LUDWIG-
MAXIMILIANS-
UNIVERSITÄT
MÜNCHEN

VOLKSWIRTSCHAFTLICHE FAKULTÄT

Fromenteau, Philippe:

Information Technology and Global Sourcing

Munich Discussion Paper No. 2016-11

Department of Economics
University of Munich

Volkswirtschaftliche Fakultät
Ludwig-Maximilians-Universität München

Online at https://doi.org/10.5282/ubm/epub.29631

Information Technology and Global Sourcing

Philippe Fromenteau*

July 2016

Abstract

This paper examines how IT influences global sourcing decisions. It develops a theoretical model to study how IT determines the decisions of firms located in the high-wage North whether to offshore production to a low-wage country in the South. Offshoring to South however is subject to costly communication reflected by partially incomplete contracting. More sophisticated IT allows more efficient communication between the Northern headquarter and its Southern intermediate input supplier and alleviates contractual frictions. The model provides several predictions about the impact of IT on the organization of the global supply chain. Complex industries for which codifiability and verifiability of information is a much harder task, are more likely to source intermediate inputs in countries with more efficient IT infrastructure. Considering the mode of firm organization, more efficient IT infrastructure is expected to reduce the share of intra-firm trade in more complex industries. These predictions are examined and validated using disaggregated industry-level trade data. Most importantly, these findings are robust to controlling for well-known sources of comparative advantage and determinants of firm organization such as factor endowments, financial development and contract enforcement.

Keywords: Information Technology, Global Sourcing, Multinational Firm, Firm Organization, Tasks

JEL classification: D23, F14, F23, L23, O33

*Philippe Fromenteau, Department of Economics, LMU Munich, Ludwigstraße 28, 80539 Munich/ Germany, Philippe.Fromenteau@econ.lmu.de

1 Introduction

The substantial growth in trade in intermediates throughout the last two decades is widely considered as a defining feature of the process of globalization. Trade in intermediates occurs both within and across the boundaries of the firm, as firms fragment production and organize their production activities on a global scale. As a result, countries do not specialize in the entire production of final goods but increasingly contribute to overall production by specializing in specific stages of the production process and providing partitions of value added. This trend in international vertical specialization and the rise of trade in intermediates has been subject to a considerable amount of research.[1] What lies behind this breaking up of the production process across borders is the reduction in the costs of offshoring due to revolutionary advances in information and communication technology. The continuous emergence of more efficient technologies of information transmission has enabled the expansion of multinational firms by codifying and communicating complex information in order to transfer technologies abroad. Nevertheless, international costs of communication still have a profound influence on the patterns of trade (see Fink, Illeana, and Neagu (2005)). As such, evidence points out that foreign investment is sensitive to geographic distance and thereby responds strongly to the costs of international knowledge transfer when making location decisions (see Yeaple (2009) and Keller and Yeaple (2013)).[2] Yet, the forces unleashed by new information technologies and their impact on the patterns of global sourcing have not been studied so far.

This study examines the impact of the advances of information technology on the organization of the vertical supply chain. In order to guide empirics, the paper develops a partial equilibrium model describing the decision of firms located in the high-wage North, whether to offshore production to a low-wage country in the South. Offshoring to the South however gives rise to costly communication. The costs of information transmission are reflected by the amount of contractual distortions which arise when production is offshored. More effi-

[1] See Campa and Goldberg (1997), Feenstra (1998), Grossman and Rossi-Hansberg (2006), Hummels, Ishii, and Yi (2001) and Yeats (2001) amongst others.

[2] While Yeaple (2009) finds total affiliate sales to decline with distance from the US headquarter, Keller and Yeaple (2013) explain this finding with increased costs at which heaquarter knowledge can be transferred to more distant affiliates.

cient information technology reduces the costs of communication and thereby the degree of contractual incompleteness. The model illustrates how the propensity to relocate production to a specific destination country increases with its level of information technology infrastructure. Assuming that vertical integration is subject to lower costs of communication than arm's-length contracting, the model demonstrates how information technology increases the scale of contracting with indendent input suppliers and thus reduces the share of intra-firm trade. Since the transmission of complex information relies to a greater extent on successful codification, the effects of information technology are stronger in more complex industries characterized by a larger degree of contractual incompleteness. These empirical predictions are tested and validated using disaggregated trade data on the operations of US industries.

The model draws on the theory of the product cycle by Antràs (2005) and features a world of two countries, the high-wage North and the low-wage South. A headquarter firm located in North needs to decide whether to purchase intermediates from a Northern or Southern manufacturer in order to produce a final good. Whenever the headquarter firm engages in offshoring to South, communication costs arise which vary with the degree of complexity of the intermediate input and take the form of additional labor costs. Production processes comprising complex inputs are assumed to be more susceptible to effective communication. In order to illustrate the degree of complexity of the intermediate good, the paper introduces partially incomplete contracting on behalf of the manufacturing firm. Complex intermediates are characterized by a larger portion of complex tasks and activities that cannot be perfectly specified in a contract. Thus, more complex products and higher costs of communication are reflected by a greater degree of contractual distortions. More sophisticated information technology, represented by lower production costs in complex components, alleviates contractual frictions. As a result, more effective information technology increases incentives of firms to shift production to South in order to exploit lower wages. Overall, the model predicts industries to be more likely to import intermediates from countries with a higher level of information technology where the effect is supposed to be increasing in product complexity.

Next, the model deals with the impact of information technology on the organization of the multinational firm. Following the property-rights approach, asset ownership determines the bargaining power throughout ex-post renegotiation and determines the ex-ante incentives of each party to invest. Outsourcing provides the manufacturer with larger incentives to invest but is related to larger costs of communication than integration. When deciding about the optimal mode of organization, the headquarter firm therefore has to trade off the contractual distortions arising due to costly information transmission with outsourcing and the incentives provided to the manufacturing firm. More effective information technology reduces the scale of communication costs and increases the incentives to opt for independent subcontracting. Again, this effect is stronger for more complex inputs.

The model's predictions are tested in the empirical section of the paper. The main measure for the adoption of information technology is based on the international internet bandwidth by country.[3] Product complexity at the industry level is measured by making use of task level data. Production processes that require more complex and non-routine activities involve less codifiable information thereby implying higher costs of knowledge transmission. I therefore use data on the specific work activities in each industry in order to estimate the intensity with which a sector employs non-routine tasks in the production process. Evidence of the impact of information technology on the geography of offshoring is based on the number of intermediate goods by industry that the US imports from South. In order to assess the impact on the mode of organization, I use data on the share of intra-firm imports as a fraction of total Southern imports to the US.[4] Since the empirical predictions relate to the interaction of information technology infrastructure and product complexity, the estimations follow a generalized difference-in-differences strategy including sector fixed effects as well as country-year-fixed effects. Identification is therefore with respect to within country variation across industries. This approach allows restricting the set of controls to variables which influence the level of information technology infrastructure as well as the intensity in non-routine tasks and might affect sourcing strategies of US firms. In line with the empirical prediction, the econometric analysis shows that the impact of information technology on the number of

[3] More precisely, I use the international internet bandwidth (kbit/s) per internet user.

[4] A country is defined as Southern if GDP per capita (at PPP) is lower than 50% of the US level in the year 2000.

imported intermediates is increasing with product complexity. In addition, the share of intra-firm imports decreases with the level of information technology with the effect being strongest for more complex industries. Comparing two industries that differ in one standard deviation in terms of product complexity, a one standard deviation change in information technology yields a positive differential effect of $2,35\%$ in the number of imported intermediates and a negative differential effect of $1,11$ percentage points in the share of intra-firm trade. These results are robust to well known determinants of offshoring, multinational firm organization and the patterns of specialization. Amongst others, effects remain significant when controlling for factor endowments as well as for institutional determinants such as financial development or judicial quality. Moreover, results are robust to the inclusion of measures for overall economic development as well as trade openness. Additionally, several robustness checks are performed in order to validate the results. Results hold when using alternative measures of information technology adoption as well as when employing alternative estimation techniques. Besides, I replace my measure of product complexity with an alternative measure reflecting the intensity in routine tasks by industry. Consistent with the predictions, the coefficients point to a reverse pattern with the effect of information technology decreasing in routine intensity.

The paper relates to several literatures. Firstly, the paper contributes to the literature on the costs of international knowledge transfer and the organization of knowledge in multinationals. Keller and Yeaple (2013) find large barriers for US multinationals to transferring knowledge from headquarter to affiliate. Similarly, Oldenski (2012b) finds US multinationals to be more likely to offshore production stages abroad the more intensively they employ routine tasks and the less intensively they are in communication. Moreover, Costinot, Oldenski, and Rauch (2011) identify the non-routine quality of production tasks as a source of contractual frictions between the multinational headquarter and its supplier. Their results show that intra-firm trade tends to be decreasing in more routine intensive industries. Antràs, Garicano, and Rossi-Hansberg (2006) study the organization of knowledge in cross-country teams and Antràs, Garicano, and Rossi-Hansberg (2008) consider the interaction of host country communication technology and human capital. Secondly, the paper relates to the literature on the determinants of global sourcing. Whereas previous literature concentrates on the impact of intellectual property rights (e.g. Ethier and Markusen (1996) and Javorcik (2004)), financial development (e.g. Carluccio and Fally (2012)), factor intensities (e.g. Antràs (2003)) and contract enforcement (e.g. Antràs and Helpman (2008) and Nunn and Trefler (2008, 2013)) I focus on the role of digitization in altering the global sourcing decisions of multinationals. Besides, the paper is based on a large literature which introduces the property-rights theory of the firm to international trade theory in order to study the organization of multinationals (e.g. Antràs and Helpman (2004) and Antràs (2005)).[5] Thirdly, several researchers have addressed the effect of the internet on trade flows. Freund and Weinhold (2002, 2004) assess the impact of the internet on international trade in services and goods. Higher internet penetration is associated with both, an increase in growth in services and bilateral goods trade. Ultimately, my paper is also related to the literature on the economic consequences of information and communication technology. Abramovsky and Griffith (2006) consider the role of information and communication technology in outsourcing and offshoring of business services. Bloom, Garicano, Sadun, and van Reenen (2014) deal with the differential impact of information and communication technology on the autonomy of employees within firms and Baker and Hubbard (2003, 2004) analyze the impact of the adoption of new information technologies on organizational changes in the trucking industry. This paper aims to contribute to these various strands of literature by studying how the advances in information technology affect the organization of the multinational firm along the global supply chain.

Section 2 introduces a simple model of offshoring and the role of information technology. Section 3 presents the data, the empirical strategy and the results of the econometric analysis. Section 4 offers some concluding comments.

[5] See Antràs (2013) and Antràs and Yeaple (2015) for a survey about the literature on incomplete contracts and the organization of multinational firms.

2 A Simple Model of Information Technology and Global Sourcing

2.1 Setup

Based on the theory of the product cycle by Antràs (2005), this section develops a simple partial equilibrium model in which contractual frictions illustrate how information technology determines the offshoring decisions of Northern firms and affects the international organization of production.

The world consists of two countries, North and South. Labor is the only factor of production in order to produce a single good y and cannot move across borders. The wage rate in the North is denoted by $w^N$and in the South by w^S. Throughout the model, wages in North are higher than in the South $w^N > w^S$.

2.1.1 Preferences

Consumer preferences are given by a standard CES utility over a range of final goods given by

$$U = \int_0^N \log \left[\int_0^{n_j} y_{j(i)}^{\alpha} di \right]^{\frac{1}{\alpha}} dj, \ \ 0 < \alpha < 1. \tag{1}$$

Total consumption of variety i in industry j is given by $y_{j(i)}$. N is the number of industries in the economy and n_j is the number of varieties in industry j. Varieties enter the utility function symmetrically with an elasticity of substitution equal to $\epsilon = {}^1\!/\!_{(1-\alpha)}$. The elasiticty between industries is one. Demand by the representative consumer for any variety $y_{j(i)}$ is therefore given by

$$y_{j(i)} = \lambda_j p_{j(i)}^{-1/(1-\alpha)}, \ \ \lambda_j = \frac{1}{N} \frac{E}{\int_0^{n_j} p_{j(i)}^{-\alpha/(1-\alpha)} di}, \tag{2}$$

where $p_{j(i)}$ is the price and λ_j is a function of total income and an aggregate price index taken as given by the consumer.

2.1.2 Production

Consider the production process of a final good i in industry j. Production of any final good $y_{j(i)}$ consists of two steps: It requires the provision of headquarter services such as engineering and marketing represented by a special and distinct high-tech input h, and it necessitates final assembly and production described by a special and distinct low-tech input m, provided by a manufacturing firm. It is assumed that the headquarter engages in a contract with an independent manufacturing firm. Output is produced using a Cobb-Douglas production function given by

$$y_{j(i)} = \left(\frac{h_{j(i)}}{1 - z_j}\right)^{1-z_j} \left(\frac{\exp\left(\int_0^1 \log m_{j(i)}(s)\, ds\right)}{z_j}\right)^{z_j}, \ 0 \leq z_j \leq 1, \tag{3}$$

where the parameter z_j describes the output elasticity of the manufacturing process m of the final good. The relative intensity of manufacuring z_j can also be interpreted as the degree of standardization of the final good in industry j. The larger z_j, the less significant are headquarter activities such as engineering and other problem solving services and the more standardized the good is. Production of one unit of a high-tech input requires the employment of one unit of Northern labor. The South however, is much less efficient at producing the high-tech input. By assumption, the productivity advantage of the North is sufficiently high enough to ensure that headquarter services are always located in the North. Labor requirements for the production of one unit of low-tech input are assumed to be equal to 1 in both North and South. High- and low-tech input are relationship-specific and have to fit precisely the needs of its counterpart, otherwise no positive output can be produced.[6] In order to focus on the impact of information technology and communication costs on the provision of inputs, headquarter services h are not subject to costly transmission of information and fully non-contractible.

