



The impact of information and communication technology adoption on multinational firm boundary decisions

Wenjie Chen¹ and
Fariha Kamal²

¹Department of International Business, George Washington University, Washington DC, USA;
²Center for Economic Studies, US Census Bureau, Suitland, MD, USA

Correspondence:

W Chen, Department of International Business, George Washington University, Washington DC 20052, USA.
Tel: +1 (202) 994 3275

Abstract

This article evaluates the effect of adopting Internet-enabled information and communication technology (ICT adoption) on the decision to reorganize production across national borders (foreign boundary decision) by multinational enterprises (MNEs). Using a transaction cost framework, we argue that ICT adoption influences foreign boundary decisions by lowering coordination costs both internally and externally for the firm. We propose that the heterogeneity in the technology's characteristics, namely complexity and the production processes' degree of codifiability, moderate this influence. Using a difference-in-differences methodology and exploiting the richness of confidential US Census Bureau microdata, we find that overall ICT adoption is positively associated with greater likelihood of in-house production, as measured by increases in intra-firm trade shares. Furthermore, we find that more complex forms of ICT are associated with larger increases in intra-firm trade shares. Finally, our results indicate that MNEs in industries in which production specifications are more easily codified in an electronic format are less likely to engage in intra-firm relative to arm's length trade following ICT adoption.

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INTRODUCTION

Profound innovations in information and communication technologies (ICTs) during the last three decades have reshaped the global landscape in which firms operate. The emergence of these technologies has enabled firms to reduce transactions costs, including those in transportation, communication, and coordination. Multinational enterprises (MNEs), in particular, have benefited from the innovations in ICT and have adopted them into their operations and international production processes. This in turn has influenced increasingly complex firm boundary decisions.

The transaction cost theory has been the leading paradigm in the analysis of the multinational firm, particularly, to answer the question of whether or not to undertake an activity within a firm's own boundaries (Buckley & Casson, 1976, 1998, 2009; Dunning, 1980; Hennart, 1982, 2009; Teece, 1986). Under this conceptual

framework firms choose over alternative governance structures in order to minimize transaction costs. By using ICT, MNEs are able to mitigate transaction costs that might alter the decision between in-house production vs arm's length exchange. Forman and McElheran (2012) study the effect of ICT adoption on the domestic boundary choices of firms by examining changes in the share of total shipments that are transferred internally within domestic firms in the United States. In contrast, Fort (2013) primarily focuses on the effect of ICT on domestic vs foreign sourcing decisions, thus highlighting the spatial location choice of the firm. Our study complements these existing studies by analyzing the role of ICT adoption in shaping the decision between how much is produced within and outside the boundaries of the firm across national borders, henceforth referred to as a firm's foreign boundary decision.

We examine ICT's impact on a firm's foreign boundary decision to make or buy through the lens of the firm's intra- and inter-firm trade choices, explicitly assuming that the firm has decided on foreign production. We propose that from the viewpoint of the firm, ICT adoption lowers both internal and external coordination costs *ex post* through two independent effects: (1) lowering of communication and search costs (Malone, Yates, & Benjamin, 1987), and (2) lowering of economic incentive costs in terms of economic moral hazards and opportunistic behavior (Clemens, Reddi, & Row, 1993; Gurbaxani & Whang, 1991). The efficient mix of a firm's in-house and arm's length production is determined by trading off external and internal coordination costs. We argue that this baseline effect of ICT on intra-firm relative to arm's length production is theoretically ambiguous and hence ultimately an empirical question.

Most existing studies – with the exception of Feinberg and Keane (2006) and Keane and Feinberg (2007) – in the area of ICT and firm organization have generally concentrated on the net effect of the impacts of ICT adoption on firm boundary decision, that is, either increased in-house production or increased arm's length production. De la Torre & Moxon (2001) provide an excellent overview of the literature pertaining to the same time period, the early 1990s, as the focus in our study. Rangan and Sengul (2009) find that MNEs in industries with higher ICT investment intensity exhibit lower propensity for transnational integration. Dosi, Gambardella, Grazzi, and Orsenigo (2008) provide

evidence on the contrary to suggest that, on balance, increased ICT investments are positively correlated with intra-organizational interactions. Both these studies capture the net effect of ICT investments on foreign boundary decisions, with the underlying premise that outsourcing and in-house production are substitutes for each other.

However, ICT affects all MNE-related production, both in-house and at arm's length, in ways that are not always mutually exclusive. In a departure from prior research, our study highlights that the choices of arm's length and intra-firm production may occur simultaneously within the *same* firm. For instance, in early 2000, the Swiss food and beverage MNE Nestlé invested US\$1.8 billion in ICT (Worthen, 2002).¹ After ICT installation, global subsidiaries exploited the new network to share price information and exert market power by acting in a coordinated manner. As a result, Nestlé reduced the number of external suppliers and procurement costs by up to 20%. Concurrently, Nestlé began using a new web-based system to contract with external suppliers directly. ICT installation can thus have significant effects on firms' boundary choices and as a result, its intra-firm and arm's length trading patterns.

Many studies in the organization and communication science research literature have examined the relationship between ICT and organizational structures (McPhee & Poole, 2001; Rice & Gattiker, 2001), but relatively little research attention has focused on the specificity and heterogeneity of ICT systems and their distinct moderating effects on a firm's boundary decisions (notable exceptions are Feinberg & Keane, 2006; Keane & Feinberg, 2007; Rangan & Sengul, 2009). In this article, we study the moderating role of characteristics of ICT systems. We hypothesize that the firm's intra-firm transactions relative to its arm's length transactions will increase, the greater the complexity of the type of ICT adopted. More complex types of technology require greater synchronization between adopting firm units in order to maximize the gains. Thus *ex post* of the firm's decision to adopt ICT, it is more likely that more complex ICT would require using parties to have the necessary ICT infrastructure and commitment in investing and maintaining the network systems.

