IT investments of customers because information sharing and coordination facilitated by customers' IT leads to more efficient production and operation (Cheng and Nault 2012).

As a multifaceted input, IT has a direct impact on production—similar to other inputs, and has indirect impacts on production by affecting other inputs (Mittal and Nault 2009). In particular, the Internet, characterized by global connectivity and open standards, helps remove incompatibility of legacy information systems within and between firms, greatly enhancing these systems' performance by allowing information sharing and coordination among trading partners (Zhu and Kraemer 2002, Zhu 2004). In our view, the Internet-enabled information sharing and coordination in supply chain logistics reduces external transaction costs, leading to an increased provision of logistics from the market. Outsourced logistics is typically more efficient than in-house logistics because 3PL providers have logistics-dedicated assets, economies of scale and scope, and logistics expertise.

From a supply chain perspective, customers' IT investments may affect an industry's output by affecting its in-bound logistics. The bullwhip effect, whereby customers' demand uncertainty causes greater demand fluctuations upstream, could trigger uncertainty in logistics demand which would be amplified back along a supply chain (Lee et al. 1997). An increase in logistics uncertainty in a supply chain increases transaction costs. In particular, the external transaction costs of outsourcing in-bound logistics would increase. If transaction costs were high enough that they exceed operational advantages of the market, then industries would prefer to use their own in-house logistics. However, on-time demand and inventory information sharing enabled by customers' investments in the Internet-based interorganizational systems (IOSs) relieves information distortion in a supply chain, which in turn reduces demand uncertainty for goods and logistics (Lee et al. 2000, Cachon and Fisher 2000). As a result, transaction costs in a supply chain are reduced, allowing an industry to outsource more logistics, making the industry more productive. These effects are depicted in Figure 1.

We are interested in how IT, including an industry's own IT and customers' IT, affects its outsourced logistics and then consequently affects its output. We develop our mathematical form of the model based on the Cobb-Douglas (CD) production function,

$$Y = AK^{\alpha}L^{\beta}Z^{\gamma}M^{\phi},$$

where Y is the quantity of gross output; A is the technology change parameter; K, L, Z, M are the quantity of non-IT capital, labor, IT capital, and total intermediate inputs, respectively. α, β, γ, and ϕ are the output elasticities of non-IT capital, labor, IT capital, and total intermediate inputs, respectively. The total intermediate inputs consist of outsourced logistics, W, and non-logistics intermediate inputs, X,

$$M = \{W, X\}.$$

Taking outsourced logistics and non-logistics intermediate inputs into the CD production function and incorporating the impact of customers' IT on industry i's output, we specify the model with customers' IT investments as

$$Y_i = A_c K_i^{\alpha} L_i^{\beta} Z_i^{\gamma} X_i^{\theta} W_i^{\delta} C_i^{\varphi},$$

or in log form

$$y_i = a_c + \alpha k_i + \beta l_i + \gamma z_i + \theta x_i + \delta w_i + \varphi c_i, \tag{1}$$

where A_c is the corresponding technology change parameter, Z_i is industry i's own IT investment, C_i is the IT spillovers from industry i's customers, θ is the output elasticity of non-logistics intermediate inputs, and φ is the output elasticity of the customer-driven IT spillovers. The lower case variables are the log forms of the upper case variables. Next, to analyze how an industry's own IT investment and its customers' IT investments affect its outsourced logistics, we use a variable coefficient approach to specify the output elasticity of outsourced logistics, δ, as a linear function of industry i's own IT investment and IT investments from customers,

$$\delta(Z_i, C_i) = b + \mu Z_i + \nu C_i. \tag{2}$$

Taking (2) into (1), we have our estimation model corresponding to the conceptual model in Figure 1,

$$y_i = a_c + \alpha k_i + \beta l_i + \gamma z_i + \theta x_i + b w_i + \varphi c_i + \mu Z_i w_i + \nu C_i w_i. \tag{3}$$

Our estimation model differs from the variants of CD forms used in prior studies, and Table A1 in our online supplement compares our model with those. Recognizing that conceptually diverse models can lead to similar estimation forms, the critical novelty of our model is the use of the variable coefficient approach to specify the relationship between IT and outsourced logistics and incorporating that relationship into an extended CD production function. Through this approach we can focus on whether our specified relationship between IT and outsourced logistics has changed in the post-Internet era.

We are able to assess the relationship between IT and outsourced logistics and examine the impact of IT on output through outsourced logistics by examining the coefficients of the two interaction terms in (3). Specifically, we examine the complementarity relationship between IT and outsourced logistics. The term "complementarity" is used in different contexts with slightly different meanings. We adopt a broad notion of complementarity and substitutability that does not depend on the special structure of prices and quantities and that permits analysis of complex phenomenon such as organizational structures (Edgeworth 1925). Edgeworth's definition of complementarity and substitutability between goods is such that: assuming the first derivatives of a production function $f(\cdot)$ with respect to r_i and r_j are positive, if the cross partial derivative is positive, $\frac{\partial(\partial f(\cdot)/\partial r_i)}{\partial r_j} = \frac{\partial^2 f(\cdot)}{\partial r_i \partial r_j} > 0$, then the goods r_i and r_j are complements; if the cross partial derivative is negative, then the two goods are substitutes. We use this conceptualization to determine the complementarity between IT and logistics pre- and post-Internet. Others have adopted this generic definition for studying related issues. Milgrom and Roberts (1992) defined the complements as "a set of activities with the property that doing more of any subgroup of the activities raises the marginal return to the other activities", and Milgrom and Roberts (1994, 1995) suggest that this conceptualization allows analysis of organizational structures and government policies.