The specialized manufacturing input m is produced with a set of activites indexed by points on the interval $[0, 1]$.[7] Activities related to input $m(s)$ in the range $[0, \mu_s]$ where $0 \leq \mu_s \leq 1$ are

[6] An input designed to fit with a particular headquarter or manufacturing firm cannot be employed in the production of other varieties. Therefore, they are useless outside the relationship.

[7] See Antràs and Helpman (2008) and Acemoglu, Antràs, and Helpman (2007).

considered as basic tasks which are fully contractible. Activities in the fraction $(\mu_s, 1]$ represent complex tasks wich are non-contractible and due to a hold-up problem when investment costs are already sunk. Complex tasks may be either of good or bad quality which cannot be verified ex-ante. If they are of bad quality, total output of the final good y is zero. The nature of non-contractible activities is only resolved when investments are already made. If non-contractible investments are of bad quality, production costs can be neglected. Both inputs h and m can be freely traded and no transport costs accrue. Altogether, the parties engage in a partially incomplete contract leading to a two-sided hold-up problem. Thus they need to bargain about the joint surplus created by the relationship.

In order to successfully implement final assembly of the final good engineered by the headquarter firm, both parties need to communicate. As a result communication costs $\Gamma > 1$ arise. So as to reflect the fact that international production sharing is associated with higher costs of communication than domestic fragmentation, it is assumed that communication costs only occur if the manufacturing firm is located in South. Communication costs Γ however are only related to the set of complex and non-contractible activities $(\mu_s, 1]$ on behalf of the manufacturer. Following Keller and Yeaple (2013) communication costs Γ take the form of additional labor requirements in Southern labor and are incurred by the Southern manufacturer. Higher costs of communication result in a less efficient production process associated with larger costs expressed as larger labor requirements. Most importantly, I assume that more sophisticated information technology reduces the costs of communication and coordination Γ.

Before a headquarter decides to produce a high-tech input it needs to decide whether to engage in a relationship with a manufacturing firm located in the North or to opt for an international fragmentation of the production process and contract with a manufacturing firm in the South. The timing of events characterizing the contract is the following: The headquarter first offers potential manufacturing firms a contract defining the manufacturer's required investment in contractible activities $\{m(s)\}_0^\mu$ and an upfront lump-sum transfer T.[8] Hence, the contract stipulates the investment levels for the contractible activities but does not specify the investment levels in the remaining $(1 - \mu)$ non-contractible activities. The manufacturing firm

[8] The transfer T can be either positive or negative.

may therefore choose to withhold its services in these activites from the headquarter firm. By assumption, there is a large pool of potential applicants, such that competition among them makes T adjust such that the final manufacturing firm exactly breaks even. The ex-ante outside option of manufacturing firms is normalized to zero in both countries. Subsequently, the manufacturer chooses its investment level in contractible activities and both, the headquarter and the manufacturer independently decide about their non-contractible investments h and $m(s)$ where $s \in (\mu, 1]$. Ultimately, the resulting output is sold, and the Nash bargaining leaves each party with one-half of the revenues (i.e. the quasi-rents).

By assumption, the setting is one of complete contracts if the manufacturing firm is located in the North.[9] However, the relationship turns into an partially incomplete contract in case of international fragmentation of production.[10] The headquarter decides whether to engage with a manufacturing firm in North or South by maximizing its ex-ante expected profits. Whenever manufacturing takes place in the South the two parties bargain over the surplus after inputs have been produced. Following Antràs (2005) the parties conduct ex post symmetric Nash bargaining and equally share the rents created by the relationship. If the parties fail to agree on the bargaining outcome, both receive nothing.

Overall, costs of international fragmentation are incorporated by contractual frictions which mirror the imperfect transmission of information across borders. More efficient information technology reflected by lower costs of communication Γ reduces these distortions.

2.2 Partial Equilibrium

This section considers the choice of the final-good producer of variety i in industry j whether to source inputs from an independent supplier located in North or South. As noted earlier, wages in South are assumed to be lower than in the North $w^N > w^S$. However, whenever production occurs in South, contracts are partially incomplete and communication costs occur.

[9]Whenever the manufacturing stage is located in the North it is assumed that the headquarter firm can hire an outside party in order to enforce a quality-contingent contract which monitors the ex-ante investments in non-contractible investments h and $m(s)$ where $s \in (\mu, 1]$.

[10]If international production sharing occurs, no third party can observe whether the inputs provided are of good or bad quality and no quality-contingent contract can be written. Likewise, no outside party can control the size of ex ante investments of the manufacturing firm and no contracts can be written contingent on revenues earned when the final good is sold.

2.2.1 Production by a Manufacturing Firm in the North

If the headquarter decides to fragment production domestically and engage in a relationship with a Northern manufacturer, both parties can write a complete contract.[11] The contract stipulates production levels of headquarter and manufacturing services such that the headquarter's ex-ante profits are maximized. Considering the transfer T , the headquarter's profits are given by $\pi^N(z) = \lambda^{1-\alpha} \left(h/_{1-z} \right)^{\alpha(1-z)} \cdot \left(m/_z \right)^{\alpha z} - hw^N - mw^N$. Maximizing with respect to h and m results in ex-ante profits for the headquarter given by

$$\pi^N(z) = (1-\alpha)\lambda \left(\frac{w^N}{\alpha} \right)^{-\alpha/(1-\alpha)}. \quad (4)$$

2.2.2 Production by a Manufacturing Firm in the South

Whenever transaction occurs between a Northern headquarter and a manufacturer in the South, the contract stipulates the investment levels in contractible activities $m(s)$, $s \in [0, \mu]$, and the lump-sum transfer T. Overall, if non-contractible inputs are of good-quality, and bargaining does not fail, revenues are given by $R = \lambda^{1-\alpha} \left(h/_{1-z} \right)^{\alpha(1-z)} \cdot \left(m/_z \right)^{\alpha z}$. Due to relationship-specificity, the inputs have no value outside the relationship and the outside option of every player is zero. Therefore, if bargainig fails, output is zero and so are revenues. Symmetric Nash bargaining gives each party its outside option plus one-half of the ex-post gains from the relationship (i.e. the difference between the sum of the player's payoff under trade and their sum under no trade). The payoffs of the headquarter firm and the manufacturer are therefore given by $0.5R$.[12] Since both parties do not capture the full surplus created by the relationship, this induces both parties to underinvest relative to a setting with Northern manufacturing and complete contracts. The game is solved by backwards induction. Rolling back in time, the headquarter and manufacturing firms first choose their investment levels in non-contractible activities. The firms' optimization problems are given by

[11] Complete contracts are not subject to ex-post renegotiation since investment levels in headquarter h and complex manufacturing activities $m(s)$, $s \in (\mu, 1]$, are specified and can be controlled by a third party.

[12] Note that $0 + 0.5(R - 0 - 0) = 0.5R$.

$$\max_{h}\ 0.5\lambda^{1-\alpha}\left(\frac{h}{1-z}\right)^{(1-z)\alpha}\left(\frac{\exp\left(\int_0^1 \log m(s)ds\right)}{z}\right)^{z\alpha} - w^N h \tag{5}$$

$$\max_{\{m_s\}_\mu^1} 0.5\lambda^{1-\alpha}\left(\frac{h}{1-z}\right)^{(1-z)\alpha}\left(\frac{\exp(\int_0^1 \log m(s)ds)}{z}\right)^{z\alpha} - \Gamma w^S \int_\mu^1 m(s)ds, \tag{6}$$

subject to contractible investments $m(s),\ s \in [0, \mu]$. The first order conditions can be simplified to describe the equilibrium investments

$$m(s) = \frac{z\alpha 0.5R}{w^S\Gamma}\ ,\ s \in (\mu, 1] \tag{7}$$

$$h = \frac{(1-z)\alpha 0.5R}{w^N}. \tag{8}$$

Obviously, larger costs of communication Γ create an additional distortion and reduce the amount of investment in complex activities of the manufacturing firm.

From there, the amount of revenues given contractible investment levels can be calculated and one can solve for investments in non-contractible activities on behalf of the headquarter h and the manufacturing firm $m(s)$ where $s \in (\mu, 1]$

$$m(s)^{1-\alpha(1-\mu z)} = \lambda^{1-\alpha}\alpha\xi_z^\alpha\left(\exp\left[\int_0^\mu \log m(s)ds\right]\right)^{\alpha z}\left(\frac{0.5(1-z)}{w^N}\right)^{\alpha(1-z)}\left(\frac{0.5z}{w^S\Gamma}\right)^{1-\alpha(1-z)} \tag{9}$$

$$h^{1-\alpha(1-\mu z)} = \lambda^{1-\alpha}\alpha\xi_z^\alpha\left(\exp\left[\int_0^\mu \log m(s)ds\right]\right)^{\alpha z}\left(\frac{0.5(1-z)}{w^N}\right)^{1-\alpha(1-\mu)z}\left(\frac{0.5z}{w^S\Gamma}\right)^{\alpha(1-\mu)z}. \tag{10}$$

Larger costs of communication Γ lower the investments in complex tasks of the manufacturing firm and reduce joint revenues. This gives rise to a negative feedback effect on headquarter activities which equally drop due to the presence of costly communication. The distortion created by costly information transmission declines with the range of basic activities μ and increases with the range of complex activities $(1-\mu)$. The contract offered by the headquarter needs to satisfy the manufacturer's participation constraint which is equal to

$$0.5R - w^S \int_0^\mu m(s)ds - w^S \Gamma \int_\mu^1 m(s)ds + T \geq 0, \tag{11}$$

where non-contractible activities in the range $(1-\mu)$ are given by equation (9) and contractible investments h and $m(s)$, $s \in [0, \mu]$, are as specified in the contract. The headquarter in turn maximizes its payoff

$$0.5R - w^N h - T \ , \ s \in (\mu, 1]. \tag{12}$$

The transfer T is set such that the manufacturer exactly breaks even and its participation constraint is binding. For this reason, the optimization problem of the headquarter firm with respect to contractible manufacturing investments reduces to

$$\max_{\{m(s)\}_\mu^1} \pi = R - w^N h - w^S \int_0^\mu m(s)ds - w^S \Gamma \int_\mu^1 m(s)ds. \tag{13}$$

Combining this with non-contractible activities given in equation (9) and (10) one can solve for contractible investments on behalf of the manufacturing firm and derive profits. Profits of the headquarter are finally equal to

$$\pi^O = (1-\alpha)\lambda \left[\alpha^\alpha w_N^{-\alpha(1-z)} w_S^{-\alpha z} \Gamma^{-\alpha z(1-\mu)} \frac{0.5^{\alpha\theta} \left(1 - \alpha 0.5\theta\right)^{(1-\alpha\theta)}}{(1-\alpha\theta)^{(1-\alpha\theta)}} \right]^{\frac{1}{1-\alpha}}, \tag{14}$$

where $\theta = (1 - \mu z)$. Profits decline with less efficient information technology Γ. This effect is larger for more standardized production processes relying to a greater extent on efficient manufacturing and for intermediates containing a larger fraction of complex investments.

2.3 Information Technology and Offshoring

When deciding whether to produce in North or South, the headquarter firm has to trade off the benefits of free information transmission in North with the costly information transmission in South for a given wage differential between both regions. By comparing profits of Northern and Southern manufacturing it follows that the headquarter will decide to purchase the low-tech input in the South only if $\pi^S \geq \pi^N$ and $A(z, \mu, \Gamma) \leq \omega \equiv {}^{w^N}/_{w^S}$, where

$$\frac{w^N}{w^S} \geq \left(\frac{(1-\alpha\theta)^{(1-\alpha\theta)}}{0.5^{\alpha\theta}\,(1-\alpha 0.5\theta)^{(1-\alpha\theta)}} \right)^{\frac{1}{z}} \Gamma^{(1-\mu)} \equiv A(z, \mu, \Gamma). \tag{15}$$

It can be shown that $A(z, \mu, \Gamma)$ is decreasing in the degree of standardization z with $\lim_{z \to 0} A(z, \mu, \Gamma) = +\infty$ and $A(1, \mu, \Gamma) > 1$. If wages in North are larger than in South $w^N > w^S$, a threshold level of standardization $\overline{z} \in (0, 1)$ arises: As long as $z < \overline{z} \equiv A^{-1}(\omega, \mu, \Gamma)$ final assembly is located in the North. If $z > \overline{z} \equiv A_O^{-1}(\omega, \mu, \Gamma)$ holds, final assembly takes place in the South. Hence, only when the final good is sufficiently standardized and the manufacturing stage sufficiently important in production, lower wages in the South are able to outweigh contractual frictions and communication costs.[13] Most importantly, the required wage differential $\omega \equiv \frac{w^N}{w^S}$ for a specific threshold level $\overline{z}$ of standardization increases with larger costs of communication Γ. This effect is stronger for final goods which exhibit a larger range of complex activities $m(s)$, $s \in (\mu, 1]$.