We further hypothesize that the firm's intra-firm transactions relative to its arm's length transactions will decrease the more readily its production process can be electronically codified. As it is easier to break up a production chain in which processes are more

readily codified, each value chain link can separately benefit from ICT adoption and result in cost reductions. Thus we would expect MNEs operating in industries where the production process is more readily codified into electronic formats to have a proclivity for arm's length relative to intra-firm transactions following ICT adoption.

We study ICT adoption in the context of globalization and increased trade integration (Antràs & Yeaple, 2014). Our sample period (1992 and 1999) spans the advent of Internet-enabled ICT and the emergence of global value chains. As Internet-enabled ICT has been commercially available only since 1995 (Forman, Goldfarb, & Greenstein, 2005), we focus on a relatively early period of Internet-enabled ICT adoption. Thus our analysis provides a valuable benchmark that can act as a baseline and lower bound on the impact of ICT adoption on MNEs' boundary decisions. We use detailed data on US manufacturers' choice of ICT adoption at the plant level for a host of different industries in the manufacturing sector using the 1999 Computer Network Use Supplement (CNUS), an addendum to the Annual Survey of Manufactures (ASM). This novel and comprehensive data set allows us to provide a nuanced picture of the role of ICT adoption on MNE boundary decisions and unlike most existing studies, we are able to exploit the heterogeneity of the disaggregated data in terms of various types of ICT adoption. We measure MNE's foreign boundary choices through its intra-firm and arm's length trade transactions obtained from the Longitudinal Foreign Trade Transactions Database (LFTTD).

We find robust empirical support for our hypotheses. Overall, ICT adoption enhances within-firm boundary transactions as measured by increased intra-firm trade shares. By using a difference-in-differences identification strategy and contrasting pre- and post-ICT adoption periods, results show that firms with more sophisticated types of ICT experience increases in intra-firm relative to arm's length trade transactions. We also confirm our expectation that following the adoption of ICT, firms in industries where production processes are more readily codified into electronic formats experience decreases in intra-firm trade shares. Our baseline results are robust to construction of alternative samples and controls for simultaneity bias. We consider two distinct samples – single-plant firms only and single-plant and multi-plant firms where all its plants either adopt or do not adopt ICT. We address the simultaneity bias that arises if firms are proactively adopting ICT in anticipation of enhancing

intra-firm or arm's length trade. We re-estimate our baseline specification controlling for a firm's prior use of proprietary network technology.

Our examination of the role of ICT on a firm's foreign boundary decisions makes a theoretical and empirical contribution to the existing literature on ICT and firm organizational choices. Although there is a growing literature on the role of fragmentation and offshore production, where technological improvements play an essential role (Antràs, Rossi-Hansberg, & Garicano, 2008; Costinot, Vogel, & Wang, 2013; Deardorff, 2001; Grossman & Rossi-Hansberg, 2008; Jones & Kierzkowski, 2001; Kohler, 2004), the theoretical and empirical analyses rely on the assumption that firms have already upgraded their technology in order to facilitate production fragmentation. Our theoretical and empirical focus is exactly on the effect of a firm's decision to adopt ICT on its foreign boundary choices. We build on the work of Rangan and Sengul (2009) by extending the theoretical model to include more detailed types of ICT applications and the moderating effects of characteristics of ICT on a firm's international boundary decisions. Our work also relates to and extends the study by Feinberg and Keane (2006), which finds that technology, measured as the residual from a structural model, is an important factor in intra-firm trade by multinationals between the United States and Canada. Whereas Rangan and Sengul (2009) and Cho (1990) employ data aggregated at the industry level, our analysis uses a direct plant-level measure of ICT and provides evidence of a link between specific types of ICT adoption and a firm's international boundary decision.

The advent of ICT has been accompanied by increased formation of global value chains that are creating new opportunities for firms to become more globally integrated, which has been associated with growth (Baldwin & Lopez-Gonzalez, 2014). Thus it is important for policymakers to understand how new avenues linking them to global production chains can be exploited. Because MNEs are a central feature of global production networks mediating 80% of global trade (UNCTAD, 2013), understanding how ICT reshapes multinational firms' global activities is an important avenue of scholarly investigation.

The following section develops our hypotheses grounded in transaction cost theory. The third section describes the data sources and variable construction, the fourth section describes our empirical methodology, the fifth section presents the results, and the final section provides discussion and conclusion.

HYPOTHESES DEVELOPMENT

Transaction Costs and ICT Adoption

An MNE has to communicate with, coordinate, search for and monitor cross-border operations. Broadly speaking, a firm's coordination costs can be divided into two distinct categories: internal coordination costs and external coordination costs (Kim & Mahoney, 2005). Internal coordination costs represent the economic costs incurred for communications, data transfer, and other economic expenditures on managing dependencies between activities within a firm. External coordination costs represent the economic costs of locating suppliers, writing contracts, and other economic costs of market procurement.

The internalization literature has highlighted the opposing nature of the outsource/offshore vs producing in-house decision yielding divergent findings. On the one hand, the adoption of ICT can reduce the economic costs of internal coordination within the firm by improving the quality and speed of information processing and management's decision making. Moreover, by adopting ICT, management can reduce agency costs through improved monitoring and evaluation systems. Bloom, Garicano, Sadun, and Van Reenen (2014) find that adoption of ICT within the same organization can reduce communication costs as well as knowledge acquisition costs. Moreover, Dosi et al. (2008) find that the size distribution of firms and industrial concentration in the advanced economies over the past few decades have not changed despite the increasing role of ICT. They deduce that intra-organizational interactions still dominate over market interactions, contradicting the notion that there has been a significant movement toward market coordination due to ICT. Along the same lines, other studies have also found greater internalization effects of ICT (Brynjolfsson, 1994; Gurbaxani & Whang, 1991; Zenger & Hesterly, 1997). Thus ICT adoption can reduce internal coordination costs and provide management with the capability to manage an organization more effectively and facilitate increased integration.