The coefficient of the interaction term between own IT capital and outsourced logistics, μ in (3), demonstrates how own IT investment affects the contribution of outsourced logistics to output, holding other inputs fixed. The coefficient μ is defined as

$$\mu = \frac{\partial \delta(Z_i, C_i)}{\partial Z_i} = \frac{\partial \left(\frac{\partial Y_i}{\partial W_i} * \frac{W_i}{Y_i} \right)}{\partial Z_i} = \frac{W_i}{Y_i} * \frac{\partial^2 Y_i}{\partial W_i \partial Z_i}. \tag{4}$$

The magnitude of μ is determined by the input share of outsourced logistics and a cross partial derivative of output with respect to own IT investment and outsourced logistics, and the sign of μ depends on the sign of the cross partial derivative. When μ is positive an industry's own IT investment and outsourced logistics are complements; when μ is negative they are not. Similarly, from the coefficient of the interaction term between customers' IT investments and an industry's outsourced logistics, ν in (3), we can know that customers' IT investment and an industry's outsourced logistics are complements when ν is positive, and not when ν is negative. In addition, based on the estimates of two interaction terms and (2), we are able to calculate the impact of IT on the output elasticity of outsourced logistics.

Based on I-O use tables, we calculate the IT investments from the customers of industry i, C_i, as a weighted average of IT investments of downstream industries. We use the relative transaction values in the total transactions made by customers as weights. C_i is

$$C_i = \sum_{j \neq i} \frac{V_{ij}}{\sum_{j \neq i} V_{ij}} Z_j, \tag{5}$$

where V_{ij} is the dollar transaction volume of industry i's sales to the customer industry j. Our constructions of customers' IT investments are consistent with those in Mun and Nadiri (2002) and Cheng and Nault (2012).

3. Empirical Estimation

3.1. Data and Variables

3.1.1. Our Measure of Outsourced Logistics Our construct of outsourced logistics consists of an industry's in-bound outsourced logistics, and is measured by an industry's for-hire transportation costs and warehousing and storage costs, needed to move intermediate inputs from producers to users. After an industry purchases goods and services from upstream suppliers, those intermediate inputs can be transported to the given industry in three ways: through the given industry's in-house logistics (Possibility 1), through suppliers' in-house logistics (Possibility 2), and through 3PL providers (Possibility 3). For all practical purposes, our measure of transportation and warehousing costs of an industry based on I-O tables (accounts) capture the costs in Possibility 3. In addition, according to TSAs (U.S. Department of Transportation et al. 2011, p.14), even if a supplier may have paid the transportation costs, the transportation activity is credited to the downstream industry, for example, "if a for-hire truck carries wheat from a farm to a mill, the I-O use table credits this activity to the mill, even though the farm may have purchased the transportation service". Therefore, we use an industry's transportation and warehousing and storage costs to capture its in-bound outsourced logistics.

The sum of for-hire transportation costs and warehousing and storage costs is a good proxy of outsourced logistics. Transportation and warehousing costs generally account for the largest proportion of total logistics expenditures—72.2% of the total in 2011 (Wilson 2012)—and more than half of those costs are dedicated to outsourcing (Langley and Capgemini 2012). We calculate transportation and warehousing costs based on I-O use tables whereby "Transportation costs are the freight charges paid to move the commodity from the producer to the intermediate user or the final user." (Streitwieser 2009, p.42). These costs consist of rail, truck, water, air, oil pipeline, and gas pipeline charges (Horowitz and Planting 2009, Streitwieser 2009).

Understanding what goes into our measure of logistics outsourcing is critical to interpreting our results, and we provide the scope of the measure of outsourced logistics in Figure 2. The measure of outsourced logistics includes purchased logistics for moving goods from producers to users between and within industries. Assume non-transportation industry i has firms F_A and F_B, and it purchases transportation and warehousing for moving intermediate inputs from other industries to F_A and F_B. L_A and L_B are the purchased logistics for moving goods from other industries to F_A and F_B, respectively. Both L_A and L_B are captured as the for-hire logistics of industry i in I-O accounts, even if producers in other industries pay for the logistics service. The measure of outsourced logistics for industry i also includes the purchased logistics used to move goods within industry i: L_{AB} is the freight charge and warehousing costs paid to logistics service providers for moving goods from F_A to F_B. At the establishment level, assume F_B has establishments E_1 and E_2, the outsourced logistics of industry i for moving goods from E_1 to E_2, L_{12}, captures purchased transportation and warehousing services from transportation industries. Therefore, our measure of outsourced logistics by an industry includes for-hire transportation expenses associated with moving intermediate inputs to the firms and establishments of an industry.

Due to the definition of I-O accounts, a negligible portion of in-house transportation is captured under for-hire transportation when it is provided by an establishment that is owned and operated by a non-transportation enterprise (U.S. Department of Transportation et al. 2011, p.14). In order to evaluate the contribution of transportation activities to the U.S. economy, the U.S. Department of Transportation provides TSAs that measure in-house and for-hire transportation separately. TSAs only differ from the I-O accounts in that they separately measure in-house transportation (U.S. Department of Transportation

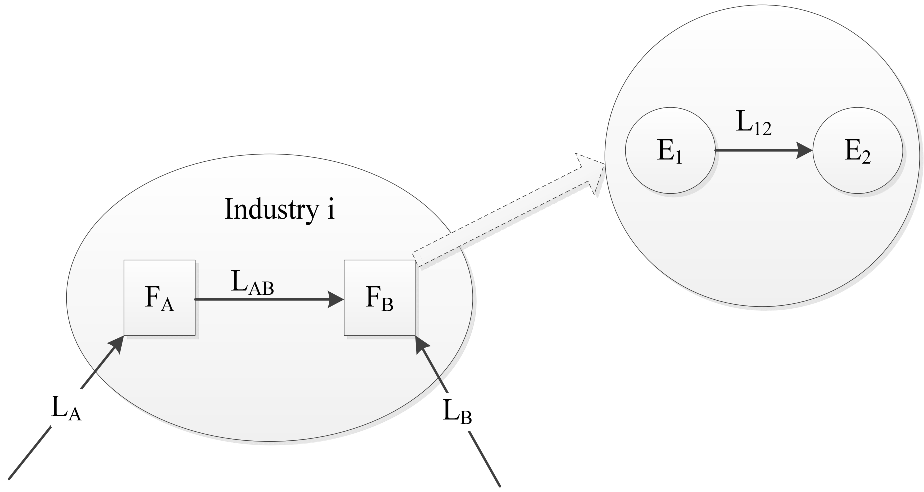

Figure 2 The Scope of Outsourced Logistics

Table 2 Transportation Costs of Manufacturing Industries in 1997 I-O Table and 1997 TSAs