2.4 Information Technology and the Mode of Firm Organization

Given that the final good producer decides to produce in South, it may now integrate the manufacturing firm and engage in FDI. Consider the same setup as in the previous section. However, it is now assumed that communication costs do not arise in case of vertical integration whereas contracting with an independent manufacturer in South is subject to costly communication.[14] This assumption is meant to reflect that offshoring is connected with less

[13] Note that if wages were identical in North and South, manufacturing would always take place in North.

[14] See Defever and Toubal (2013) for recent research in international trade wich combines the incomplete contracting approach to the theory of the firm with similar key elements of the transaction cost approach by Williamson (1985).

efficient communication if the headquarter opts for outsourcing than in case of integration. This can be justified, as whenever production of intermediates occurs within the boundaries of the firm, the headquarter may fully exert control over the Southern manufacturer and thus align the modes of communication in North and South. It may for instance substitute managers in South by managers from North and improve the efficiency of knowledge transmission. Ownership dictates the residual rights of control over assets. As given in Antràs (2005), if the manager of the manufacturing plant refuses to trade after investments have been conducted, the headquarter manager may fire the manager in South and take possession of the amount of intermediates produced by the manufacturing plant. Failed bargaining is costly and firing the manufacturing manager is associated with a loss in the amount of the output produced equal to $(1-\delta)y$ with $\delta < 1$. The final good producer can then only generate sale revenues equal to $\delta^{\alpha}R$. This yields quasi rents given by $(1-\delta^{\alpha})R$. Consequently, the headquarter firm chooses its optimal investment level with respect to anticipated revenues $0.5(1+\delta^{\alpha})R$ whereas the manufacturing firm sets basic and complex investments with respect to $0.5(1-\delta^{\alpha})R$. Accordingly, outsourcing provides the manufacturing firm with a larger share of the joint surplus $(0.5R > 0.5(1-\delta^{\alpha})R)$ for which reason it faces larger incentives to invest in the joint relationship than with integration. Therefore, ex ante efficiency requires to prefer outsourcing over integration whenever the manufacturing firm becomes relatively more important in the production process (i.e. z increases).[15] This however relates to additional distortions due to costly information transmission which in turn gives advantage to integration. Solving the game along the lines of section 2.2 yields profits of the headquarter firm given by

$$\pi^{VI} = (1-\alpha)\,\lambda\left[\alpha^{\alpha} w_N^{-\alpha(1-z)} w_S^{-\alpha z}\frac{0.5^{\alpha\theta}\,(1-\delta^{\alpha})^{\alpha(1-\mu)z}\,(1+\delta)^{\alpha(1-z)}\,\triangle^{(1-\alpha\theta)}}{(1-\alpha\theta)^{(1-\alpha\theta)}}\right]^{\frac{1}{1-\alpha}}, \qquad (16)$$

with $\triangle = [1-\alpha 0.5\,(\theta+\delta^{\alpha}\,(1-z\,(2-\mu)))]$ and $\theta = (1-\mu z)$. Thus, the headquarter firm

[15] The reverse pattern holds for the headquarter firm which faces a larger fraction of the joint surplus under integration compared to outsourcing $(0.5\,(1+\delta^{\alpha})\,R > 0.5R)$. The headquarter firm therefore has larger incentives to invest if both parties integrate. Thus, ex ante efficiency implies that integration is preferred over outsourcing if the headquarter firm is relatively more important in the relationship (i.e. z is low).

has to trade off the efficiency loss due to costly information transmission with the level of incentives provided to the manufacturing firm when choosing between integration and arm's-length contracting. The trade-off is governed by the relative importance of the manufacturing firm and the costs of information transmission. An increase in the relative importance of the manufacturer favors outsourcing whereas larger costs of information transmission promote integration. This effect is exacerbated by a wider range of complex activities. Considering the choice between offshoring via FDI and arm's-length contracting, it can be inferred that production of intermediates will take place in South within the boundaries of the firm whenever $\pi^{VI} > \pi^{O}$. This can also be written as

$$A^*(z,\mu,\Gamma) \equiv \left(\frac{(1-\delta^\alpha)^{\alpha z(1-\mu)} (1+\delta^\alpha)^{\alpha(1-z)} \triangle^{(1-\alpha\theta)}}{(1-\alpha 0.5\theta)^{(1-\alpha\theta)}} \right)^{\frac{1}{\alpha z}} \Gamma^{1-\mu} \geq 1. \tag{17}$$

$A^*(z,\mu,\Gamma)$ is decreasing in the manufacturing intensity z with $\lim_{z\to 0} A^*(z,\mu,\Gamma) = +\infty$ and $A^*(1,\mu,\Gamma) > 1$ for all $z \in (0,1)$. Hence a cutoff $z^* \in (0,1)$ arises. Whenever $z < z^*$ the headquarter opts for integration. If the manufacturing firm is sufficiently important in the production process and $z > z^*$ the headquarter prefers outsourcing.

2.5 Empirical Predictions

The impact of information technology in the partial equilibrium model has direct implications for the optimal sourcing strategies of industries. In the first instance firms offshore production in order to exploit differences in labor costs across countries. The model alludes that the overall pattern of offshoring might be affected by the necessity to transmit information between the headquarter in North and its manufacturing counterpart in South. Hence, by considering varying degrees of complexity across industries, the model illustrates how information technology leads to differential effects across industries which depend to a different extent on knowledge transmission.

Consider now the impact of information technology on the choice whether to source inputs in South in equation (15). Taking the derivatives of the log of the $A(z,\mu,\Gamma)$-curve with respect to communication costs Γ and the degree of complexity of the final good μ yields

$$\frac{\partial \ln A(z,\mu,\Gamma)}{\partial \Gamma} > 0 \ \ , \ \ \frac{\partial \ln A(z,\mu,\Gamma)}{\partial \Gamma \partial \mu} < 0. \tag{18}$$

Hence, an increase in the costs of communication Γ shifts the $A(z,\mu,\Gamma)$-curve to the right as for any given relative wage $\frac{w^N}{w^S}$ industries shift production to the South only at a higher level of relative importance of the manufacturing firm z (i.e. a later stage of standardization). This effect is dampened, the larger the range of basic activities μ and the smaller the range of complex activities $(1-\mu)$ in an industry. Overall, considering an increase in the costs of communication, the new equilibrium threshold level $\bar{z}$ at which offshoring occurs has increased. Considering the reverse case of more efficient information technology: A reduction in the cost of communication and coordination reduces the cutoff level $\bar{\bar{z}}$ at which an industry offshores production to the South. More efficient information transmission alleviates contractual frictions in South and thereby permits international fragmentation of production at lower levels of manufacturing intensity z.[16] Figure 1 depicts the impact of an increase in the efficiency of information technology $\Gamma' < \Gamma$ for a varying degree of product complexity $\mu^{\circ} < \mu$ on the cutoff level $\bar{\bar{z}}$ at which an industry starts to offshore production. A reduction in the costs of communication $\Gamma' < \Gamma$ shifts the $A(z,\mu,\Gamma)$-curve to the left and lowers the cutoff level $\bar{z}$. This effect however is stronger for the more complex industry characterized by a smaller fraction of contractible activities $\mu^{\circ} < \mu$. By emphasizing differences in complexity across industries and differences in information technology infrastructure across countries, the model can be used to derive a prediction about the geography of offshoring.

Prediction 1 *Industries are more likely to import inputs from a country with a higher level of information technology infrastructure. This effect is more pronounced for more complex industries.*

Turning towards the mode of firm organization, less sophisticated information technology increases the costs of outsourcing and favors vertical integration. Since costly communication

[16] An alternative interpretation would be that more efficient information technology allows for international fragmentation of production at an earlier stage of the life cycle of a product. Thus, advances in information technology shift comparative advantage in manufacturing from North to South and speed up the product cycle.

applies only to the complex fraction of inputs, this effect drops with the level of basic activities μ and increases with the range of complex activities $(1-\mu)$:

$$\frac{\partial \ln A^*(z,\mu,\Gamma)}{\partial \Gamma} > 0 \ , \ \frac{\partial \ln A^*(z,\mu,\Gamma)}{\partial \Gamma \partial \mu} < 0. \tag{19}$$

Hence, the cutoff level of standardization z^* at which firms adapt their mode of organization increases and more firms purchase intermediate inputs within the boundaries of the firm. Figure 2 displays the reverse case of an increase in the efficiency of information technology $\Gamma' < \Gamma$. More efficient information technology reduces the costs of outsourcing and shifts the $A^*(z,\mu,\Gamma)$-curve to the left. Thus, distortions created by information transmission are reduced for which reason outsourcing becomes the more viable mode of organization at even lower levels of importance of the manufacturing process z. Again, the effect is stronger for the more complex industry featuring a smaller fraction of contractible activities $\mu^{\circ} < \mu$ as a larger range of complex activities reinforces the distortions of costly communication. From there I can conclude:

Prediction 2 *Outsourcing is more likely to occur in countries with a higher level of information technology infrastructure. This effect is more pronounced for more complex industries.*

3 Empirical Evidence

This section first describes the data used to test the predictions of the model. Subsequently, I assess how information technology determines the geography of offshoring. Last, I estimate the impact of information technology on the sourcing mode. Several robustness checks are included within each of the empirical sections. Testing the empirical predictions requires in first instance data on North-South vertical offshoring, the degree of product complexity and the level of information technology.

3.1 Data Description

3.1.1 Global Sourcing

Estimations with respect to the geography of offshoring *(Prediction 1)* are based on trade data provided by the NBER.[17] This data provides a detailed documentation of the entire set of industries and countries exporting to the US up to the 10-digit level of the Harmonized System (HS). In order to focus on North-South trade and follow the setup of the model, I restrict the set of trading partners to countries located in the South, where I follow Romalis (2004) and define the South to be any country with per capita GDP (at PPP) lower than 50% of the US level in the year 2000. In addition, so as to measure vertical offshoring and trade in intermediates, I make use of the end-use classification established by the Bureau of Economic Analysis and drop all final goods and raw materials following Feenstra and Jensen (2012). The proxy variable to model the geography of offshoring is given by the number of intermediate goods per industry that a country exports to the US. This is because in the model *Prediction 1* and the geography of imports captures the extensive margin of offshoring. A good is defined as a 5-digit SITC category and an industry is classified by a 4-digit NAICS category.[18] The focus of the analysis is on the years 2002 - 2006.

Estimation of the impact of information technology on firm organization *(Prediction 2)* is based on related party trade data collected by the US Census Bureau. US cross-border shipments are required to report whether a transaction occurs between related parties such that the data covers almost the entire universe of related party shipments. The data reports both, the scale of related party (intra-firm) and non-related party (arm's-length) US imports. A related party transaction is defined as a transaction between two parties in which one owns at least 6% of the outstanding voting stock or shares of its counterpart. A shortcoming of the data is that it is not possible to infer whether the US importer is a US parent firm or a foreign-based affiliate. Nunn and Trefler (2013) investigate all headquarter-subsidiary pairs for

[17] See Feenstra, Romalis, and Schott (2002).

[18] See Basco (2013) for recent research using a similar approach in order to quantify the number of imported goods by industry. In the econometric analysis industry fixed effects control for the fact that the number of goods may be varying in different industries.

global multinationals for which the headquarter firm or the subsidiary are from the US. They find that for a large range of countries the US can commonly be considered as the headquarter. Moreover, countries for which this turns out not to be the case are mostly developed countries. Therefore, once more I concentrate on North-South trade and drop all trading partners if per capita GDP (at PPP) is lower than 50% of the US level in the year 2000. I follow Nunn and Trefler (2008, 2013) and Bernard, Jensen, Redding, and Schott (2010) and compute the share of related party imports by industry and country to the US in order to measure the degree of vertical integration of the offshoring activities of an industry. Alternatively, for the purpose of further robustness tests, I construct a dummy variable which indicates whether the share of intra-firm trade is above the 90% percentile of the distribution. Estimation is again at the 4-digit NAICS level and for the years 2002 - 2006.

3.1.2 Country Variables

The level and efficiency of information technology infrastructure is measured by the international internet bandwidth (kbit/s) per internet user derived from the ICT indicators database provided by the International Telecommunication Union (ITU). International internet bandwidth refers to the capacity that backbone operators provide to carry internet traffic. As such, the international bandwidth represents the maximum quantity of data transmission from a country to the rest of the world. An internet connection with a larger bandwidth can move a given amount of data much faster than an internet connection with a lower bandwidth. Thus, countries with a higher international internet bandwidth (kbit/s) per internet user are characterized by a more efficient information technology infrastructure.[19] Table 4 in the appendix presents the top and bottom 10 countries in information technology infrastructure in the data. In my robustness tests I also employ various alternative measures of information technology adoption. First of all, I rescale the level of international internet bandwidth (bit/s) with the population in order to account for country size. Moreover, I directly exploit the share of internet users per 100 people (ITU) as well as the number of secure internet servers per 1 mil-

[19]This approach is similar to Freund and Weinhold (2002, 2004) who use the number of top-level host domain names in order measure the adoption of information technology at the country level.

lion people (World Bank). While internet users provide extensive information about internet adoption in developing countries, secure servers protect data from unauthorized interception and reflect the security level of online transactions within the local information technology network.

I introduce several controls in order to take account of prior research on the determinants of offshoring. There is a considerable amount of research which studies the role of financial frictions on trade and investment. Carluccio and Fally (2012) study the impact of access to external finance on French multinationals and find evidence, that financial development provides comparative advantage in the supply of complex products and promotes arm's-length contracting relative to intra-firm imports. Similar evidence has been produced by Beck (2003) and Manova (2013) who demonstrate how financial frictions act as a source of comparative advantage and affect firms' export decisions at the micro-level. I follow the literature and concentrate on the share of financial resources provided to the private sector (i.e. loans, nonequity securities, trade credits) as a share of GDP. The variable is procured from the Global Financial Development Database provided by the World Bank.