On the other hand, adoption of ICT can directly reduce market transaction costs by providing a cost-effective means to access and process market information, thus reducing external coordination costs to the firm. ICT can also reduce market transaction costs by facilitating closer inter-firm links through information sharing and mutual monitoring. Rangan and Sengul (2009), for instance, argue

and provide empirical evidence for increased internationalization at arm's length associated with increased ICT spending. Hitt (1999) observes that an increased use of IT systems is associated with a substantial decrease in vertical integration, and suggests that the empirical evidence points to the effect of IT systems lowering external coordination costs more than internal coordination costs. Malone et al. (1987) propose that ICT can lead to an overall decline in coordination costs in terms of searching and communicating with external transacting parties. Both Gurbaxani and Whang (1991) and Clemens et al. (1993) argue that the usage of ICT can reduce transaction risks such as the contractual hazards of shirking and opportunism through improved monitoring and reduced specificity in coordination with external partners. Thus ICT systems can reduce external coordination costs and encourage outsourcing.

Given these simultaneous channels whereby ICT can reduce costs for both external and internal transactions, Gurbaxani and Whang (1991) aptly note that "the net effect of IT on firm size varies from situation to situation, depending on the cost structure of the firm and the modes of synergy generated by integration" (71). Hence the net effects are theoretically ambiguous and we rely on empirical evidence to guide us.

Thus far, we have abstracted from heterogeneity in types of ICT as well as differences across industries in the application of ICT. In the following sections, we develop two testable hypotheses. First, we address the adoption of different types of ICT and how it moderates the effect of a firm's choice in internal vs external forms of transactions. Second, we examine how exogenous industry characteristics influence firm's boundary choices through the use of ICT.

Complexity of ICT

ICT systems vary widely in terms of their complexity and sophistication and with them, the level of investment that is required of the firm to undertake. Complex types of ICT, entailing relation-specific investments and high sunk costs, often requires the firm to incur additional costs of coordination among adopting firm units. We note here that *a priori*, it is not clear what type of firm would be more prone to adopt complex types of ICT, and it is not the focus of our study. Existing research shows that the costs to adopt business process innovations are variable depending on the mix between internal and external adjustment costs that are firm specific (McElheran, 2015). She describes that the amount

of complementary adjustment needed to adapt to new innovations involving “new processes, supporting organizational structures and enabling ICT was difficult to predict and varied widely by firm and by the type of business process innovation they were pursuing” (1200). Our argument is that in order to be effective *ex post*, however, the adoption of firm-specific ICT requires matching investments for co-specialization with other firm-specific resources, such as ICT-trained employees or ICT-supported distribution network. Furthermore, *ex post* of adoption, more complex types of ICT that have features of enhancing coordination and information sharing would become less valuable if the partnering units’ ICT systems are not compatible.

Even after adoption of ICT, more complex types of ICT requires coordinated effort between transacting parties for optimizing the benefits. Moreover, complexity may lead to increased interdependence between transacting parties due to the need to implement similar customization of technology. Thus given that firms have already adopted ICT, it is more likely that higher degree of complexity in the ICT is associated with more internal integration in order to ensure maximization of benefits from ICT adoption. Thus we hypothesize the following:

Hypothesis 1: All else being equal, the more complex the type of ICT adopted, the more likely it is to facilitate increased integration between internal firm units.

Electronic Codifiability of the Production Process

Industry characteristics may influence the scope and nature of the impacts of ICT adoption on a firm’s internal vs external integration. One of the main barriers to externalization is the non-codifiable nature of tasks and production specifications along with specific customization requirements of the product. Industries in which the production process lends itself to fragmentation would benefit from the adoption of ICT in locating the lowest cost producers for each chain of its various production stages. For certain industries, for instance, Sturgeon (2002) describes how production processes are broken down into distinct value chains, whereby linkages are achieved between the chains via the transfer of codified information.

Technological innovations in manufacturing processes, such as the introduction of computer-aided design (CAD) and computer-aided engineering (CAE) software, have made it possible for the firm to translate manufacturing designs and specifications

into electronic formats, and share production requirements and designs (Fort, 2013) with other firms. For firms in these industries that are able to make use of CAD and CAE technologies to break up their production into smaller and simpler tasks by codifying product specifications, it is possible to minimize leakage of crucial proprietary knowledge by choosing to outsource certain intermediate input production to external suppliers and maintain in-house the production of intermediates that have higher intellectual property content. From an external supplier’s viewpoint, the codifying process addresses hold-up problems by reducing the cost of customization significantly, resulting in greater diversification of the supplier’s risk and reducing costs of being a “hold-up hostage” to each buying firm. Then, ICT adoption in industries where the production process is easily codified into electronic formats eases the outsourcing process by finding the lowest cost producer in the market place. We propose the following:

Hypothesis 2: All else being equal, the higher the degree of electronic codifiability of the production process of the MNE’s industry, the more likely it is to experience increased outsourcing following ICT adoption.

DATA

Sample

We use four confidential micro data sets sourced from the US Census Bureau – ASM that includes the CNUS, Census of Manufactures, LFTTD, and the Longitudinal Business Database (LBD) – in order to carry out the analysis. In what follows below, we describe the steps to construct our analysis data set and then we describe our variables of interest in detail.