Transportation Costs	1997 I-O table	1997 TSAs	
		For-hire	In-house
Total transportation	96,126.11 (A)	93,927 (B)	36,740
Air	15,082.43	14,904	3,751
Rail	15,308.45	12,371	717
Water	968.94	2,624	1,969
Truck	59,990.57	57,427	30,303
Pipeline	4,775.72	6,601	
% Change ((A-B)/A)	2.3%		

Notes: For-hire and in-house transportation costs are from "Table 7. TSA's Use of Major Commodity Groups by Industry Sector: 1997" in 1997 TSAs (U.S. Department of Transportation et al. 2011); In-house transportation costs captured in 1997 TSAs cover the costs for moving an industry's intermediate inputs or output; For-hire transportation costs based on 1997 TSAs and 1997 I-O table are the costs for moving intermediate inputs from producers to users; Transportation costs are in millions of dollars at producers' prices.

et al. 2011, p. 14). There are three sets of available TSAs – 1992, 1996, and 1997. TSAs for 1992 and 1996 follow the same methodology, while TSAs for 1997, published in 2011, differ because of the change in industry classification systems and the measure in for-hire and in-house transportation services. The 1997 TSAs isolate freight from passenger transportation, and are thus comparable to our measure of outsourced transportation costs that focus on freight transportation. These TSAs show that our measure of outsourced logistics is more than 97.5% outsourcing—Table 2 shows that with TSAs numbers from 1997 only 2.3% of the transportation costs are in-house (in-sourcing).

To provide more evidence that the mixed in-house transportation costs are negligible, we compare for-hire transportation costs reported in TSAs 1992 and TSAs 1996 with what we calculated based on I-O tables 1992 and 1996. We find that our measurements of for-hire logistics costs in 1992 and 1996 are even lower than those reported in TSAs 1992 and 1996, respectively: outsourced logistics costs that we calculate based on I-O table 1992 are smaller than what is reported by TSAs 1992 by 3.49%, and outsourced logistics costs that we calculate based on I-O table 1996 are smaller than what is reported by TSAs 1996 by 0.02%. Further details are available on request.

As long as the methods of allocating transportation costs to industries in I-O accounts remain consistent across years, our measure of outsourced transportation costs consistently reflect purchases of transportation from the market. In addition, because outsourced transportation costs account for the largest proportion of the total outsourced logistics costs—on average 99.8% in Dataset I and 91.4% in Dataset II, our measure of outsourced logistics consisting of outsourced transportation costs and warehousing and storage costs, represents purchases of logistics from the market.

3.1.2. Dataset I: 1987-1999 Dataset I consists of the multifactor productivity (MFP) dataset for 3-digit SIC manufacturing industries from 1987 to 1999 and the I-O tables from 1983 to 1999.[3] Both were requested from the Bureau of Labor Statistics (BLS). The data about output, intermediate inputs, labor, and capitals is similar to that used by Cheng and

[3] The Economic Census collects data to develop the I-O tables at the establishment level, where an establishment is defined as "a business or industrial unit at a single physical location that produces or distributes goods or that performs services". It classifies establishments into industries according to SIC or NAICS and aggregates establishment-level data to obtain industry-level data (Horowitz and Planting 2009).

Nault (2007), Han et al. (2011), and Cheng and Nault (2012). Table A2, in the Appendix, shows the data source and construction procedure of Dataset I. The MFP data contains 140 3-digit SIC manufacturing industries. It provides us with the series of output and the series of intermediate purchase compensation in millions of nominal dollars, and it also has the output deflator and the intermediate purchase price deflators with 1987 as the base year. Dividing the series of output and intermediate inputs by their corresponding deflators, we obtained the series for output Y and intermediate inputs M in millions of 1987 dollars, respectively. We also obtained the labor input L in millions of all employee hours from the MFP data.

We obtained information capital stock that was used as IT capital Z from the BLS. The information capital stock consisted of computers and related equipment, office equipment, communication, instruments, photocopy and related equipment; and all are in millions of 1987 dollars. Capital stock in millions of 1987 dollars consists of equipment, structures, inventories, land, and special tools. To obtain non-IT capital K, we summed the equipment and structure components and then subtracted the IT capital stock from the total.

Following the method of measuring outsourced logistics above, we obtained data on outsourced logistics W for each manufacturing industry by summing the transportation commodities and warehousing and storage commodity in use tables: Railroad Transportation (SIC 40), Trucking and Courier Services, except Air (SIC 421,423), Water Transportation (SIC 44), Air Transportation (SIC 45), Pipelines, except Natural Gas (SIC 46), and Warehousing and Storage (SIC 422).[4] We calculated non-logistics intermediate inputs X by subtracting outsourced logistics from total intermediate inputs. Again, outsourced logistics and the non-logistics intermediate inputs are in 1987 dollars.

[4] The U.S. statistical system does not currently have a separate classification system for commodities. Each commodity is assigned the code of the industry in which the commodity is the primary product (Horowitz and Planting 2009).

Based on I-O tables, we calculated customers' IT investments. I-O tables contain manufacturing industries and non-manufacturing industries, and some of the rows/columns for manufacturing industries are the combination of 3-digit SIC codes. We dropped all non-manufacturing industries in the I-O tables and aggregated the corresponding industries in the MFP data according to the manufacturing industries listed in I-O tables, which generated 98 manufacturing industries in the MFP data and the I-O tables. After matching MFP data and I-O data, we set the diagonals in the I-O tables to zero to isolate the transactions with other industries, and then we followed (5) to calculate the transaction weighted customers IT capital.