Similarly, a related strand of literature emphasizes the quality of the contracting environment ('rule of law') as a further source of comparative advantage and determinant of multinationals' organization. Levchenko (2007) and Nunn (2007) find that the quality of a country's legal system provides comparative advantage in contract intensive industries. According to Antràs and Helpman (2008) judicial quality also affects the decision whether to integrate the foreign production facility. The measure for the rule of law is taken from Kaufmann, Kraay, and Mastruzzi (2010). I also control for the level of intellectual property rights since firms might refrain from offshoring and outsourcing sensitive production processes in countries featuring little protection of intellectual property.[20] The index of patent protection is drawn from Ginarte and Park (1997, 2008).

Next, using data from Hall and Jones (1999) I take account of traditional trade theory and control for factor endowments as determinant of comparative advantage.[21] Moreover, in order

[20] See e.g. Ethier and Markusen (1996).
[21] See Romalis (2004) for recent evidence.

to control for a country's degree of integration into global trade, I use the sum of imports and exports over GDP as measure of openness. Finally, the overall level of economic development is considered by the level of GDP per capita (at PPP). Both variables are drawn from the Word Development Indicators (World Bank).

3.1.3 Industry Variables

The measure for the costs of knowledge transmission and product complexity is based on task level data. Production processes that are based on more complicated activities (i.e. non-routine tasks) are subject to less codifiable information and exhibit higher costs of knowledge transmission between the headquarter and the manufacturing firm. Therefore, they rely to a larger extent on efficient information technology. In the model, more complex production processes being subject to more costly transmission of information, are reflected by non-contractible inputs. Information technology is supposed to ease knowledge transmission and to reduce the inefficiencies generated by contractual incompleteness. I follow the construction of task intensities by Oldenski (2012a,b). Raw data on tasks is taken from the Department of Labor's Occupational Information Network (O*NET) which comprises data on the importance of 277 worker and job characteristics in about 800 occupations. The O*NET data distinguishes between seven broad categories of worker and job characteristics given by abilities, interests, knowledge, skills, work activities, work context and work values. I follow Oldenski (2012a,b) and focus on work activities. So as to match the relevant task measures to the industry level trade data, I aggregate the raw O*NET scores up to the 4-digit NAICS level by combining them with employment data from the Occupational Employment Statistics (OES) provided by the Bureau of Labor Statistics.[22] The importance of a task i in a sector s is given by

$$M_{is} = \sum_{o} \alpha_{so} \ell_{io}, \tag{20}$$

where o denotes occupations and α_{so} is the share of occupation o in an industry s. ℓ_{io} in

[22] The O*NET dataset and the occupational employment shares by the Bureau of Labor Statistics both use 6-digit SOC codes such that both datasources can be combined without any concordance problems.

turn measures the importance of task i in occupation o.[23] Summing over occupations for a given industry yields M_{is} which is an index for the unscaled importance score for a task i in industry s. Ultimately, each raw score is then divided by the sum of scores for each task. This results in an intensity measure for each task i in each industry s:

$$I_{is} = \frac{M_{is}}{\sum_i M_{is}}. \tag{21}$$

Since offshoring activities might likewise influence the task composition of industries, the measure is constructed for the year 2000 which precedes the panel data under investigation. Subsequently, I create a measure of complexity (i.e. non-routine intensity) by computing the average task intensity of 'analyzing data and information', 'developing objectives and strategies', 'interacting with computers', 'making decisions and solving problems', 'provide consultation and advice' and 'thinking creatively'. This procedure is akin to Oldenski (2012a,b). The basic idea is to capture tasks that are sufficiently complex such that they exhibit a low degree of codifiability and high costs of information transmission thereby making the use of information technology more valuable. In order to conduct further robustness checks I also construct a measure of routine intensity by building the average intensity of 'handling and moving objects', 'controlling machines and processes' and 'performing general physical activities'. Table 5 in the appendix displays the correlations between the task intensities and the measures for complexity and routine intensity. As expected, the measures for routine intensive and non-routine intensive tasks are highly negatively correlated.

Moreover, I control for R&D intensity as additional proxy for product complexity. R&D intensity is given by R&D expenditures over sales and taken from Keller and Yeaple (2013). Additionally, I also employ a dummy variable indicating whether an industry represents a high-technology sector. The variable is derived from the Science and Engineering Indicators 2010 by the National Science Foundation and based on the intensity of high-technology employment within an industry. Furthermore, I include data on a sector's contract intensity as developed

[23] ℓ_{io} is a $0-100$ score reported by O*NET in order to measure the importance of each task in each occupation. The data is derived from surveys of individuals in different occupations and normalized to a $0-100$ scale by the Bureau of Labor Statistics.

by Nunn (2007). The variable measures the importance of relationship-specific investments based on the proportion of inputs an industry processes which are not sold on markets or organized exchanges. Thus, an industry which uses a smaller fraction of inputs which are traded on markets exhibits a higher degree of relationship-specificity and is considered more contract intensive.[24]

Ultimately, I control for the skill and capital intensity of industries by using data from the NBER CES Manufacturing Industry Database. Skill intensity is defined as the share of non-production workers in total employment and capital intensity is measured as the capital stock per employee.

3.2 Information Technology and the Geography of Imports

3.2.1 Empirical Strategy and Results

Next, I turn towards the impact of information technology infrastructure on the location choice of Northern firms where to purchase intermediates in South. Following *Prediction 1*, industries are expected to prefer to source inputs from countries providing more sophisticated information technology infrastructure. This effect should increase with the level of product complexity. This implies a difference-in-differences approach.[25] The dependent variable is the number of goods imported to the US by a given industry from a specific country. For this reason I run a count data regression based on a negative binomial distribution. In contrast to the Poisson regression, the negative binomial regression allows for overdispersion and does not assume that the mean and variance coincide.[26] Moreover, I follow Allison and Waterman (2002) who recommend to estimate an unconditional negative binomial regression with dummy variables

[24] I focus on the proportion of inputs of products that are not traded on organized exchanges (differentiated) but which might be reference priced based on the liberal classification of commodities into organized exchange, reference priced, and differentiated by Rauch (1999).

[25] This generalized difference-in-differences approach has been pioneered by Rajan and Zingales (1998).

[26] The Poisson distribution can be considered as a particular case of the negative binomial distribution (see Cameron and Trivedi (2009), Ch. 20 for further explanation).

in order to take account of fixed effects.[27][28] This yields the following estimation equation

$$E\left[N_{cst}|\mathbf{X_{cst}}\right] = exp\left[\beta_1 \times complexity_s \times IT_{ct} + \mathbf{X'_{cst}}\gamma + \mu_s + \eta_{ct} + \varepsilon_{cst}\right]. \qquad (22)$$

The number of goods N_{cst} imported from country c by industry s in year t is regressed on the interaction of sectoral product complexity $complexity_s$ and the level of information technology IT_{ct} reflected by the international internet bandwidth (kbit/s) per internet user in country c in year t. The focus of the empirical strategy is on the interaction terms. Therefore, I include country-year fixed effects η_{ct} that control for country characteristics in a given year that might affect sourcing activities by US industries. In addition, I also control for sector characteristics with sector fixed-effects μ_s. Hence, identification of the coefficient of interest β_1 is across industries and within countries for a given year. The fixed-effects capture the direct effects of the country and industry level variables for which reason the empirical strategy mainly requires to control for variables $\mathbf{X_{cst}}$ that might affect the level of international internet bandwidth (kbit/s) per internet user and that might likewise be correlated with the degree of complexity of industries. According to *Prediction 1*, if information technology influences the decision of firms where to source inputs, the number of imported goods should increase with the complexity of the industry. Thus, the coefficient of interest is expected to be positive. The regressions are based on standard erros which are clustered at the country level. Besides, taking logs on both sides of the estimation equation allows to interpret the coefficients as semi-elasticities.[29]

Table 1 reports the estimation results. Column (1) presents the baseline equation: The international internet bandwith (kbit/s) per internet user is interacted with the measure of complexity which is given by the intensity in non-routine tasks by industry. Consistent with *Prediction 1*, the coefficient is positive and highly significant. Thus, firms relying to a larger

[27] Allison and Waterman (2002) find in their simulations that an unconditional negative binomial regression with dummy variables does not underestimate the standard errors and create the incidental parameters problem.

[28] This approach is similar to Carluccio and Fally (2012) who estimate the impact of financial development and product complexity on the number of multinationals which source intermediates from a specific country.

[29] Taking logs implies that the coefficients reflect the impact of the explanatory variables on the log of the expected number of imported goods.

	negative binomial regression				
	(1)	(2)	(3)	(4)	(5)
Dependent variable:	**number of imported goods**				
complexity_{s} * IT_{ct}	0.0611***	0.0445**	0.0311*	0.0356**	0.0329**
	(0.0180)	(0.0175)	(0.0184)	(0.0144)	(0.0138)
R&D int_{s} * fin devt_{ct}			-0.000211		
			(0.000835)		
high-tech_{s} * patent prot_{c}			0.137*		
			(0.0782)		
contract int_{s} * rule of law_{ct}			1.636**		
			(0.738)		
complexity_{s} * H/L_{c}				0.816*	
				(0.459)	
complexity_{s} * K/L_{c}				-0.00894	
				(0.0577)	
complexity_{s} * cgdp_{ct}					6.02e-06
					(7.00e-06)
complexity_{s} * openness_{ct}					0.00376***
					(0.000974)
skill int_{s} * H/L_{c}		1.122*	0.574	-0.584	0.442
		(0.642)	(0.809)	(1.190)	(0.733)
capital int_{s} * K/L_{c}		0.246	0.231	0.271	0.255
		(0.290)	(0.297)	(0.301)	(0.292)
alpha	0.0903	0.0877	0.0855	0.0877	0.0867
sector FE	yes	yes	yes	yes	yes
country-year FE	yes	yes	yes	yes	yes
Observations	10,014	9,573	9,276	9,573	9,556
log likelihood	-20,942	-20,128	-19,629	-20,119	-20,070
country clusters	86	76	68	76	76

Notes: Robust standard errors clustered by country. The dependent variable is the *number of imported goods*. The coefficient of interest is the interaction of complexity at the sector level $complexity_{s}$ and the level of information technology infrastructure at the country-year level IT_{ct}. Information technology infrastructure is measured by the international internet bandwidth (kbit/s) per internet user. Complexity is measured by the intensity in non-routine tasks by industry (see section 3.1.3 for detailed explanations). For a definition of the covariates see Table 12. *** p<0.01, ** p<0.05, * p<0.1

Table 1: Prediction 1 - Impact of Information Technology and Complexity on the Geography of Imports

extent on knowledge transmission are more likely to invest in countries with better information technology infrastructure. In the following regressions, I subsequently add several control variables which affect multinationals' sourcing decisions and might be correlated with both, the level of information technology as well as complexity. In column (2) I start with capital and skill endowments which are interacted with capital and skill intensity in order to control for Heckscher-Ohlin effects. This results in a drop in the size of the coefficient of interest which nevertheless remains highly significant. Consistent with traditional trade theory, the interaction of skill intensity and skill endowment is positive and significant. This however is not the case for the capital endowment and capital intensity interaction. Further control variables in column (3) include interactions of financial development and the protection of intellectual property rights with R&D intensity and the technology indicator while the rule of law is interacted with contract intensity. These interactions are included because several studies on institutions and trade have stressed the importance of financial development and judicial quality as sources of comparative advantage in R&D and contract intensive industries.[30] Moreover, prior research has emphasized the quality of intellectual property rights as determinant of FDI flows in industrial sectors being sensitive to the protection of intellectual property.[31] The coefficient of interest remains stable in size and significant. Overall, the control variables are in line with economic theory. The interactions of patent protection and the high-technology dummy as well as the interaction of the rule of law and contract intensity are both positive and significant. Hence, these results are in line with previous studies on institution driven comparative advantage. Information technology infrastructure however might be determined by both, a country's skill and capital endowment. In order to take account of this relationship I control for the interactions of skill as well as capital endowment and my measure for complexity in column (4). The coefficient of interest is stable in size and remains significant at the 5% level. The skill endowment interaction is likewise positive and significant, whereas this is not the case for the capital endowment interaction. Ultimately, I aim to control for the overall level of economic development and for a country's integration in the

[30] See e.g. Beck (2003), Berkowitz, Moenius, and Pistor (2006), Nunn (2007), Levchenko (2007) and Carluccio and Fally (2012).

[31] See e.g. Javorcik (2004), Branstetter, Fisman, Foley, and Saggi (2011) and Bilir (2014).

world economy. Therefore I include per capita GDP and openness and interact both measures with product complexity in column (5). The two variables are positively correlated with the international internet bandwidth (kbit/s) per internet user. The additional interaction term based on openness is positive and significant. Most importantly however, the main coefficient for information technology remains unaffected, robust and significant.[32]

The empirical strategy might nevertheless create doubts on the direction of causality. An argument that could be advanced is that US sourcing activities might trigger economic growth which might drive demand for more sophisticated information technology. Similarly, foreign firms might have an incentive to lobby for improvements in local information technology infrastructure. These effects might be systematically driven by complex industries which rely to a larger extent on efficient information transmission. Following this reasoning, the estimated coefficient of interest might therefore be subject to an upward bias induced by reverse causality. The sign of the coefficient would however still be correct and in line with the empirical prediction. Nevertheless, if demand for information technology adoption is independent from sector specific product complexity, these effects are captured by the country-year fixed effects and the coefficient of interest can be interpreted as causal.