ICT data

In order to measure ICT adoption within a firm, we utilize the 1999 survey addendum to the US Census’s Annual Survey of Manufacturers called the CNUS. The CNUS is a unique data set due to its wealth of detail on the firm’s networking technologies at the plant level and its national representativeness as an addendum to a legally required Census survey. The survey was intended primarily to measure electronic commerce (e-commerce) over computer-mediated networks (Messénbourg, 2001). Our measure of ICT captures computer networking technologies that can be used to communicate with

and share information between both internal and external parties, and is therefore ideally suited for our analyses. In particular, we use the first question in the CNUS that asks if the responding establishment uses various types of computer networks: Internet, intranet, extranet, Local Area Network (LAN), Electronic Data Interchange (EDI). The associated variables in the survey data are separate indicator variables that take on a value 1 if the plant uses any one of these types of networks, and 0 otherwise. We use the first four indicator variables to create an overall ICT measure, described shortly.

We consider LAN, Internet, intranet, and extranet as Internet-enabled network technologies since these technologies accompanied the commercialization of the Internet and therefore would have been unlikely to have diffused widely prior to 1995. We utilize the information if a firm uses EDI in robustness checks as a control for the existence of previous network technology. The CNUS sample consists of about 38,000 plants belonging to about 22,000 firms; together, they account for more than half of manufacturing employment and output in the United States at the time (US Census Bureau, 1999).

Intra-firm trade transactions data

We link the computer network data to a firm's international merchandise trade transactions in the LFTTD. We focus on intra-firm trade shares because of the absence of detailed plant-level trade data in the annual surveys or censuses of manufacturing. The LFTTD is a transaction firm-linked database linking the universe of individual merchandise trade transactions, both exports and imports, to the US firms that make them. We use information on the value, date of transaction, and the categorical variable that indicates whether a trade transaction took place between related parties or not. Exporting parties are related when either owns 10% or more of the other party, whereas for imports, the threshold for related party is 5% under US Code 19, §1401a(g). Ruhl (2013) discusses the comparability of the intra-firm trade measure derived from merchandise trade transactions data compared with that derived from Bureau of Economic Analysis (BEA) surveys and finds them mostly similar. The related party variable has previously been used to identify multinational activity by Bernard, Jensen, and Schott (2009) and Nunn and Trefler (2013) among others.

We first select firms in the LFTTD that are present in both 1992 and 1999, since we adopt a difference-in-differences methodology requiring us to follow changes in intra-firm trade shares within a firm

between two time periods. Then we merge the resulting data set to the CNUS data. The CNUS data is first aggregated at the firm level prior to the merge, and we describe the details of the aggregation method below. We further restrict our analysis sample to firms that operate in the manufacturing sector, since CNUS was sent to manufacturing establishments only. Using the LBD, which consists of data on all existing establishments that have at least one paid employee in the US non-farm, private economy (Jarmin & Miranda, 2002), we identify the primary two-digit sector – manufacturing, retail, wholesale trade, or others – in which a firm operates. Since multi-unit firms may operate in several sectors of the economy, the firm is considered to be operating in the sector that houses the largest share of its total employment. We find that 94% of all firms in the merged LFTTD and CNUS data sets operate in the manufacturing sector. This results in our analysis sample of 5850 unique firms that engaged in international trade – related party, unrelated party, or both – in 1992 and 1999.

Measures

Dependent variable

Since we are interested in the firm's make or buy decisions across international borders, we operationalize the foreign boundary choice of MNEs between in-house and arm's length production by utilizing information on (1) intra-firm trade between US parents and their foreign affiliates as well as between foreign-controlled US affiliates and their foreign parent groups; and (2) inter-firm trade between US parents and other non-affiliated parties as well as between US affiliates of foreign parents and other non-affiliated parties.² Specifically, the dependent variable is the change in intra-firm trade as a share of total trade value at the firm level between 1992 and 1999. We construct intra-firm trade shares using both import and export transactions in the LFTTD. The numerator is the sum of total exports and imports of the firm that are conducted between related parties, and the denominator is the sum of total exports and imports that the firm conducts between both related and unrelated parties. Our proposed measure allows us to contrast intra-firm and arm's length trade flows (Hipple, 1990). In particular, it is measured in levels as:

$$IF_{it} = (\text{Exports}_{irt} + \text{Imports}_{irt}) / (\text{Exports}_{it} + \text{Imports}_{it}), \quad (1)$$

where i indexes firm, r related party, and t year. The variable used in our empirical specification is therefore given by:

$$\Delta IF_i = IF_{i,1999} - IF_{i,1992} \quad (2)$$

Note that our explicit assumption here is that the firm has already made a decision whether or not to engage in foreign production. We do not model the decision of a firm to become a multinational.

Independent variables

Our explanatory variable of interest is a firm-level measure of ICT adoption, ICT_{it} , bounded between 0 and 1. We first create an indicator variable, $Network_{jt}$, that takes on a value 1 if plant j has any one of the target types of Internet-enabled computer networks – the Internet, LAN, intranet, or extranet – and 0 otherwise. This variable takes on a value of 0 for all plants in 1992 following the assumption of little or no diffusion of Internet-enabled ICT pre-1995. Since none, few, or all of the plants belonging to a firm may adopt ICT, in order to create a firm-level measure of ICT adoption, we weigh this indicator variable by the plant's share in total firm employment as follows:

$$ICT_{i,1999} = \sum_{j=1}^n \left(\text{Employment}_{j,1999} / \text{Employment}_{i,1999} \right) * \text{Network}_{j,1999}, \quad (3)$$

where j indexes manufacturing plants belonging to firm i , and a firm may have n number of plants. For a single-plant firm and multi-plant firm where all its plants adopt an Internet-enabled network technology, the employment weight is one. Approximately, 85% of the firms in our analysis sample are multi-plant firms, and in about half of these firms, some but not all of their plants adopt a network technology. Therefore we create an employment weighted measure of network adoption at the firm level. We also carry out robustness checks to ensure that our results are not being driven by this particular weighting scheme. In particular, we re-run our base specification on a sample of single-plant firms only as well as multi-plant firms where all of the plants belonging to the firm adopt ICT. Finally, our dependent variable of interest, assuming all plants in 1992 had not adopted Internet-enabled ICT, is as follows:

$$\Delta ICT_i = ICT_{i,1999}. \quad (4)$$

In order to evaluate Hypothesis 1, we appeal to Forman (2005) in ranking the various types of networking technologies as simple or more complex.