Based on 98 manufacturing industries, we dropped the industries with missing data and those without customer industries. Because of missing intermediate inputs data from 1997 to 1999, we dropped 6 industries: Logging (SIC 241), Newspapers (SIC 271), Periodicals (SIC 272), Books (SIC 273), Miscellaneous Publishing (SIC 274), and Greeting Cards (SIC 277). Next, we eliminated 7 industries which did not supply to others: Ordnance and Ammunition (SIC 348), Aerospace (SIC 372, 376), Ship and Boat Building and Repairing (SIC 373), Railroad Equipment (SIC 374), Toys and Sporting Goods (SIC 394), Footwear except Rubber and Plastic (SIC 313, 314), and Tobacco Products (SIC 21). In total, we have a balanced panel of 85 industries across 13 years.

3.1.3. Dataset II: 2000-2008 The second dataset was acquired in December 2011 from the BLS, is based on 3-digit 2002 NAICS codes, and contains 9 years from 2000 to 2008. It consists of the MFP data for 3-digit NAICS codes providing our measures of IT capital, non-IT capital, and labor; gross output, Y, was obtained from the gross domestic product (GDP) by industry accounts on the Bureau of Economic Analysis (BEA) website; total intermediate inputs, M, from the I-O use tables also obtained from the BEA. Table A3, in the Appendix, shows the data source, construction procedure, and deflators used for each variable. We used chain-type quantity indexes as deflators to obtain the real values by multiplying the 2005 current-dollar value of the series by the corresponding chain-type quantity indexes and then dividing by 100.

IT capital stock includes computers, software, communication, and others, and we use the total as IT capital, Z. The IT assets in Dataset II differ from those in Dataset I as software is included. Capital includes equipment, structures, rental residential capital, inventories, and land. To calculate non-IT capital, K, we aggregated equipment and structures and then subtracted IT capital. Our measure of labor, L, is in millions of hours.

We calculated outsourced logistics based on the I-O use tables and by following the method above. We measured outsourced logistics as the purchases of: Air Transportation (NAICS 481), Rail Transportation (NAICS 482), Water Transportation (NAICS 483), Truck Transportation (NAICS 484), Pipeline Transportation (NAICS 486), and Warehousing and Storage (NAICS 493). Subtracting outsourced logistics from total intermediate inputs, we obtained non-logistics intermediate inputs, X. We converted the nominal values of outsourced logistics and non-logistics intermediate inputs to chained 2005 U.S. dollars by using the chain-type quantity indexes for gross output of the warehousing and transportation sector and for intermediate inputs, respectively.

We followed the same method as that used in Dataset I to obtain customers' IT investments. In particular, I-O tables show transactions among manufacturing industries and transactions between manufacturing and non-manufacturing industries. To be consistent with Dataset I, we captured the transactions among manufacturing industries as weights for calculating customers' IT investments. In addition, to match the I-O tables with the MFP data, we combined codes 3361MV and 3364OT in I-O tables. Therefore, the final

Table 3 Summary Statistics

Variable	Obs	Mean	Std. dev.	Min	Max
Dataset I (1987-1999)					
Output (in millions of 1987 dollars)	1105	30,294.40	46,044.20	557.62	738,130.80
Non-IT capital stock (in millions of 1987 dollars)	1105	20,641.51	22,836.99	461.80	135,540.60
Labour (in millions of hours)	1105	414.45	342.97	12.20	2,350.90
IT capital stock (in millions of 1987 dollars)	1105	1,814.49	3,165.67	30.30	27,661.10
Total Intermediate inputs (in millions of 1987 dollars)	1105	16,970.93	20,999.34	313.18	202,082.50
Non-Logistics intermediate inputs (in millions of 1987 dollars)	1105	16,112.12	20,043.91	307.17	193,899.60
Outsourced logistics (in millions of 1987 dollars)	1105	858.81	1,115.23	4.48	8,211.68
Customers' IT investments (index)	1105	2,969.07	2,444.52	69.16	19,508.81
Dataset II (2000-2008)					
Output (in millions of 2005 dollars)	162	253,048.40	196,900.70	20,728	738,084
Non-IT capital stock (in millions of 2005 dollars)	162	139,626.80	95,180.63	22,269	336,823
Labour (in millions of hours)	162	1,644.82	989.78	239	4,227
IT capital stock (in millions of 2005 dollars)	162	14,693.33	16,815.21	919	62,336
Total Intermediate inputs (in millions of 2005 dollars)	162	170,303.70	143,106.3	7,568.15	529,658.60
Non-Logistics intermediate inputs (in millions of 2005 dollars)	162	164,606.30	139,135.90	7,328.36	517,997.90
Outsourced logistics (in millions of 2005 dollars)	162	5,675.38	5,093.44	614.01	24,355.66
Customers' IT investments (index)	162	23,694.58	7,570.42	7,200.11	39,179.31

Notes: NAICS is a six-digit system and SIC is a 4-digit system. Dataset I is based on 3-digit SIC codes and Dataset II is based on 3-digit NAICS codes. The 3-digit NAICS level (subsector) corresponds roughly to 2-digit SIC level (major group). Dataset II is at a higher aggregation level than Dataset I, so the number of observations in Dataset II is lower.

dataset is a balanced panel of 18 manufacturing industries across 9 years. Table A4, in the Appendix, describes the 18 manufacturing industries in 3-digit NAICS codes.

The summary statistics for both Datasets I and II are provided in Table 3.

3.1.4. Econometric Adjustments The years covered in our two Datasets, 1987-1999 and 2000-2008, contain changes in political and economic activities, such as the e-commerce boom in the late 1990s, the e-commerce collapse and the 9/11 terrorist attacks after 2000, and the financial crisis in 2008. These changes took place along with the variations in fiscal, monetary, and trade policies. Consequently, to control for any economy-wide shocks which could affect all industries, we add year fixed effects. In addition, to better interpret the interaction terms and to reduce possible multicollinearity between the interaction effects and the main effects (Wooldridge 2009), we center the covariates, IT capital Z, log of logistics w, and customers' IT capital C, before constructing the interactions terms and without centering main terms in the estimation model.