Considering the size of the effect of information technology, I compare two industries that differ in one standard deviation in terms of complexity (i.e. intensity in non-routine tasks). Based on the coefficient in column (2), I then calculate the differential effect of a one standard deviation change in information technology (i.e. international internet bandwidth (kbit/s) per internet user) on the number of imported goods. This results in a differential effect of about 2,35%. This appears to be a noticeable effect, given that the effect of skill endowment with respect to industries that differ by one standard deviation in skill intensity is about 3,02%.

3.2.2 Robustness

I perform different robustness checks to test the validity of the results. In Table 7, I estimate the baseline specification with alternative OLS regressions where the dependent variable is the

[32]Throughout all specifications, the estimated overdispersion parameter *alpha* is about 0.08 and the likelihood-ratio test for $alpha = 0$ is rejected. This implies that the variance of the residuals is larger than the mean and the residuals do not follow a Poisson distribution.

logarithm of the number of imported inputs. Additionally, standard errors are now two-way clustered at the country and sector level. Results given in Table 6 indicate that the coefficient of interest remains unaffected. Finally, in order to check that results are not sensitive to outliers, I restrict the sample to the 75% percentile of the distribution of the number of imported goods. This amounts to restricting the maximum number of imported inputs to 6 imported goods. I obtain significant coefficients that are smaller than those in the full sample, reducing the concern of industry-country combinations importing a larger number of inputs driving the results (see Table 8). Table 9 presents various additional specifications based on the negative binomial regression. First of all, in columns (1) to (3) I control for the interaction of institutional determinants and the measure for complexity. The coefficient of interest remains positive and significant. Afterwards I substitute the complexity measure with routine intensity. Following *Prediction 1*, the number of imported goods increases with the level of information technology for more complex inputs. Consequently, the effect of information technology is expected to decrease for industries that are more basic in nature as they rely to a lesser extent on information transmission. The coefficients in columns (4) and (5) are both negative. However, only the former is statistically significant. Finally, throughout columns (6) to (7) I use alternative measures of information technology given by the international internet bandwidth (bit/s), the amount of internet users as well as the amount of secure internet servers relative to the population. The regressions yield a positive and significant coefficient of interest. Altogether, the results confirm that the country of origin's level of information technology is strongly correlated with the number of imported inputs in complex industries compared to basic industries.

3.3 Information Technology and the Mode of Organization

3.3.1 Empirical Strategy and Results

So far, I have tested *Prediction 1* by analyzing the impact of information technology and the complexity of traded intermediates on the number of imported inputs. I now turn towards *Prediction 2* and the effect of information technology on the optimal mode of organization.

Prediction 2 states that more efficient information technology should lead to a larger fraction of arm's-length contracting compared to FDI, with the effect being larger for more complex industries. The dependent variable is therefore now given by the share of intra-firm trade by industry and country in order to measure the optimal organizational mode of an industry. Again, the empirical strategy follows the difference-in-differences approach taken in the previous section. This allows once more to focus on the interaction terms and to control for all unobserved sector characteristics and country characteristics that vary across years by means of fixed effects. The estimation equation is now given by

$$IntraShare_{cst} = \beta_2 \times complexity_s \times IT_{ct} + \mathbf{X'_{cst}}\gamma + \mu_s + \eta_{ct} + \varepsilon_{cst}, \tag{23}$$

where $IntraShare_{cst}$ reflects the share of intra-firm trade, $complexity_s$ denotes the measure of complexity (i.e. intensity in non-routine tasks) and IT_{ct} is the level of information technology represented by the international internet bandwidth (kbit/s) per internet user. In addition, the specification employs sector and country-year fixed effects μ_s and η_{ct} and controls for observable factors $\mathbf{X_{cst}}$ that might have an impact on information technology and product complexity as well as the share of intra-firm trade. Hence, identification is again based on variation across industries within countries for a given year. Following *Prediction 2*, the coefficient of interest β_2 is expected to be negative: Higher levels of information technology resolve contractual frictions in arm's-length relationships by reducing the inefficiencies due to imperfect knowledge transfer and raise the amount of market transactions. The effect is supposed to increase with the complexity of industries. All regressions are based on robust standard errors which are corrected for clusters by sector as well as by country-year combination.

Results are presented in Table 2. As before, the coefficient of interest is the interaction of information technology and product complexity. The coefficient in column (1) is negative and significant. Moreover, the coefficient is robust to the inclusion of the full set of sector and country-year fixed effects as well as to controls for traditional determinants of comparative advantage given by the interaction of relative factor endowments and factor intensities. Hence, a higher level of information technology in the country of origin reduces the share of related

	OLS				
	(1)	(2)	(3)	(4)	(5)
Dependent variable:			**share of intra-firm trade**		
$complexity_s$ * IT_{ct}	-0.0205***	-0.0206***	-0.0167*	-0.0194***	-0.0245***
	(0.00705)	(0.00708)	(0.00842)	(0.00714)	(0.00819)
R&D int_s * fin $devt_{ct}$		-0.000427*			
		(0.000220)			
high-$tech_s$ * patent $prot_c$			-0.0443		
			(0.0414)		
R&D int_s * rule of law_{ct}			0.211***		
			(0.0330)		
contract int_s * rule of law_{ct}			-0.226		
			(0.141)		
$capital_s$ * IT_{ct}				-0.0237	
				(0.0201)	
capital int_s * rule of law_{ct}				0.370**	
				(0.165)	
$complexity_s$ * $openness_{ct}$					0.00107**
					(0.000416)
$complexity_s$ * $cgdp_{ct}$					2.40e-06
					(4.09e-06)
skill int_s * H/L_c	0.121	0.129	0.190	0.104	-0.0589
	(0.165)	(0.166)	(0.234)	(0.163)	(0.194)
capital int_s * K/L_c	-0.0165	-0.0168	-0.0417	-0.0232	-0.0178
	(0.0299)	(0.0302)	(0.0410)	(0.0268)	(0.0301)
sector FE	yes	yes	yes	yes	yes
country-year FE	yes	yes	yes	yes	yes
Observations	10,926	10,926	7,043	10,926	10,915
R-squared	0.286	0.287	0.320	0.287	0.289
sector clusters	85	85	85	85	85
country-year clusters	314	314	192	314	313

Notes: Robust standard errors two-way clustered by sector and country-year. The dependent variable is the *share of intra-firm trade*. The coefficient of interest is the interaction of complexity at the sector level $complexity_s$ and the level of information technology infrastructure at the country-year level IT_{ct}. Information technology infrastructure is measured by the international internet bandwidth (kbit/s) per internet user. Complexity is measured by the intensity in non-routine tasks by industry (see section 3.1.3 for detailed explanations). For a definition of the covariates see Table 12. *** p<0.01, ** p<0.05, * p<0.1

Table 2: Prediction 2 - The Impact of Information Technology and Complexity on the Sourcing Mode

party imports. The relationship is stronger in more complex industries relying to a larger extent on efficient codification and transmission of information. In column (2) I add the interaction of R&D intensity and financial development. The main coefficient of interest remains negative and significant. Besides, the additional control variable is negative and significant and in line with Carluccio and Fally (2012) who find that R&D intensive inputs are more likely to be traded intra-firm from countries with a lower level of financial development. Subsequently, I add controls for further institutional determinants in column (3) by including interactions of the technology indicator, R&D and contract intensity and the level of patent protection and the quality of the legal system. The enforcement of intellectual property rights might drive firms' decisions whether to outsource or integrate if they are subject to technological imitation. Next, firms' organizational decisions might be affected by the quality level of the judicial system. My coefficient of interest reduces in size and loses some of its statistical significance while the number of observations in the estimation drops considerably. Nevertheless, the coefficient remains negative and statistically different from zero in line with *Prediction 2*. The coefficients of patent protection and the interaction of contract intensity and the rule of law are insignificant. The interaction based on R&D intensity and the rule of law however is positive and significant which is in line with the idea of rule of law effects being larger in more contract dependent industries (see Antràs and Helpman (2008)). In column (4) I control for the interactions of capital intensity and information technology as well as the rule of law, respectively. Capital intensity is intended to reflect the headquarter intensity of the industry. The coefficient of interest is unaffected and stays negative and highly significant. This suggests, that the impact of information technology on the sourcing mode is not driven by the overall level of contract enforcement and further institutional determinants. In a final step, I add controls in order to account for the degree of openness of the country of origin and its level of economic development. My main coefficient of interest is again robust to the controls and shows up negative in line with *Prediction 2*.[33]

As in section 3.2.1 my estimation results might suffer from reverse causality. The share

[33] My result of information technology being negatively related with the share of intra-firm trade is consistent with Bloom, Garicano, Sadun, and van Reenen (2014) who find the adoption of information technology at the firm level to be positively associated with more decentralized decision making within firms.

of goods purchased from integrated suppliers by multinational firms might systematically affect the level of information technology adoption where the effect might be induced by more complex industries that are more dependent on sophisticated information technology infrastructure. Nevertheless, it is a priori not clear by what mechanism this might take place for which reason the direction of the potential reverse causality bias is not obvious.

Based on the coefficient in column (1) and a comparison of two industries that differ in one standard deviation in their level of complexity, a one standard deviation increase in information technology creates a negative differential effect of about $1,11$ percentage points in the share of intra-firm trade.

3.3.2 Robustness

I engage in various robustness tests to evaluate the validity of the results (see Table 10). First, I replace the sectoral degree of product complexity with routine intensity. More routine intensive industries are less dependent on efficient information transmission. In this regard, *Prediction 2* implies a positive coefficient of interest. Throughout columns (1) to (3) I control for Heckscher-Ohlin effects as well as institutional determinants. Across all specifications, the new coefficient of interest is positive and significant. Thus, information technology reduces the share of intra-firm trade with a less pronounced effect for routine intensive industries. In columns (4) and (5) I resort again to my main measure of complexity and control directly for the interaction of complexity and institutional determinants. Sign and significance of the main coefficient are unaffected. A possible problem of the estimations so far might be that the dependent variable is given by a share that is bounded between zero and one. Therefore, in column (6) the dependent variable is replaced with a dummy variable indicating whether the share of intra-firm trade is above the 90% percentile of the distribution in order to estimate a linear probability model. Again, the main result is stable showing a negative and significant coefficient of interest.[34]

[34] Replacing the share of intra-firm trade in the baseline regression in Table 2 with the integration indicator as dependent variable yields a negative and significant coefficient of interest throughout all specifications.

4 Conclusion

This paper studies the impact of the advances in information technology on the global sourcing decisions of multinationals. While previous research has found large spatial barriers to knowledge transmission across borders, the impact of the digitization of the business world on the global supply chain has received only little attention.

In order to guide the empirical analysis, I provide a model based on the product cycle theory by Antràs (2005) which illustrates the impact of information technology on the geography of offshoring and the sourcing mode. More sophisticated information technology allows more efficient knowledge transmission between the headquarter firm in North and its supplier in South by alleviating contractual distortions. Overall, imperfect information transmission induces larger disruptions in the production process of more complex industries. This yields two predictions. Firstly, industries which are more intensive in complex and non-routine intensive activities are more likely to offshore parts of their production process to countries with high levels in information technology infrastructure. Secondly, information technology is expected to reduce the share of intra-firm trade with the effect being larger for more knowledge intensive industries. The paper provides empirical evidence in support of these hypotheses by combining data on the number of imported goods and the share of intra-firm imports with data on the international internet bandwidth by country and the intensity in non-routine production activities by industry. The measure of sectoral complexity and non-routine intensity is based on data at the occupational level. The empirical strategy concentrates on the identification of the interaction of information technology and product complexity which allows making use of a generalized difference-in-differences approach with fixed effects along the industry and country-year dimension. Econometric results are in line with the empirical predictions. US firms find it more profitable to offshore the production of complex intermediates to Southern countries with higher levels of information technology infrastructure. In equal measure, information technology creates incentives to engage in arm's-length contracting with the relationship being stronger in more complex industries. Estimates suggest that a one standard deviation change in information technology yields a differential effect of about $2,35\%$ in the number of imported intermediates and a differential reduction of about 1.11 percentage points in the share of intra-firm trade when comparing two industries that differ by one standard deviation in terms of product complexity. The econometric estimates remain persistent in the presence of alternative determinants of the patterns of global sourcing and firm organization such as factor endowments, institutions and economic development.

Altogether, the paper highlights the effects of information technology adoption for the patterns of trade and the mode of firm organization along the global supply chain. Prior research has primarily hinted to the importance of skill endowments as well as contracting and financial institutions in shaping the location decisions of multinationals. Nevertheless, given that the development of human capital and trustworthy institutions takes a long time, the adoption of information technology might be a particularly viable economic policy for developing countries which lack these factors in order to attract knowledge intensive foreign investment and outsourcing.

References

Abramovsky, L., and R. Griffith (2006): "Outsourcing and Offshoring of Business Services: How Important is ICT?," *Journal of the European Economic Association*, 4(2-3), 201–213.

Acemoglu, D., P. Antràs, and E. Helpman (2007): "Contracts and Technology Adoption," *American Economic Review*, 97(3), 916–943.

Acemoglu, D., S. Johnson, and T. Mitton (2009): "Determinants of Vertical Integration: Financial Development and Contracting Costs," *Journal of Finance*, 63(3), 1251–1290.