Forman (2005) considers basic Internet access as simple while complex technologies include business-to-customer and business-to-business e-commerce. Following this logic, we rank the computer networks reported in CNUS in ascending order of complexity as Internet and all other Internet applications for e-commerce, namely, LAN, intranet, and extranet. $Internet_{it}$ is measured as in (3) where $Network_{jt}$ takes on a value 1 if a plant chose Internet as the type of network used as indicated in Question 1. We create similar measures as in (3) for LAN, intranet, and extranet separately. Then we create an indicator variable, $Ecommerce\ Applications_{it}$, that takes on a value of 1 if a firm has any of the following – LAN, intranet, or extranet – and 0 otherwise. Finally, we have our measures of interest similar to (4) as $\Delta Internet_i$ and $\Delta E-commerce\ Applications_i$, respectively.

Although Internet is the largest computer network by definition, because of its global scope, it cannot be customized by the firm. The other three types of networks allow restricted access to various parties depending on the firm's goals. LAN is a private network that links computers at a single location, such as at an office building. Intranets and extranets are both far more complex than LAN. Extranets allow controlled access – typically to customers or suppliers but also to geographically dispersed divisions of a company – from outside of an organization's intranet. We consider the Internet as the simplest type of network since no particular control or access infrastructure are required, while the rest are increasingly more complex in their configurations relative to the Internet.

To assess the degree of electronic codifiability of the production process in industry k , $Codifiability_k$, we calculate the fraction of plants in a six-digit North American Industrial Classification System (NAICS) industry that used integrated CAD or CAE business processes in 1999. Therefore this measure does not vary over time. We utilize Question 7, Part C, Number 1, in the CNUS to construct the share of plants in an industry that uses CAD/CAE relative to plants that did not use CAD/CAE and had no plans to use it by 2002, following Fort (2013). Both CAD and CAE are computer-aided processes that may be used to translate manufacturing designs and specifications into electronic formats. Therefore $Codifiability_k$ measures the intensity of CAD/CAE use in an industry and captures the relative degree to which industry production processes can be fragmented and codified into electronic formats.

Table 1 Summary statistics (1992 and 1999)

Variable name	Variable description	Mean (standard deviation)	
		1992	1999
ICT	1 if a firm adopts an Internet-enabled computer network 0 otherwise	NA	0.666 (0.323)
Types of ICT			
Internet	1 if a firm adopts Internet 0 otherwise	NA	0.574 (0.367)
E-commerce applications	1 if a firm adopts LAN, intranet, or extranet 0 otherwise	NA	0.852 (0.355)
Intra-firm Trade Share	Intra-Firm (Exports + Imports)/Total Trade	0.133 (0.239)	0.143 (0.237)
Intra-firm Export Share	Intra-Firm Exports/Total Trade	0.072 (0.158)	0.074 (0.149)
Intra-firm Import Share	Intra-Firm Imports/Total Trade	0.061 (0.166)	0.070 (0.169)
Initial Age	Firm Age as of 1992	12.568 (5.551)	NA
Labor Productivity	Total Value of Shipments/Total Employment	159.041 (214.421)	224.45 (236.553)
Observations		5850	5850

Notes: Internet-enabled computer networks are defined as Internet, LAN, extranet, or intranet from Question 1 in the CNUS. Total trade refers to both exports and imports. Number of observations rounded to the nearest integer for disclosure avoidance.

Control variables

We additionally include firm specific variables of age as of 1992, Initial Age_{*i*}, and change in labor productivity between 1999 and 1992, ΔLaborProductivity_{*i*}, to control for experience and productivity of the firm. We obtain information on firm age from the LBD. For firms with multiple plants, age is calculated as the difference between the year of interest and the year of establishment of its oldest plant. We consider age as of 1992, since in our difference-in-differences specification, the change in age will be a constant 7 years for all firms. Labor productivity is measured as total value of shipments per employee and we measure the change between 1992 and 1999. Firm-level measures of shipments and employment are constructed as the sum of these respective variables over all plants belonging to the firm. The plant-level data on the value of shipments and employment in 1992 and 1999 is sourced from the 1992 Census of Manufactures and the 1999 ASM, respectively.

Table 1 provides summary statistics of all our main variables in 1992 and 1999. We can see that about 67% of the firms in our sample adopt ICT. This share varies by the various types of ICT. About 57% of the firms adopt the Internet, while a larger share, 85%, adopt the LAN, intranet, and/or extranet. The table also provides the average intra-firm trade shares further differentiated by exports and imports. We see that in 1992, 13% of total trade is intra-firm in nature for an average firm in our sample with about an even split between intra-firm exports and imports. This share rises to over 14% by 1999. Finally, average age as of 1992 of a firm in our sample is about 13 years and average labor productivity

increases from \$159,000 per employee to \$224,000 per employee between 1992 and 1999.