Because both of our Datasets are cross-sectional time series, we test for autocorrelation and heteroskedasticity (HE). First, we anticipate autocorrelation in error terms because the output of any industry is highly correlated with its output in the previous year under relatively smooth business cycles. Following the Wooldridge test for autocorrelation in panel data (Wooldridge 2002), we reject the null hypothesis of no first-order autocorrelation (AR1) at all reasonable levels of significance both in Dataset I (F (1, 84) = 73.60 for the full sample, 117.40 for the sample from 1987 to 1993, and 33.42 for the sample from 1994 to 1999) and in Dataset II (F (1, 17) = 12.50). In addition, the autocorrelation could differ in magnitude for different industries if the magnitudes of the responses to the changes in business cycles differ across industries, so the AR1 process could be panel specific AR1 (PSAR1). We use the likelihood ratio test to check whether AR1 coefficients are common across the industries (Greene 2008). The null hypothesis that the regression with correction of AR1 is nested in the regression with the correction of PSAR1 is rejected at all levels of significance in Dataset I ($\chi^2(84) = 295.59$ for the full sample, $\chi^2(84) = 207.29$ for the sample from 1987 to 1993, and $\chi^2(84) = 224.77$ for the sample from 1994 to 1999), so we control for PSAR1 for Dataset I. In Dataset II, we fail to reject the null ($\chi^2(17) = 4.13$), so we adjust for AR1 in the estimations.

We also test for panel-level HE by using the likelihood ratio test (Greene 2008). We anticipate panel-level HE because the variances of the error terms for each industry are likely to fluctuate over time and the variances of the error terms could differ across industries. The null hypotheses of no panel-level HE is rejected at all levels of significance in Dataset I ($\chi^2(84) = 1624.82$ for the full sample, $\chi^2(84) = 572.89$ for the sample from 1987 to 1993, and $\chi^2(84) = 924.39$ for the sample from 1994 to 1999) and in Dataset II ($\chi^2(17) = 141.09$).

Consequently, after adding year fixed effects, we estimate our models by adjusting PSAR1 and panel-level HE for Dataset I, and AR1 and panel-level HE for Dataset II. We use feasible generalized least squares to generate our estimates (Wooldridge 2002).

3.2. Estimation Results

We estimate the simple CD and the extended CD specified in (1) to compare our results with those from previous studies. Columns 1 and 6 of Table 4 report the estimation results for the simple CD for Dataset I and Dataset II, respectively. The estimation results for the extended CD are shown in Columns 2 and 7 of Table 4 for Dataset I and Dataset II, respectively. These results are similar across Datasets and are consistent with those in previous studies.

Next, we estimate the model specified in (3) with corresponding econometric adjustments for Datasets I and II. To capture whether the effects of IT investments on outsourced logistics change over time, we split Dataset I into the pre- and post-Internet eras. Commercialization of the Internet began in 1994 when business and media started to use the Internet (Zakon 2011). In April 1995, NSFNET (National Science Foundation Network) backbone was decommissioned, which removed the last restriction on the use of the Internet to carry commercial traffic (Leiner et al. 1997). Since 1995, the Internet has grown dramatically. Therefore, we split our first dataset at 1993, and define 1987–1993 as the pre-Internet era and 1994–1999 as the post Internet era. To show whether the complementarity relationship between IT and outsourced logistics continues after 1999, we use Datset II covering the later post-Internet era. Our estimation results for the three time periods are shown in Columns 4, 5, and 8 of Table 4, respectively.

3.2.1. The Effects of IT on Outsourced Logistics in the Pre-Internet Era The estimated coefficient of the interaction term *"OwnIT * OutsourcedLogistics"*, μ, is negative

Table 4 The Estimation Results for Two Datasets

Variables	Dataset I (1987-1999)					Dataset II (2000-2008)		
	The Simple CD	The Extended CD	Main Estimation			The Simple CD	The Extended CD	Main Estimation
			Full Sample 1987-1999	Pre-Internet 1987-1993	Post-Internet 1994-1999			2000-2008
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Non-IT Capital	0.082*** (0.010)	0.037*** (0.010)	0.029*** (0.010)	0.062*** (0.009)	0.058*** (0.009)	0.196*** (0.044)	0.202** (0.083)	0.164*** (0.062)
Labour	0.237*** (0.008)	0.264*** (0.007)	0.272*** (0.007)	0.233*** (0.007)	0.264*** (0.009)	0.122*** (0.028)	0.209*** (0.041)	0.141*** (0.032)
IT Capital	0.080*** (0.006)	0.083*** (0.005)	0.073*** (0.005)	0.088*** (0.004)	0.085*** (0.006)	0.062** (0.0273)	0.042 (0.046)	0.061* (0.037)
Non-Logistics		0.539*** (0.009)	0.546*** (0.009)	0.581*** (0.007)	0.513*** (0.011)		0.521*** (0.026)	0.536*** (0.025)
Outsourced Logistics		0.104*** (0.006)	0.118*** (0.007)	0.052*** (0.005)	0.116*** (0.008)		0.068 (0.051)	0.107*** (0.038)
CustomerIT		0.025*** (0.005)	0.034*** (0.005)	0.012*** (0.004)	0.053*** (0.006)		0.011 (0.031)	0.082** (0.033)
OwnIT * Outsourced_ Logistics			4.24e-06** (1.72e-06)	-8.13e-06*** (1.70e-06)	5.63e-06*** (1.79e-06)			3.88e-06*** (1.47e-06)
CUSIT * Outsourced_ Logistics			6.19e-06*** (1.79e-06)	-8.57e-06*** (2.20e-06)	8.67e-06*** (2.10e-06)			2.35e-06** (1.10e-06)
Intermediate Inputs	0.639*** (0.010)					0.611*** (0.024)		
Constant	1.275*** (0.0518)	1.653*** (0.064)	1.526*** (0.073)	1.597*** (0.063)	1.355*** (0.082)	1.278*** (0.274)	1.138** (0.531)	0.697 (0.465)
Observations	1105	1105	1105	595	510	162	162	162