Allison, P. D., and R. P. Waterman (2002): "Fixed-Effects Negative Binomial Regression," *Sociological Methodology*, 32(1), 247–265.

Antràs, P. (2003): "Firms, Contracts and Trade Structure," *Quarterly Journal of Economics*, 118(4), 1375–1418.

——— (2005): "Incomplete Contracts and the Product Cycle," *American Economic Review*, 95(4), 1054–1073.

——— (2013): "Grossman-Hart (1986) Goes Global: Incomplete Contracts, Property Rights, and the International Organization of Production," *Journal of Law, Economics and Organization*, 0(0), 1–58.

Antràs, P., L. Garicano, and E. Rossi-Hansberg (2006): "Offshoring in a Knowledge Economy," *Quarterly Journal of Economics*, 121(1), 31–77.

——— (2008): "Organizing Offshoring: Middle Managers and Communication Costs," in *The Organization of Firms in a Global Economy*, ed. by E. Helpman, D. Marin, and T. Verdier, pp. 311–339. Harvard University Press, Cambridge MA.

Antràs, P., and E. Helpman (2004): "Global Sourcing," *Journal of Political Economy*, 112(3), 552–580.

——— (2008): "Contractual Frictions and Global Sourcing," in *The Organization of Firms in a Global Economy*, ed. by E. Helpman, D. Marin, and T. Verdier, pp. 9–54. Harvard University Press, Cambridge MA.

Antràs, P., and S. R. Yeaple (2015): "Multinational Firms and the Structure of International Trade," in *Handbook of International Economics Vol. 4*, ed. by E. Helpman, K. Rogoff, and G. Gopinath, pp. 55–130. Elsevier.

Baker, G. P., and T. N. Hubbard (2003): "Make versus Buy in Trucking: Asset Ownership, Job Design, and Information," *American Economic Review*, 93(3), 551–572.

——— (2004): "Contractibility and Asset Ownership: On-Board Computers and Governance in U.S. Trucking," *Quarterly Journal of Economics*, 119(4), 1443–1479.

Basco, S. (2013): "Financial development and the product cycle," *Journal of Economic Behavior & Organization*, 94, 295–313.

Beck, T. (2003): "Financial Dependence and International Trade," *Review of International Economics*, 11(2), 296–316.

Becker, R., W. Gray, and J. Marvakov (2013): "NBER-CES Manufacturing Industry Database: Technical Notes," .

Berkowitz, D., J. Moenius, and K. Pistor (2006): "Trade, Law, and Product Complexity," *Review of Economics and Statistics*, 88(2), 363–373.

Bernard, A. B., J. B. Jensen, S. J. Redding, and P. K. Schott (2010): "Intrafirm Trade and Product Contractibility," *American Economic Review: Papers & Proceedings*, 100(2), 444–448.

Bilir, K. (2014): "Patent Laws, Product Lifecycle Lengths, and Multinational Activity," *American Economic Review*, 104(7), 1979–2013.

Bloom, N., L. Garicano, R. Sadun, and J. van Reenen (2014): "The distinct effect of communication technology and information technology on firm organization," *Management Science*, 60(12), 2859–2885.

Bloom, N., R. Sadun, and J. V. Reenen (2012): "Americans Do IT Better: US Multinationals and the Productivity Miracle," *American Economic Review*, 102(1), 167–201.

Blum, B. S., and A. Goldfarb (2006): "Does the internet defy the law of gravity," *Journal of International Economics*, 70(2), 384–405.

Branstetter, L., R. Fisman, C. F. Foley, and K. Saggi (2011): "Does Intellectual Property Rights Reform Spur Industrial Development?," *Journal of International Economics*, 83(1), 97–112.

Cameron, A. C., J. B. Gelbach, and D. L. Miller (2011): "Robust Inference With Multi-way Clustering," *Journal of Business and Economic Statistics*, 29(1), 238 – 249.

Cameron, A. C., and P. K. Trivedi (2009): *Microeconometrics: Methods and Applications*. Cambridge University Press, New York.

Campa, J., and L. Goldberg (1997): "The Evolving External Orientation of Manufacturing Industries: Evidence from Four Countries," *Federal Reserve Bank of New York Economic Policy Review*, 3(2), 53–81.

Carluccio, J., and T. Fally (2012): "Global Sourcing under Imperfect Capital Markets," *Review of Economics and Statistics*, 94(3), 740–763.

Corcos, G., D. M. Irac, G. Mion, and T. Verdier (2013): "The Determinants of Intrafirm Trade: Evidence from French Firms," *Review of Economics and Statistics*, 95(3), 825–838.

Costinot, A., L. Oldenski, and J. Rauch (2011): "Adaptation and the Boundary of Multinational Firms," *Review of Economics and Statistics*, 93(1), 298–308.

Cristea, A. D. (2015): "The effect of communication costs on trade in headquarter services," *Review of World Economics*, 151(2), 255–289.

Defever, F., and F. Toubal (2013): "Productivity, relationship-specific inputs and the sourcing modes of multinationals," *Journal of Economic Behavior & Organization*, 94, 345–357.

Ethier, W. J., and J. R. Markusen (1996): "Multinational firms, technology diffusion and trade," *Journal of International Economics*, 94(3), 740–763.

Feenstra, R. (1998): "Integration of Trade and Disintegration of Production in the Global Economy," *Journal of Economic Perspectives*, 12(4), 31–50.

Feenstra, R., and G. Hanson (2005): "Ownership and Control in Outsourcing to China: Estimating the Property Rights Theory of the Firm," *Quarterly Journal of Economics*, 120(2), 729–762.

Feenstra, R., and J. B. Jensen (2012): "Evaluating Estimates of Materials Offshoring from US Mannufacturing," NBER Working Paper No. 17916.

Feenstra, R., J. Romalis, and P. K. Schott (2002): "US Imports, Exports, and Tariff Data, 1989-2001," NBER Working Paper No. 29387.

Fink, C., A. M. Illeana, and C. Neagu (2005): "Assessing the impact of communication costs on international trade," *Journal of International Economics*, 67(2), 428–445.

Fort, T. (2011): "Breaking Up is Hard to Do: Why Firms Fragment Production Across Locations," University of Maryland Working Paper.

Freund, C. L., and D. Weinhold (2002): "The Internet and International Trade in Services," *American Economic Review: Papers & Proceedings*, 92(2), 236–240.

——— (2004): "The effect of the Internet on international trade," *Journal of International Economics*, 62(1), 171–189.

Ginarte, J. C., and W. G. Park (1997): "Determinants of patent rights: A cross-national study," *Research Policy*, 26(3), 283–301.

——— (2008): "International patent protection: 1960-2005," *Research Policy*, 37(4), 761–766.

Grossman, G. M., and E. Rossi-Hansberg (2006): "The Rise of Offshoring: It's Not Wine for Cloth Anymore," *Proceedings - Economic Policy Symposium - Jackson Hole*, pp. 59–102.

——— (2008): "Trading Tasks: A Simple Theory of Offshoring," *American Economic Review*, 98(5), 1978–1997.

Grossman, S. J., and O. D. Hart (1986): "The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration," *Journal of Political Economy*, 94(4), 691–719.

Guimarães, P. (2008): "The fixed effects negative binomial model revisited," *Economics Letters*, 99(1), 63 – 66.

Hall, R. E., and C. I. Jones (1999): "Why Do Some Countries Produce So Much More Output per Worker than Others?," *Quarterly Journal of Economics*, 114(1), 83–116.

Hart, O. D., and J. Moore (1990): "Poperty Rights and the Nature of the Firm," *Journal of Political Economy*, 98(6), 1119–1158.

Helpman, E., M. Melitz, and S. R. Yeaple (2004): "Export Versus FDI with Heterogeneous Firms," *American Economic Review*, 94(1), 1695–1725.

Hummels, D. L., J. Ishii, and K.-M. Yi (2001): "The nature and growth of vertical specialization in world trade," *Journal of International Economics*, 54(1), 75–96.

Ioannides, Y. M., H. G. Overman, E. Rossi-Hansberg, and K. Schmidheiny (2008): "The effect of information and communication technologies on urban structure," *Economic Policy*, 23(54), 201–242.

Javorcik, B. (2004): "The Composition of Foreign Direct Investment and Protection of Intellectual Property," *European Economic Review*, 48(1), 39–62.

Kaufmann, D., A. Kraay, and M. Mastruzzi (2010): "The Worldwide Governance Indicators: Methodology and Analytical Issues," World Bank Policy Research Working Paper No. 5430.

Keller, W., and S. R. Yeaple (2013): "The Gravity of Knowledge," *American Economic Review*, 103(4), 1414–1444.

Levchenko, A. (2007): "Institutional Quality and International Trade," *Review of Economic Studies*, 74(3), 791–819.

Manova, K. (2013): "Credit Constraints, Hererogeneous Firms, and International Trade," *Review of Economic Studies*, 80(2), 711–744.

Marin, D., and T. Verdier (2008): "Competing in Organizations: Firm Heterogeneity and International Trade," in *The Organization of Firms in a Global Economy*, ed. by E. Helpman, D. Marin, and T. Verdier, pp. 142–172. Harvard University Press, Cambride MA.

——— (2014): "Corporate Hierarchies and International Trade: Theory and Evidence," *Journal of International Economics*, 94(2), 295–310.

Melitz, M. (2003): "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity," *Econometrica*, 71(6), 1695–1725.

Nunn, N. (2007): "Relationship-Specificity, Incomplete Contracts and the Pattern of Trade," *Quarterly Journal of Economics*, 122(2), 569–600.

Nunn, N., and D. Trefler (2008): "The Boundaries of the Multinational Firm: An Empirical Analysis," in *The Organization of Firms in a Global Economy*, ed. by E. Helpman, D. Marin, and T. Verdier, pp. 55–83. Harvard University Press, Cambride MA.

——— (2013): "Incomplete Contracts and the Boundaries of the Multinational Firm," *Journal of Economic Behavior & Organization*, 94(1), 330–344.

Oldenski, L. (2012a): "Export Versus FDI and the Communication of Complex Information," *Journal of International Ecoonomics*, 87(2), 312–322.

——— (2012b): "The Task Composition of Offshoring by US Multinationals," *International Economics*, 131, 5–21.

Rajan, R. G., and L. Zingales (1998): "Financial Dependence and Growth," *American Economic Review*, 88(3), 559–586.

Rauch, J. (1999): "Networks Versus Markets in International Trade," *Journal of International Economics*, 48(1), 7–35.

Romalis, J. (2004): "Factor Proportions and the Structure of Commodity Trade," *American Economic Review*, 94(1), 67–97.

Williamson, O. E. (1985): *The Economic Institutions of Capitalism*. Free Press, New York.

Yeaple, S. R. (2009): "Firm heterogeneity and the structure of US multinational activity," *Journal of International Economics*, 78(2), 206 – 215.

Yeats, A. (2001): "Just How Big is Global Production Sharing?," in *Fragmentation: New Production Patterns in the World Economy*, ed. by S. W. Arndt, and H. Kierzkowski, pp. 108–148. Oxford University Press.