ECONOMETRIC MODEL

We use a fixed effects panel data model as in Forman and McElheran (2012), thus implementing a difference-in-differences identification strategy. We have a simple set-up with two time periods, 1992 and 1999, and two distinct groups of firms, those that adopt ICT (treated firms) and those that do not (control firms). We compare the share of intra-firm trade in overall trade prior to adoption of ICT to the share after adoption, and relative to those that do not adopt ICT. Thus the first difference is the difference in intra-firm trade shares between 1992 and 1999 and the second being the difference between ICT adopters and non-adopters. Our key identification assumption is that diffusion of Internet-enabled ICT was not widespread among firms prior to 1995 (Forman et al., 2005). Therefore we choose the earliest year for which trade data is available as the pre-period, 1992, at which time all firms, following previous studies (Forman et al., 2005; Forman & van Zeebroeck, 2012), are assumed to have no or narrowly diffused Internet-enabled ICT technology.

Our empirical approach removes firm-level time-invariant characteristics that may be correlated with both ICT adoption and intra-firm trade shares. However, time-varying firm characteristics such as productivity may influence the decisions to simultaneously engage in intra-firm trade and adopt ICT. We include controls for firm productivity and age to address such concerns about omitted variables.

Table 2 Correlation matrix (1992 and 1999)

Variable	(1)	(2)	(3)	(4)	(5)	(6)
1. Change in Intra-firm Trade Share	1.00	—	—	—	—	—
2. Change in ICT	0.035	1.00	—	—	—	—
3. Change in Internet	0.029	0.868	1.00	—	—	—
4. Change in E-commerce applications	0.038	0.739	0.619	1.00	—	—
5. Initial Age	-0.022 ^a	0.016 ^b	0.010 ^c	-0.018 ^a	1.00	—
6. Change in Labor Productivity	0.049	0.088	0.085	0.136	-0.019 ^a	1.00
Observations	11,700					

^aSignificant at 5% level.

^bSignificant at 10% level.

^cNot significant. Number of observations rounded to the nearest integer for disclosure avoidance.

Notes: All pairwise correlations are significant at the 1% level, unless otherwise noted.

Since we estimate a two period difference-in-differences model, we implement the following regression equation:

$$\Delta IF_i = \beta_1 \Delta ICT_i + \beta_2 \Delta Labor Productivity_i + \beta_3 Initial Age_{i,1992} + \Delta \varepsilon_i, \quad (5)$$

where Δ denotes change between t and $t-1$ such that $\Delta IF_i = IF_{i,1999} - IF_{i,1992}$ represents change in intra-firm trade shares between 1999 and 1992 and similarly for the explanatory variables. We rely on the data to reveal the sign of β_1 .

For testing Hypothesis 1, we separately include specific measures of ICT, that is, $\Delta Internet_i$ and $\Delta E-commerce Applications_i$ as follows:

$$\Delta IF_i = \beta_1 \Delta Internet_i + \beta_2 \Delta Labor Productivity_i + \beta_3 Initial Age_{i,1992} + \Delta \varepsilon_i, \quad (6a)$$

$$\Delta IF_i = \beta_1 \Delta Ecommerce_i + \beta_2 \Delta Labor Productivity_i + \beta_3 Initial Age_{i,1992} + \Delta \varepsilon_i, \quad (6b)$$

Abstracting from the initial decision of whether or not to adopt ICT, the ability to maximize the benefits of having complex ICT systems would be easier between two parties that have more integration and coordination, and thus favor in-house production, which should be reflected in increased intra-firm transactions relative to arm's length. Thus we hypothesize that the sign of β_1 will be larger in Eq. (6b) compared with Eq. (6a).

To assess Hypothesis 2, the extent to which the impact of ICT on intra-firm trade shares varies in industries with varying degrees of electronic codifiability, that is, propensity to codify product specifications in an electronic format, and thus easily communicate with parties in foreign locations, we

run the following specification:

$$\Delta IF_i = \beta_1 \Delta ICT_i + \beta_2 \Delta ICT_i * Codifiability_k + \beta_3 \Delta Labor Productivity_i + \beta_4 Initial Age_{i,1992} + \Delta \varepsilon_i, \quad (7)$$

where the industry codifiability measure is constructed based on the fraction of plants in an industry, k , that used CAD/CAE software in their production process in 1999. Our interest is in the interaction term and we expect β_2 to be negative.

RESULTS

Baseline Results

Table 2 presents a correlation matrix of the main variables over our sample period. Since we employ changes over time in our empirical specifications, we provide correlations between the change measure of a variable rather than in levels, except for initial firm age that is calculated as of 1992. We find that ICT and each of its types separately are positively and statistically significantly correlated with changes in intra-firm trade shares. The overall ICT adoption measure is highly correlated with the adoption of the Internet and other e-commerce applications. This is not surprising given that our overall ICT measure is comprised of the Internet, LAN, intranet, and extranet.

In Table 3 we present regression results to examine the net effect of ICT on MNE foreign boundary choices. The estimates reported in the tables reflect the average difference in intra-firm trade shares between ICT adopters and non-adopters, net the initial difference in the pre-period. The first column of Table 3 displays results from specification (5). We see that overall ICT adoption at the firm level is associated with a 1.8 percentage point increase in intra-firm trade shares compared with those MNEs

Table 3 Difference-in-Differences regressions explaining intra-firm trade shares: The role of ICT

Variable	(1)	(2)	(3)
ICT	0.018** (0.006)		
Types of ICT			
Internet		0.026** (0.005)	
E-commerce applications			0.032*** (0.005)
Initial Age	-1.030* (0.000)	-0.022* (0.000)	-0.021* (0.000)
Labor Productivity	0.033** (0.000)	0.046** (0.000)	0.044** (0.000)
Observations	11,700	11,700	11,700

Notes: Significance level: * if $p < 0.05$; ** if $p < 0.01$; *** if $p < 0.001$. Robust standard errors in parentheses. All regressions are estimated in first differences; initial age included in levels. Columns (2) and (3) report β coefficients. Age and Labor Productivity coefficients multiplied by 1000 for ease of interpretation. Number of observations rounded to the nearest integer for disclosure avoidance.

that do not adopt ICT, net of the difference in the initial period. Our result suggests that, for MNEs operating in the US manufacturing sector, ICT-induced internal cost reductions outweigh external cost reductions, thus favoring internal cross-border transactions over external ones.