Notes: (1) OwnIT and CUSIT are an industry's IT investment and its customers' IT investments, respectively. OwnIT and CUSIT are in levels and other variables are in natural logs. (2) We control for panel-level heteroskedasticity (HE) and panel specific autocorrelation (PSAR1) for Dataset I, and We control for panel-level heteroskedasticity (HE) and first-order autocorrelation (AR1) for Dataset II. Details of the year fixed effects are suppressed. Standard errors are in parentheses following the estimated coefficients. *p<0.10, **p<0.05, ***p<0.01.

and significant at 1% level from 1987 to 1993 (Column 4 of Table 4). It suggests that an industry's own IT investment and outsourced logistics are not complements during the pre-Internet era, meaning that increasing IT investment reduces the marginal return of outsourced logistics. An example of such an investment is an information system that automates business activities, improves information timeliness, accuracy, and availability, and facilitates information sharing across functions within firms, leading to upgraded internal connectivity and integration. Thus, internal governance costs, such as information processing costs, monitoring costs, and opportunity costs due to poor information, etc., are reduced. Because of the reduction in internal governance costs, the efficiency of existing business processes are improved. In particular, in-house logistics become more efficient, and firms prefer the internal provision of logistics.

The estimated coefficient of the interaction term *"CUSIT * OutsourcedLogistics"*, ν, is negative and significant at 1% level from 1987–1993 (Column 4 of Table 4). This suggests that customers' IT investments do not complement an industry's outsourced logistics, meaning that increasing customers' IT investments reduces the marginal return of an industry's outsourced logistics. For example, the IT investments in EDI from an industry's customers electronically send demand information to a given industry, which in turn uses the data to forecast, analyze, and plan for orders, to optimize its production plan and procurement plan, and to better utilize its transportation capabilities and manage inventory. Thus, the given industry can more efficiently manage its transportation and warehousing across a supply chain from procurement to distribution, and this works towards lowering the costs of conducting logistics in-house.

3.2.2. The Effects of IT on Outsourced Logistics in the Post-Internet Era Columns 5 and 8 of Table 4 show the estimation results for Dataset I from 1994 to 1999 and for Dataset II from 2000 to 2008, respectively.

The estimated coefficient of the interaction term *"OwnIT * OutsourcedLogistics"*, μ, is positive and significant at 1% level. This suggests that an industry's own IT investment and outsourced logistics are complements in the post-Internet era, which means that the greater the own IT investment, the higher marginal return of outsourced logistics. For instance, an industry's IT investment in Internet-based IOSs substantially facilitates information sharing and coordination among a focal industry, its suppliers, and 3PL providers, reducing external transaction costs associated with logistics. Because transaction costs are reduced, the focal industry outsources more logistics to 3PL providers that typically conduct logistics activities more efficiently.

Table 5 The Impact of Own IT on the Output Elasticity of Outsourced Logistics

	Dataset I 1987-1993 (1)	Dataset I 1994-1999 (2)	Dataset II 2000-2008 (3)
The change in the output elasticity of outsourced logistics with respect to one more unit of own IT investment (μ in equation (3))	-8.13E-06	5.63E-06	3.88E-06
The output elasticity of outsourced logistics at the mean level of own IT and customers' IT (b in equation (3))	0.052	0.116	0.107
1% of own IT on average (in millions of dollars) (η)	13.992	22.989	146.933
The change in the output elasticity of outsourced logistics, given 1% increase of own IT on average (ξ= μ∗η/b*100)	-0.22	0.11	0.53
Interpretation of ξ	1% increase in own IT on average is associated with 0.22% decrease in the output elasticity of outsourced logistics	1% increase in own IT on average is associated with 0.11% increase in the output elasticity of outsourced logistics	1% increase in own IT on average is associated with 0.53% increase in the output elasticity of outsourced logistics

Notes: Keeping customers' IT at the mean level and other variable constant when interpreting the relationship.

The estimated coefficient of the interaction term *"CUSIT * OutsourcedLogistics"*, ν, is positive, and significant at 1% level for the dataset from 1994 to 1999 and at 5% level for the dataset from 2000 to 2008, respectively. This suggests that IT investments of a focal industry's customers and this focal industry's outsourced logistics are complements, meaning that an increase in customers' IT investments increases the marginal return of the focal industry's outsourced logistics. For example, an increase in customers' IT investments in Internet-based IOSs enables demand and inventory information sharing. Because of the Internet's global connectivity, open standards, and low communication costs, information can be transferred swiftly to suppliers and 3PL providers, enabling the focal industry and its supply chain partners to coordinate logistics at lower costs, leading to a greater demand for logistics outsourcing.

3.2.3. The Effects of IT on Output through Outsourced Logistics Based on our estimates of two interaction terms, we calculate the impact of an industry's own IT capital

Table 6 IT Investment and Outsourced Logistics of Three Industries based on Dataset II

I-O Codes (NAICS)	Industry	IT Investment (In Millions of 2005 Dollars)	The Output Elasticity of Outsourced Logistics
315AL	Apparel and leather and allied products	1,109.778	0.054
311FT	Food and beverage and tobacco products	15,861.780	0.111
333	Machinery	33,761.220	0.181

and the impact of customers' IT on the output elasticity of outsourced logistics. Table 5 shows that at the mean level of customers' IT and keeping other factors constant, 1% increase in own IT on average is associated with 0.11% (for Dataset I) and 0.53% (for Dataset II) increase in the output elasticity of outsourced logistics in the post-Internet era. This suggests that at the mean level of customers' IT, keeping other variables constant, the higher the IT investment, the larger the effect of outsourced logistics on gross output.