Appendix

A Figures

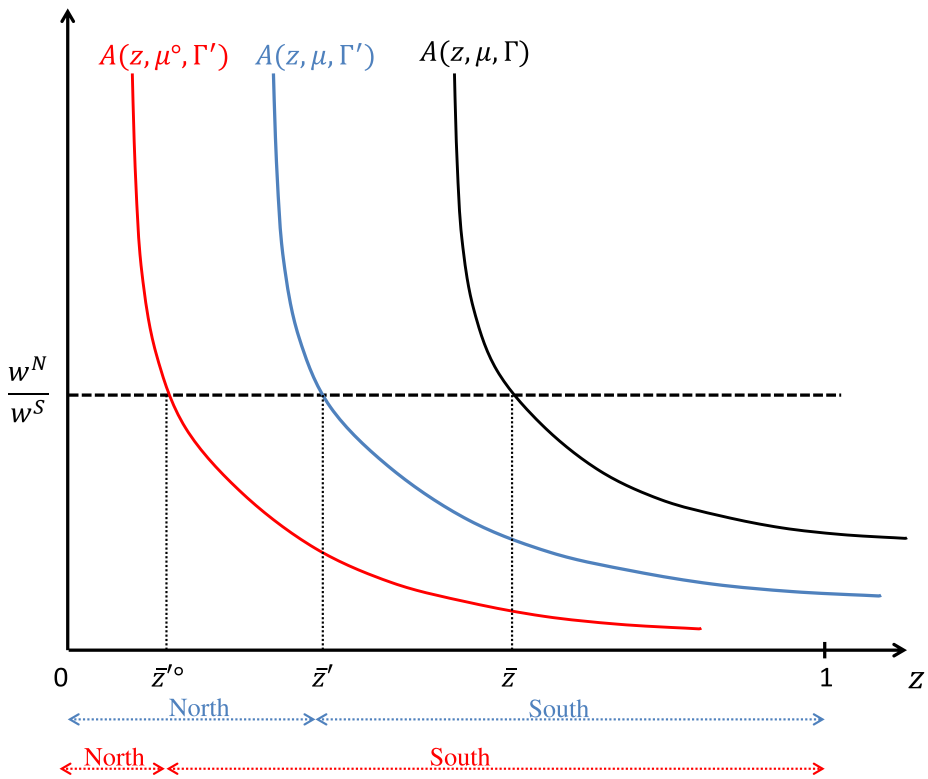

Figure 1: The Impact of Information Technology on Offshoring

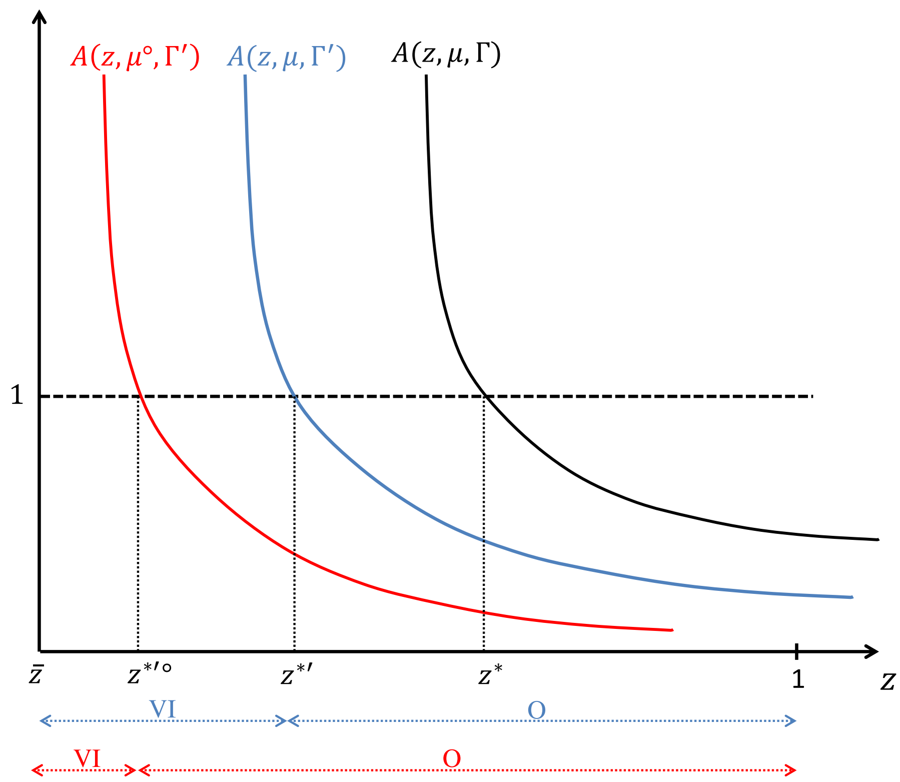

Figure 2: The Impact of Information Technology on the Sourcing Mode

B Tables

Table 3: List of Countries in the Data

Algeria	Czech Republic	Indonesia	Mozambique	South Africa
Bangladesh	Djibouti	Iran	Nepal	Sri Lanka
Barbados	Dominican Rep.	Iraq	Nicaragua	Suriname
Belize	Ecuador	Jamaica	Niger	Tanzania
Benin	Egypt	Jordan	Nigeria	Thailand
Bolivia	Ethiopia	Kenya	Pakistan	Togo
Brazil	Fiji	Korea (Rep. of)	Panama	Trinidad and Tobago
Bulgaria	Gabon	Lao P.D.R.	Paraguay	Tunisia
Burkina Faso	Gambia	Liberia	Peru	Turkey
Burundi	Ghana	Madagascar	Philippines	Uganda
Cameroon	Guatemala	Malawi	Poland	Uruguay
Chad	Guinea	Malaysia	Portugal	Venezuela
Chile	Guinea-Bissau	Mali	Romania	Yemen
China	Guyana	Mauritania	Rwanda	Zambia
Colombia	Haiti	Mauritius	Samoa	Zimbabwe
D.R. Congo	Honduras	Mexico	Senegal	
Costa Rica	Hungary	Mongolia	Seychelles	
Cote d'Ivoire	India	Morocco	Sierra Leone	

Table 4: Top and Bottom 10 Countries in Information Technology Infrastructure

Top 10		Bottom 10	
country	IT	country	IT
Hungary	8.144	Guinea-Bissau	0.019
Czech Republic	8.045	Guinea	0.040
Jamaica	6.884	Congo D.R.	0.053
Djibouti	5.757	Zimbabwe	0.055
Portugal	3.918	Nigeria	0.068
Barbados	3.481	Chad	0.074
Panama	3.094	Zambia	0.085
Romania	2.819	Kenya	0.100
Chile	2.819	Pakistan	0.102
Colombia	2.787	Malawi	0.105

Notes: Information technology is given by the average *international internet bandwidth (kbit/s) per internet user* over the 2002 - 2006 period. Data is derived from the ICT indicators database by the International Telecommunication Union.

Table 5: Correlations of Task Intensities

	analyze data	develop objectives	computers	solve problems	consultation	creativity	complexity	handle objects	control machines	physical activities	routine int
analyze data	1.00										
develop objectives	0.84	1.00									
	(0.00)										
computers	0.83	0.93	1.00								
	(0.00)	(0.00)									
solve problems	0.87	0.65	0.64	1.00							
	(0.00)	(0.00)	(0.00)								
consultation	0.82	0.93	0.96	0.67	1.00						
	(0.00)	(0.00)	(0.00)	(0.00)							
creativity	0.67	0.73	0.77	0.57	0.77	1.00					
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)						
complexity	0.91	0.95	0.97	0.77	0.97	0.84	1.00				
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)					
handle objects	-0.74	-0.88	-0.88	-0.57	-0.88	-0.61	-0.86	1.00			
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)				
control machines	-0.55	-0.84	-0.84	-0.36	-0.86	-0.61	-0.78	0.89	1.00		
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)			
physical activities	-0.80	-0.85	-0.89	-0.64	-0.88	-0.79	-0.91	0.88	0.77	1.00	
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		
routine int	-0.74	-0.91	-0.92	-0.56	-0.92	-0.71	-0.90	0.98	0.93	0.94	1.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	

Notes: p-values in parentheses. For a detailed exposition of the construction of task intensities and measures of complexity and routine intensity see section 3.1.3.

Table 6: Top and and Bottom 10 Most and Least Complex Industries

Top 10 Most Complex Industries

NAICS 4-digit sector	description	complexity
3341	computer and peripheral equipment	2.901
3345	navigational, measuring, electromedical, and control instruments	2.850
3342	communications equipment	2.763
3364	aerospace product and parts	2.740
3344	semiconductor and other electronic component	2.676
3333	commercial and cervice industry machinery	2.583
3332	industrial machinery	2.581
3343	audio and video equipment	2.550
3254	pharmaceutical and medicine	2.520
3339	other general purpose machinery	2.472

Bottom 10 Least Complex Industrises

NAICS 4-digit sector	description	complexity
3116	animal slaughtering and processing	1.326
3273	cement and concrete product manufacturing	1.564
3211	sawmills and wood preservation	1.719
3115	dairy product manufacturing	1.733
3131	fiber, yarn, and thread mills	1.754
3114	fruit and vegetable preserving and specialty food manufacturing	1.767
3274	lime and gypsum product manufacturing	1.792
3222	converted paper product manufacturing	1.797
3122	tobacco manufacturing	1.807
3119	other food manufacturing	1.811

Notes: Complexity is measured by the intensity in non-routine tasks by industry. See section 3.1.3 for detailed explanations on the construction of task intensities and the measure for complexity.

	OLS				
	(1)	(2)	(3)	(4)	(5)
Dependent variable:	**log(number of imported goods)**				
$\text{complexity}_{\text{s}}$ * IT_{ct}	0.0615***	0.0550***	0.0414**	0.0401***	0.0361***
	(0.0167)	(0.0164)	(0.0173)	(0.0108)	(0.0126)
R&D int_{s} * fin devt_{ct}			0.000130		
			(0.000560)		
$\text{high-tech}_{\text{s}}$ * patent prot_{c}			0.125		
			(0.0935)		
contract int_{s} * rule of law_{ct}			2.013***		
			(0.692)		
$\text{complexity}_{\text{s}}$ * H/L_{c}				1.075**	
				(0.506)	
$\text{complexity}_{\text{s}}$ * K/L_{c}				0.00791	
				(0.0447)	
$\text{complexity}_{\text{s}}$ *cgdp_{ct}					1.57e-05
					(1.15e-05)
$\text{complexity}_{\text{s}}$ * $\text{openness}_{\text{ct}}$					0.00344***
					(0.00127)
skill int_{s} * H/L_{c}		0.264	-0.372	-2.171	-0.609
		(0.892)	(0.747)	(1.547)	(0.836)
capital int_{s} * K/L_{c}		0.421*	0.438**	0.452*	0.431*
		(0.232)	(0.211)	(0.234)	(0.229)
sector FE	yes	yes	yes	yes	yes
country-year FE	yes	yes	yes	yes	yes
Observations	10,007	9,566	9,270	9,566	9,549
R-squared	0.716	0.725	0.733	0.727	0.728
sector clusters	73	73	73	73	73
country clusters	85	75	67	75	75

Notes: Robust standard errors two-way clustered by sector and country. The dependent variable is the natural log of the *number of imported goods*. The coefficient of interest is the interaction of complexity at the sector level $complexity_s$ and the level of information technology infrastructure at the country-year level IT_{ct}. Information technology infrastructure is measured by the international internet bandwidth (kbit/s) per internet user. Complexity is measured by the intensity in non-routine tasks by industry (see section 3.1.3 for detailed explanations). For a definition of the covariates see Table 12. *** p<0.01, ** p<0.05, * p<0.1

Table 7: Prediction 1 - Impact of Information Technology and Complexity on the Geography of Imports. Robustness Check 1 - OLS Regression

	OLS				
	(1)	(2)	(3)	(4)	(5)
Dependent variable:	**log(number of imported goods)**				
$complexity_s$ * IT_{ct}	0.0442***	0.0356***	0.0278**	0.0264**	0.0218*
	(0.0126)	(0.0132)	(0.0132)	(0.0110)	(0.0115)
R&D int_s * fin $devt_{ct}$			0.000515		
			(0.000529)		
$high\text{-}tech_s$ * patent $prot_c$			0.102		
			(0.0650)		
contract int_s * rule of law_{ct}			0.956**		
			(0.458)		
$complexity_s$ * H/L_c				0.517	
				(0.370)	
$complexity_s$ * K/L_c				0.0228	
				(0.0348)	
$complexity_s$ * $cgdp_{ct}$					1.51e-05*
					(8.09e-06)
$complexity_s$ * $openness_{ct}$					0.00158**
					(0.000726)
skill int_s * H/L_c		0.598	0.0384	-0.729	-0.0438
		(0.461)	(0.502)	(0.945)	(0.488)
capital int_s * K/L_c		0.122	0.118	0.135	0.128
		(0.0826)	(0.0776)	(0.0811)	(0.0796)
sector FE	yes	yes	yes	yes	yes
country-year FE	yes	yes	yes	yes	yes
Observations	7,582	7,185	6,891	7,185	7,168
R-squared	0.472	0.479	0.486	0.480	0.483
sector clusters	73	73	73	73	73
country clusters	85	75	67	75	75

Notes: Robust standard errors two-way clustered by sector and country. The dependent variable is the natural log of the *number of imported goods* which is restricted to the 75% percentile of the distribution (i.e. 6 imported goods). The coefficient of interest is the interaction of complexity at the sector level $complexity_s$ and the level of information technology infrastructure at the country-year level IT_{ct}. Information technology infrastructure is measured by the international internet bandwidth (kbit/s) per internet user. Complexity is measured by the intensity in non-routine tasks by industry (see section 3.1.3 for detailed explanations). For a definition of the covariates see Table 12. *** p<0.01, ** p<0.05, * p<0.1

Table 8: Prediction 1 - Impact of Information Technology and Complexity on the Geography of Imports. Robustness Check 2 - Number of Imported Goods Restricted to the 75% Percentile. OLS Regression

	negative binomial regression							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable:	**number of imported goods**							
Measure of IT:	*bandwith per internet user*					*bandwidth per capita*	*internet users*	*secure servers*
complexity$_s$ * IT$_{ct}$	0.0469**	0.0316*	0.0333*			1.513***	0.00665**	0.00372***
	(0.0196)	(0.0169)	(0.0173)			(0.477)	(0.00321)	(0.000997)
routine int$_s$ * IT$_{ct}$				-0.0152**	-0.00688			
				(0.00599)	(0.00517)			
complexity$_s$ * fin devt$_{ct}$	0.00108							
	(0.00111)							
complexity$_s$ * patent prot$_c$		0.175**						
		(0.0839)						
complexity$_s$ * rule of law$_{ct}$			0.817**					
			(0.413)					
skill int$_s$ * H/L$_c$	0.961	0.784	0.585		1.348**	0.909	0.861	1.512**
	(0.733)	(0.797)	(0.791)		(0.645)	(0.702)	(0.720)	(0.620)
capital int$_s$ * K/L$_c$	0.247	0.236	0.249		0.239	0.248	0.258	0.191
	(0.290)	(0.292)	(0.292)		(0.290)	(0.292)	(0.272)	(0.293)
alpha	0.0877	0.0868	0.0874	0.0909	0.0880	0.0889	0.0890	0.0895
sector FE	yes	yes	yes	yes	yes	yes	yes	yes
country-year FE	yes	yes	yes	yes	yes	yes	yes	yes
Observations	9,565	9,284	9,573	10,014	9,573	9,644	10,056	7,852
log likelihood	-20,111	-19,668	-20,115	-20,954	-20,136	-20,276	-21,054	-16,630
country clusters	76	68	76	86	76	77	76	73