To test Hypothesis 1, we consider various types of ICT separately in Columns 2 and 3 following specifications (6a) and (6b), respectively. We find that more complex Internet-enabled ICT tends to have a larger impact on internal cross-border transactions, as exhibited by increased intra-firm trade shares. In order to compare the magnitudes of the coefficients on our Internet and e-commerce application variables, we compute and report β coefficients. β coefficients refer to how many standard deviations a dependent variable will change, per standard deviation increase in the explanatory variable, thereby allowing us to compare the magnitude of coefficients across different regression specifications. We find that the β coefficient on the Internet variable is 0.026 while the e-commerce applications variable is 0.032. This implies that a one standard deviation change in Internet use is associated with an increase of 0.026 in intra-firm trade shares, while the increase is 0.032 when considering e-commerce applications. These findings together provide support for Hypothesis 1, in that more complicated forms of ICT adoption that require simultaneous investments in ICT infrastructure encourage more internal firm activities, highlighted by increased trade between internal firm units relative to arm's length trade.

Next, Table 4 presents the results evaluating Hypothesis 2 following specification (7). The number of firms in the analysis sample is reduced because we were not able to create a measure of electronic codifiability for every six-digit NAICS represented in our sample. As predicted, the degree of electronic codifiability in an industry dampens the impact of

Table 4 Difference-in-Differences regressions explaining intra-firm trade shares: The role of ICT and industry electronic codifiability

Variable	(1)
ICT	0.021*** (0.007)
ICT \times Codifiability	-0.002† (0.001)
Initial Age	-0.066 (0.000)
Labor Productivity	0.033** (0.000)
Observations	11,640

Notes: Significance level: † if $p < 0.10$, * if $p < 0.05$; ** if $p < 0.01$; *** if $p < 0.001$. Robust standard errors in parentheses. All regressions are estimated in first differences; initial age included in levels. "Codifiability" is measured as the share of plants that use CAD/CAE technology in a six-digit NAICS industry. Age and Labor Productivity coefficients multiplied by 1000 for ease of interpretation. Number of observations rounded to the nearest integer for disclosure avoidance.

Internet-enabled ICT adoption on intra-firm trade. Although ICT adoption itself is associated with higher intra-firm trade shares, in industries more prone to electronic codifiability of its production process, this effect is muted.

In all our specifications, the coefficients on the firm-level control variables of age and labor productivity are similar. Initial firm age is negative and statistically significant implying that older firms in our sample tend to experience decreased intra-firm trade over the sample period. The coefficient on labor productivity is positive and statistically significant implying that changes in firm productivity are positively correlated with changes in intra-firm trade shares.

Robustness Checks

We conduct several robustness checks to further test for simultaneity bias and to check whether our results are sensitive to sample selection. In order to address concerns that firms may proactively adopt ICT in anticipation of enhancing intra-firm or arm's length trade, we re-run our baseline specification



using information on a firm's use of EDI. EDI is an older and proprietary network technology used to exchange documents between businesses in a standardized format. It is one of the choices of computer networks included in Question 1 of the CNUS. The existence of EDI indicates prior investments in information and communication technology at a firm. As Forman (2005) finds, one of the important factors determining likelihood of Internet adoption is prior network investment. We re-run our baseline results controlling for the existence of EDI that is constructed as outlined in Eq. (3) and find that results still remain quantitatively and qualitatively unchanged.

Due to the aggregation of plant-level data to the firm level, the results may be influenced by the weighting mechanism that we employ. To account for that, we re-run our econometric specifications on a sample consisting of only firms that are single plants in the United States. The reasoning here is that we are not using any weights in constructing the ICT measures, since the firm and plant is synonymous. The results are virtually identical to those using the whole sample including both multi- and single-plant firms. Next, in cases where only a few plants within multi-plant firms adopt ICT, the identification of adoption vs non-adoption at the firm level is not strict. Thus we impose a stricter definition of adoption and non-adoption, similar to considering single-unit firms only, but including only multi-plant firms where all or none of its plants adopt ICT. In this subsample, the explanatory variable is a purely categorical variable that takes on a value 1 when all plants within a firm adopt ICT and 0 if none of the plants within a firm adopt ICT. The results are robust to these sample variations.

It could also be the case that ICT has a stronger influence on certain functions within the firm. The CNUS includes various questions about the stage of the production process that utilizes ICT. We follow the survey's breakdown in areas of plant operation (Question 7): purchasing, orders of manufactured products, production management, logistics, and communication and support services. Under each of these categories, the adoption of ICT is positive and statistically significant with respect to its relationship with intra-firm trade shares. The results support Keane and Feinberg's (2007) finding that improvements in logistics encouraged intra-firm trade between US parents and their Canadian affiliates. Yet more importantly, it also highlights that logistics is not the only area of production that was affected by ICT adoption and subsequently a firm's intra-firm

trade patterns. We find that the adoption of ICT to carry out each of these functions has a positive effect on intra-firm trade shares.

Since we can distinguish between related party exports and related party imports in our data, we further explore the role of imports or exports in driving the overall results. To this end, we rerun the regressions using only intra-firm exports as a share of total trade, and then separately using only intra-firm imports as a share of total trade. The results again are statistically significant and similar to those using total intra-firm trade shares, suggesting that ICT adoption impacted both intra-firm exports and imports similarly. All robustness check results are available upon request.