To derive further economic intuition from our results we provide examples of industries with different levels of IT investment based on Dataset II. Table 6 shows the IT investment and output elasticity of outsourced logistics for three industries: Apparel and leather industry (NAICS 315AL) has the lowest IT investment, Food industry (NAICS 311FT) has an average level of IT investment, and machinery industry (NAICS 333) has a relative higher level of IT investment. As seen, the higher the IT investment, the larger is the output elasticity of outsourced logistics, and this suggests that, keeping other factors constant, IT increases the efficiency of outsourced logistics, leading to more logistics outsourcing.

The online supplement presents a plethora of robustness tests – including sector fixed effects and instrumental variable estimates – and a detailed discussion on alternative explanations we considered in interpreting the results.

4. Conclusion

4.1. Contributions

Our study has three important contributions. First, we provide systematic empirical evidence that IT in its most interconnected instance—the Internet—enables a move to the market. Previous work theoretically argued that IT was associated with the shift from hierarchies to markets by reducing transaction costs, and other studies only provided indirect evidence in support of those arguments. In the context of logistics, we show that the increasing use of IT is associated with greater logistics outsourcing in the post-Internet era. In particular, our study identifies a change in the relationship between IT and outsourced logistics. In the pre-Internet era, an industry's own IT investment and outsourced logistics were not complements, and they became complements after the Internet was widely used. By focusing on logistics outsourcing, we can rule out the compounding factors that arise from offshoring in more general outsourcing.

Second, we show the impact of IT on output through logistics outsourcing. Previous studies about IT productivity converged to the contribution of IT to output. Our study shows the moderating role of IT in the contribution of logistics outsourcing to output. In particular, we show that an increase in IT is associated with an increase in the output elasticity of outsourced logistics in the post-Internet era. It suggests that after the Internet, IT contributed to greater output by increasing the efficiency of outsourced logistics. We also find similar impacts of customers' IT investments on outsourced logistics.

Third, our study reconciles the theoretical arguments about the effects of IT on reducing coordination costs within and between firms. Previous studies argued that IT could reduce internal governance costs and external transaction costs, and IT would have different impacts on organizational change depending on which effect predominates. However, it was not known which effect dominated a priori. Our study suggests that, at least in the context of logistics, the effect of IT on reducing internal governance costs dominates in the pre-Internet era, and the effect of IT on reducing external transaction costs dominates in the post-Internet era.

4.2. Implications

One implication is that activities with the potential to be outsourced and that use the Internet for coordination are more likely to be outsourced in the post-Internet era. Our findings are in the context of logistics, where coordination is key and Internet-based IOSs have been used to improve coordination between supply chain members. A current revolution, mobile computing, also affects coordination costs. It remains to be seen whether mobile computing has greater effects on internal or external coordination costs.

The other implication is that the popularity of outsourcing has a technological and theoretical basis. The Internet with its universal connectivity and open standards has enabled the integration of IT infrastructure between firms, facilitating information sharing and coordination, which in turn improves visibility and transparency of supply chains. In addition, the Internet enables online markets where firms can connect with potential providers of goods and services at low cost, resulting in reduced transaction costs for outsourcing.

4.3. Limitations and Qualifications

Our focus is on the impact of IT on outsourced logistics downstream in the supply chain. As such, this study examines the impact of IT, including a focal industry's own IT and customers' IT, on the focal industry's outsourced logistics in the pre- and post-Internet eras. Logistics outsourcing needs coordination among suppliers, 3PL providers, and customers. Thus, the IT capabilities of upstream supply chain members and 3PL providers also play an important role in improving coordination.

Suppliers' IT investments not only improve the coordination of logistics activities, but also help increase downstream industry output through improved quality of goods and services which are used as intermediate inputs for downstream industries (Cheng and Nault

2007). With summary data on IT capital, it is not possible to differentiate the quality and coordination effects from suppliers' IT. However, our study still sheds light on the impact of suppliers' IT on a focal industry's logistics outsourcing based on our unique data. In the I-O accounts, some supplying industries are also customer industries, so we can infer the impact of suppliers' IT from our results about the effects of customers' IT. Moreover, we avoid double-counting issue by the virtue of not estimating the impact of suppliers' IT in our model.

For similar reasons, our industry-level data does not enable us to directly estimate the impact of IT on logistics processes to get insight about which specific transaction costs are reduced by IT after the Internet. Consequently, we can only study the summary effects of make or buy decisions and infer that relative reductions in transaction costs have favored external provision. However, our industry level data allows us to investigate the economy-wide impact of IT on outsourced logistics, which increases the generalizability of our study.

We also note that, in the absence of a direct measure for Internet usage, we are limited to exploiting the complementarity in a CD production function to derive our insights. Although we can establish time precedence between pre- and post-Internet eras using our time series datasets and we have a powerful theoretical lens using transaction costs theory, there remains a chance of alternative explanations whose timing might have coincided with the commercialization of the Internet. Future work with finer measures of Internet usage may confirm our results.

Acknowledgments

We thank Byungwan Koh, Victoria Mitchell, Giovani da Silveira, Nancy Southin, Dawei (David) Zhang, the seminar participants at the University of Texas at Dallas and Salisbury University, and the session participants at INFORMS 2011 in Charlotte, North Carolina as well as at POMS 2014 in Atlanta, Georgia for helpful feedback. We also thank Zhuo (June) Cheng for sharing the productivity data from 1987 to 1999 and Jeanette Burman for proofreading and editing assistance. The research was supported in part by the Natural Sciences and Engineering Research Council and the Social Sciences and Humanities Research Council of Canada.

References

Ashenbaum, B., A. Maltz, E. Rabinovich. 2005. Studies of trends in third-party logistics usage: What can we conclude? *Transportation Journal* **44**(3) 39–50.

Bakos, J. Y. 1997. Reducing buyer search costs: Implications for electronic marketplaces. *Management Science* **43**(12) 1676–1692.

Brousseau, E. 1994. EDI and inter-firm relationships: toward a standardization of coordination processes? *Information Economics and Policy* **6**(3) 319–347.

Brynjolfsson, E., T. W. Malone, V. Gurbaxani, A. Kambil. 1994. Does information technology lead to smaller firms? *Management Science* **40**(12) 1628–1644.

Cachon, G. P., M. Fisher. 2000. Supply chain inventory management and the value of shared information. *Management Science* **46**(8) 1032–1048.

Cheng, Z., B. R. Nault. 2007. Industry level supplier-driven IT spillovers. *Management Science* **53**(8) 1199–1216.

Cheng, Z., B. R. Nault. 2012. Relative industry concentration and customer-driven IT spillovers. *Information Systems Research* **23**(2) 340–355.

Clemons, E. K., S. P. Reddi, M. C. Row. 1993. The impact of information technology on the organization of economic activity: The "move to the middle" hypothesis. *Journal of Management Information Systems* **10**(2) 9–35.

Danese, P. 2006. Collaboration forms, information and communication technologies, and coordination mechanisms in CPFR. *International Journal of Production Research* **44**(16) 3207–3226.

Deepen, J. M. 2007. *Logistics Outsourcing Relationships: Measurement, Antecedents, and Effects of Logistics Outsourcing Performance*. Physica-Verlag HD.

Edgeworth, F. Y. 1925. The pure theory of monopoly. *Papers Relating to Political Economy*, vol. 1. Macmillan & Co., London, 111–142.

Greene, W. H. 2008. *Econometric Analysis*. 6th ed. Pearson Prentice Hall, Upper Saddle River, N.J.

Gurbaxani, V., S. Whang. 1991. The impact of information systems on organizations and markets. *Communications of the ACM* **34**(1) 59–73.

Han, K., R. J. Kauffman, B. R. Nault. 2011. Returns to information technology outsourcing. *Information Systems Research* **22**(4) 824–840.

Hitt, L. M. 1999. Information technology and firm boundaries: Evidence from panel data. *Information Systems Research* **10**(2) 134–149.

Horowitz, K., M. Planting. 2009. Concepts and methods of the U.S. input-output accounts. Tech. rep., the U.S. Bureau of Economic Analysis of the U.S. Department of Commerce.

Langley, C. J. Jr., Capgemini. 2012. 2012 third party logistics: Results and findings of the 16th annual study. Tech. rep., Capgemini, Penn State University, The Panalpina Group, Heidrick & Struggles, and eyefortransport.

Lee, H. L., V. Padmanabhan, S. Whang. 1997. Information distortion in a supply chain: The bullwhip effect. *Management Science* **43**(4) 546–558.

Lee, H. L., K. C. So, C. S. Tang. 2000. The value of information sharing in a two-level supply chain. *Management Science* **46**(5) 626–643.

Leiner, B. M., V. G. Cerf, D. D. Clark, R. E. Kahn, L. Kleinrock, D. C. Lynch, J. Postel, L. G. Roberts, S. S. Wolff. 1997. The past and future history of the Internet. *Communications of the ACM* **40**(2) 102–108.

Lieb, R. C., H. L. Randall. 1996. A comparison of the use of third-party logistics services by large american manufacturers, 1991, 1994, and 1995. *Journal of Business Logistics* **17**(1) 305–320.

Malone, T. W., J. Yates, R. I. Benjamin. 1987. Electronic markets and electronic hierarchies. *Communications of the ACM* **30**(6) 484–497.

Milgrom, P., J. Roberts. 1992. *Economics, Organization and Management*. Prentice-Hall.

Milgrom, P., J. Roberts. 1994. Complementarities and systems: Understanding japanese economic organization. *Estudios Economicos* 3–42.

Milgrom, P., J. Roberts. 1995. Complementarities and fit strategy, structure, and organizational change in manufacturing. *Journal of accounting and economics* **19**(2) 179–208.

Mittal, N., B. R. Nault. 2009. Investments in information technology: Indirect effects and information technology intensity. *Information Systems Research* **20**(1) 140–154.

Mun, S., M. I. Nadiri. 2002. Information technology externalities: Empirical evidence from 42 U.S. industries. Working Paper 9272, National Bureau of Economic Research.

Nault, B. R. 1998. Information technology for freight transportation coordination. National Research Council Special Report 252 of the Transportation Research Board, ed., *Policy Options for Intermodal Freight Transportation*. National Academy Press, Washington D.C., 234–257.

Nault, B. R., A. S. Dexter. 2006. Agent-intermediated electronic markets in international freight transportation. *Decision Support Systems* **41**(4) 787–802.

Rabah, M., H. S. Mahmassani. 2002. Impact of information and communication technologies on logistics and freight transportation: Example of vendor-managed inventories. *Transportation Research Record: Journal of the Transportation Research Board* **1790**(1) 10–19.

Rutner, S. M., C. J. Langley Jr. 2000. Logistics value: Definition, process and measurement. *International Journal of Logistics Management* **11**(2) 73–82.

Streitwieser, M.L. 2009. A primer on BEA's industry accounts. *Survey of Current Business,* **June** 40–52.

U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics. 2011. *Transportation Satellite Accounts: A Look at Transportation's Role in the Economy*. Washington, DC.

Williamson, O. E. 1981. The economics of organization: The transaction cost approach. *American Journal of Sociology* **87**(3) 548–577.

Wilson, R. 2012. 23rd state of logistics report: The long and winding recovery. CSCMP annual state of logistics report presentation, June 13, 2012.

Wooldridge, J. M. 2002. *Econometric Analysis of Cross Section and Panel Data*. MIT Press, Cambridge, MA.

Wooldridge, J. M. 2009. *Introductory Econometrics: A Modern Approach*. 4th ed. South-Western, Cengage Learning.

Zakon, R. H. 2011. Hobbes' Internet timeline 10.2. http://www.zakon.org/robert/internet/timeline.

Zhu, K. 2004. The complementarity of information technology infrastructure and e-commerce capability: A resource-based assessment of their business value. *Journal of Management Information Systems* **21**(1) 167–202.

Zhu, K., K. L. Kraemer. 2002. E-commerce metrics for net-enhanced organizations: Assessing the value of e-commerce to firm performance in the manufacturing sector. *Information Systems Research* **13**(3) 275–295.