We acknowledge that even after conducting the above-discussed robustness checks, the difference-in-differences methodology implemented in this article may be subject to endogeneity concerns. In particular, aside from controlling for prior technology investment at a firm, we are not fully able to control for all time-varying factors that may simultaneously impact ICT adoption and intra-firm trade shares. However, in the absence of a longer panel of the CNUS or other similar surveys, we utilize this unique data to provide valuable insights into the impact of ICT adoption on foreign boundary choices for a group of early technology adopters.

DISCUSSION AND CONCLUSIONS

We analyzed the impact of ICT adoption on MNEs' foreign boundary choices. Through the lens of transactions cost theory, we argue that the choices of arm's length and intra-firm trade within the MNE are not mutually exclusive, but rather complementary. ICT can lower search and communications costs between the focal firm and both its internal and external trading partners. However, we highlight that as the complexity of the adopted ICT increases, it requires matching capabilities and mutual commitment in the trading partner's ICT adoption, hence increasing the likelihood of intra-firm trade. At the same time, ICT adoption tends to favor external transactions in industries where the production processes are readily translated into electronic formats. For firms operating in these industries, ICT adoption facilitates the fragmentation of production processes. This breaking up of the production process into smaller value chains allows the firm to control the extent of intellectual property shared at each stage of the production and to partner with the least cost provider at each juncture of the supply chain, thus creating more channels of

contracting with external partners. Regression results confirm our hypotheses.

Our findings contribute to two main strands of literature, that is, one on information technology and firm boundaries, and a second one on offshoring and global value chains. While the first strand has been intensively studied in the domestic context (Bloom et al., 2014; Brynjolfsson, Malone, Gurbaxani, & Kambil, 1994; Forman & McElheran, 2012), the link to the international dimension of firm boundary has received less attention (exceptions are Feinberg & Keane (2006), Keane & Feinberg (2007), Rangan & Sengul (2009)). In the burgeoning literature on offshoring and global value chains (Gereffi, Humphrey, & Sturgeon, 2005), most existing studies implicitly and explicitly make the assumption that ICT developments and adoption have contributed to the process of the slicing and dicing of the production chain. In this article we establish a specific link between Internet-enabled ICT adoption and intra-firm trade shares. Our *within* firm-level measures of detailed ICT adoption and trade patterns allows analysis at a highly disaggregated level that can account for the heterogeneity in ICT adoption. Moreover, our relatively early period of study coincides with the first significant wave of Internet-enabled ICT adoption (Forman et al., 2005; Forman & van Zeebroeck, 2012) that is still the basis for many types of ICT that are being introduced today. Since these types of Internet-enabled technology had just become available around that time period, our analysis provides a valuable benchmark that can act as a baseline and lower bound of the effects of ICT adoption on a firm's global production patterns. Our results also show that the propensity for fragmented production in industries favors outsourcing by firms following ICT adoption. The advent of CAD and manufacturing has been proposed as an explanation for the relative intensity with which activities stay within the confines of the firm boundary and the subsequent nature of trade patterns (Helpman, 2006). Our results highlight that ICT adoption acts as a catalyst to exploit the extent to which production processes may be translated into electronic formats leading to more complex trade patterns, with the caveat that we focus on a sample of firms operating in the US manufacturing sector.

Having highlighted the contributions of our study, we acknowledge that more remains to be done. The explicit assumption that firms have already decided on foreign production limits our results in that we focus solely on the intensive margin decision – how much does intra-firm trade change

following ICT adoption. Our study is silent on the role of ICT adoption on the extensive margin decision – should a firm choose to become or cease to exist as a multinational. We are not alone, however, in making this assumption. Feinberg and Keane (2006) employ data from the Benchmark and Annual Surveys of US Direct Investment Abroad administered by the BEA, which contains the population of US-based MNEs, thus, by virtue of being included in this data set, a firm must be an MNE. Rangan and Sengul (2009) make use of industry-level data set of US manufacturing MNEs in their study of ICT and transnational integration. Future studies could explore the timing of both ICT adoption and becoming an MNE.

Moreover, our sample period represents a time in which US manufacturing sectors adopted major, yet basic, Internet-enabled ICT advancements that changed production processes in fundamental ways. Future research examining current developments in ICT and the effect of more sophisticated technologies on firm's foreign boundary choices could build on the insights from our results. Recent developments in digital manufacturing – such as additive manufacturing, continuous manufacturing, collective manufacturing, crowdsourcing, cloud computing and cloud manufacturing, and 3D printing – have revolutionized production processes and created new outlets for global value chain production. In particular, future studies could examine how specific types of ICT adoption may lead to upgrading of the global value chain and affect global value chain governance (see Gereffi et al., 2005 for a comprehensive overview of global value chain). As ICT itself is subject to constant changes and development, it would be worthwhile to assess the effects of more recent developments in ICT on MNEs' boundary choices, which we leave for future research.

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NOTES

¹References to specific companies in the text are based on public information.

²Although we cannot distinguish between US and foreign MNEs in the trade transactions data, about

70% (60%) of intra-firm exports (imports) are between US parents (foreign parents) and their foreign affiliates (US affiliates) in 1992 and 1999 (Zeile, 2003).

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ABOUT THE AUTHORS

Wenjie Chen is an Assistant Professor of International Business at the School of Business at George Washington University. She holds a PhD in Economics from the University of Michigan. Her area of research is in foreign direct investment, cross-border mergers and acquisitions, trade, and applied economic methods.

Fariha Kamal is a Senior Research Economist at the Center for Economic Studies at the US Census Bureau. She has a MBA from Clark University and PhD in Economics from Syracuse University. Her research interests are in the areas of international trade, development, and economic geography.

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