Notes: Robust standard errors clustered by country. The dependent variable is the *number of imported goods*. In columns (1) - (3) and (6) - (8) the coefficient of interest is the interaction of complexity at the sector level *complexity*$_s$ and the level of information technology infrastructure at the country-year level IT_{ct}. In columns (4) - (5) the coefficient of interest is based on routine intensity at the sector level *routine int*$_s$. Complexity and routine intensity are measured by the intensity in non-routine and routine tasks by industry (see section 3.1.3 for detailed explanations). In columns (1) - (5) information technology infrastructure is measured by the international internet bandwidth (kbit/s) per internet user. In columns (6) - (9) the measure is replaced by the international internet bandwidth (kbit/s) per capita, the share of internet users per 100 people and the number of secure servers per 1 million people. For a definition of the covariates see Table 12. *** p<0.01, ** p<0.05, * p<0.1

Table 9: Prediction 1 - Impact of Information Technology and Complexity on the Geography of Imports. Robustness Check 3 - Routine Intensity, Institutions and Alternative Measures of Information Technology

	OLS					LPM
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:			**share of intra-firm trade**			**integration**
routine int_s * IT_ct	0.00719***	0.00724***	0.00708**			
	(0.00242)	(0.00243)	(0.00292)			
$\text{complexity}_\text{s}$ * IT_ct				-0.0188***	-0.0181**	-0.0168**
				(0.00683)	(0.00846)	(0.00802)
R&D int_s * fin devt_ct		-0.000433*				
		(0.000220)				
$\text{complexity}_\text{s}$ * fin devt_ct				0.00107**		
				(0.000461)		
$\text{high-tech}_\text{s}$ * patent prot_c			-0.0420			
			(0.0415)			
$\text{complexity}_\text{s}$ * patent prot_c					-0.0864	
					(0.0565)	
R&D int_s * rule of law_ct			0.211***			
			(0.0339)			
contract int_s * rule of law_ct			-0.242*			
			(0.142)			
$\text{complexity}_\text{s}$ * rule of law_ct					0.389**	
					(0.150)	
skill int_s * H/L_c	0.129	0.138	0.221	-0.0104	0.0590	0.174
	(0.166)	(0.167)	(0.240)	(0.169)	(0.256)	(0.183)
capital int_s * K/L_c	-0.0122	-0.0124	-0.0371	-0.0172	-0.0446	0.00767
	(0.0297)	(0.0299)	(0.0407)	(0.0301)	(0.0398)	(0.0305)
sector FE	yes	yes	yes	yes	yes	yes
country-year FE	yes	yes	yes	yes	yes	yes
Observations	10,926	10,926	7,043	10,926	7,043	10,926
R-squared	0.286	0.287	0.320	0.288	0.321	0.148
sector clusters	85	85	85	85	85	85
country-year clusters	314	314	192	314	192	314

Notes: Robust standard errors two-way clustered by sector and country-year. In columns (1) - (5) the dependent variable is the *share of intra-firm trade*. In column (6) the dependent variable *integration* is a dummy variable indicating whether the share of intra-firm trade is above the 90%-percentile of the distribution. In columns (1) - (3) the coefficient of interest is the interaction of routine intensity at the sector level *routine* $\textit{int}_\text{s}$ and the level of information technology infrastructure at the country-year level IT_{ct}. In columns (4) - (6) the coefficient of interest is based on complexity at the sector level $\textit{complexity}_\text{s}$. Complexity and routine intensiy are measured by the intensity in non-routine and routine tasks by industry (see section 3.1.3 for detailed explanations). Information technology infrastructure is measured by the international internet bandwidth (kbit/s) per internet user. For a definition of the covariates see Table 12. *** p<0.01, ** p<0.05, * p<0.1

Table 10: Prediction 2 - The Impact of Information Technology and Complexity on the Sourcing Mode. Robustness Check: Routine Intensity, Institutions and Linear Probability Model

Table 11: Summary Statistics

variable	observations	mean	min	max	std. dev.
global sourcing					
number of imported goods$_{cst}$	10682	6.123104	1	213	12.28056
log(number of imported goods)$_{cst}$	10682	1.097822	0	5.361292	1.067945
share of intra-firm trade$_{cst}$	11902	0.2746167	0.0000196	0.9997116	0.2813905
integration indicator$_{cst}$	11902	0.0999832	0	1	0.2999902
country level					
int'l internet bandwidth (kbit/s) per internet user$_{ct}$	391	1.071124	0.0023679	12.48208	1.732975
int'l internet bandwidth (bit/s) per capita$_{ct}$	402	0.0175254	4.50E-06	0.4671284	0.0496992
share of internet users per 100 people$_{ct}$	420	9.057331	0.0310112	78.1	12.69666
secure servers per 1 million people$_{ct}$	291	17.15283	0.0071846	520.0945	55.04144
financial development$_{ct}$	427	32.90474	0.7735366	163.369	31.35263
rule of law$_{ct}$	433	0.4154873	0.118	0.79	0.1442786
openness$_{ct}$	427	77.23927	21.67383	290.4993	39.01523
per capita gdp$_{ct}$	433	6208.162	405.4827	27044.03	5544.011
patent protection$_{c}$	74	3.124324	1.78	4.54	0.7115526
H/L$_{c}$	77	0.482419	0.07236	1.127	0.2397439
K/L$_{c}$	77	8.663346	5.76262	10.66226	1.362734
sector level					
complexity$_{s}$	73	2.09736	1.32669	2.901543	0.3050399
routine int$_{s}$	73	4.500416	2.254529	6.621832	0.836662
R&D int$_{s}$	73	0.0588022	0	2.665776	0.312024
high-tech$_{s}$	73	0.260274	0	1	0.4418206
contract intensity$_{s}$	73	0.8546387	0.0959204	0.9995984	0.1862124
skill int$_{s}$	73	0.2799016	0.0969529	0.6265237	0.1124233
capital int$_{s}$	73	0.140219	0.0155472	0.8833231	0.1412792

Table 12: Variables: Description and Sources

variables	**descriptions and sources**
number of imported goods$_{cst}$	Number of 5-digit SITC products by 4-digit NAICS industry which are imported to the US. Raw materials and final goods are dropped according to the end-use classification following Feenstra and Jensen (2012). The sample is based on countries that exhibit per capita GDP (at PPP) of less than 50% of the US level in the year 2000. Data is derived from the *NBER trade database*.
log(number of imported goods)$_{cst}$	Natural logarithm of the number of 5-digit SITC products by 4-digit NAICS industry which are imported to the US. See above for further explanations.
share of intra-firm trade$_{cst}$	Share of related party transactions in both related and non-related party transactions of US imports at the 4-digit NAICS level. A related party transaction is defined as a transaction between two parties in which one owns at least 6% of the outstanding voting stock or shares of its counterpart. The sample is based on countries that exhibit per capita GDP (at PPP) of less than 50% of the US level in the year 2000. Data is from the *US Census Bureau*. For a discussion of the data see 3.1.1.
integration$_{cst}$	Dummy variable that indicates whether the share of intra-firm trade is above the 90% percentile of the distribution. See above for further explanations.
IT$_{ct}$	Information technology infrastructure is measured by the international internet bandwidth (kbit/s) per internet user. Alternative measures are the international internet bandwith (bit/s) per capita, the share of internet users per 100 people and the number of secure servers per 1 million people. Data for the first three measures is from the *ICT indicators database* by the *International Telecommunications Union (ITU)*. Data on secure servers is from the *World Development Indicators (World Bank)*.
financial development$_{ct}$	Domestic credit to the private sector by banks and other financial institutions as a share of GDP. Data is from the *Global Financial Development Database (World Bank)*.
rule of law$_{ct}$	Index of the quality of contract enforcement, the protection of property rights, the police, and the courts as well as the likelihood of crime and violence. Data is from the *Worldwide Governance Indicators 2013*.
openness$_{ct}$	Ratio of the sum of imports and exports over GDP taken from the *World Development Indicators (World Bank)*.
per capita gdp$_{ct}$	GDP per capita at PPP and current international Dollar taken from the *World Development Indicators (World Bank)*.
patent protection$_{c}$	Index of the protection of patent rights developed by Ginarte and Park (1997, 2008) for the year 2005.
H/L$_{c}$	Natural logarithm of human capital augmented labor relative to total labor which is based on estimations of the returns to schooling by Hall and Jones (1999) .
K/L$_{c}$	Natural logarithm of physical capital relative to total labor. See Hall and Jones (1999) for more detailed explanations.
complexity$_{s}$	Reflects the intensity in non-routine tasks by industry. Task intensities are contructed based on worker and job characteristics provided by the *Department of Labor's Occupational Information Network (O*NET)* for about 800 occupations. The task measures are aggregated to the 4-digit NAICS industry level by weighting them with employment shares from the *Occupational Employment Statistics (OES)* by the *Bureau of Labor Statistics*. Data is for the year 2000. *complexity*$_{s}$ is the average of selected tasks representing non-routine activities. See 3.1.3 for a detailed explanation.
routine intensity$_{s}$	Reflects the intensity in routine tasks by industry at the 4-digit NAICS level. Routine intensity is the average of selected tasks representing routine activities. See section 3.1.3 and above for more detailed explanations.
R&D intensity$_{s}$	R&D expenditures over sales at the 4-digit NAICS level taken from Keller and Yeaple (2013). The measure is based on firm-level data from *COMPUSTAT*.
high-tech indicator$_{s}$	Dummy variable indicating whether a 4-digit NAICS sector represents a high-technology industry. Data is from the *Science and Engineering Indicators 2010* by the *National Science Foundation*. The classification is based on the intensity of high-technology empoyment within an industry. An industry is considered a high-technology industry if employment in technology-oriented occupations (scientific, engineering and technician occupations) accounts for a proportion of that industry's total employment that is more than twice the average for all industries.
contract intensity$_{s}$	Reflects the share of inputs that are relationship-specific. The measure is based on the proportion of inputs of products that are not traded on organized exchanges but which might be reference priced based on the liberal classification of commodities into organized exchange, reference priced, and differentiated by Rauch (1999). The data is aggregated to the 4-digit NAICS level by means of the BEA's input-output table on input use. See Nunn (2007) for a detailed exposition.
skill intensity$_{s}$	Share of non-production workers in total employment at the 4-digit NAICS level. Data is from the *NBER CES Manufacturing Industry Database*.
capital intensity$_{s}$	Capital stock per employee at the 4-digit NAICS level. Data is from the *NBER CES Manufacturing Industry Database*.

C Mathematical Appendix

Profit Maximization with Manufacturing Firm in North

The headquarter firm's optimization problem is given by

$$\max_{h,m} \pi^N(z) = \lambda^{1-\alpha} \left(\frac{h}{1-z}\right)^{\alpha(1-z)} \left(\frac{m}{z}\right)^{\alpha z} - hw^N - mw^S. \tag{24}$$

From the first order conditions the optimal investment levels can be characterized by $\frac{h}{m} = \frac{1-z}{z}$. Plugging this back into the first order conditions, one can solve for the first best levels of investments in headquarter and manufacturing activities:

$$h = \left(\frac{\alpha\lambda}{w^N}\right)^{\frac{1}{1-\alpha}} (1-z) \tag{25}$$

$$m = \left(\frac{\alpha\lambda}{w^N}\right)^{\frac{1}{1-\alpha}} z. \tag{26}$$

Inserting the first best investment levels into the profit function given in equation (1) yields:

$$\pi^N = (1-\alpha)\,\lambda \left(\frac{w^N}{\alpha}\right)^{\frac{-\alpha}{1-\alpha}}. \tag{27}$$

Profit Maximization with Manufacturing Firm in South

Headquarter firm and manufacturing firm first choose their investment level in non-contractible activities h and $m\,(s) s \in (\mu, 1]$:

Headquarter

$$\max_{h} \phi\lambda^{1-\alpha} \left(\frac{h}{1-z}\right)^{(1-z)\alpha} \left(\frac{\exp\left(\int_0^1 \log m(s)ds\right)}{z}\right)^{z\alpha} - w^N h \tag{28}$$

$$\frac{\partial}{\partial h} = (1-z)\alpha\phi h^{-1}\lambda^{1-\alpha}\left(\frac{h}{1-z}\right)^{(1-z)\alpha}\left(\frac{\exp\left(\int_0^1 \log m(s)ds\right)}{z}\right)^{z\alpha} - w^N = 0 \tag{29}$$

$$h = \frac{(1-z)\alpha\phi R}{w^N} \tag{30}$$

Manufacturer

$$\max_{\{m_s\}_\mu^1} \ (1-\phi)\lambda^{1-\alpha}\left(\frac{h}{1-z}\right)^{(1-z)\alpha}\left(\frac{\exp\left(\int_0^1 \log m(s)ds\right)}{z}\right)^{z\alpha} - \Gamma w^S \int_\mu^1 m(s)ds \tag{31}$$

$$\frac{\partial}{\partial m} = z\alpha(1-\phi)m(s)^{-1}\lambda^{1-\alpha}\left(\frac{h}{1-z}\right)^{(1-z)\alpha}\left(\frac{\exp\left(\int_0^1 \log m(s)ds\right)}{z}\right)^{z\alpha} - w^S\Gamma \ , \ s \in (\mu, 1] \tag{32}$$

$$m(s) = \frac{z\alpha(1-\phi)R}{w^S\Gamma} \ , \ s \in (\mu, 1]. \tag{33}$$

Plugging non-contractible headquarter and manufacturing activities into revenues R and solving for R yields:

$$R^{1-\alpha(1-\mu z)} = \lambda^{1-\alpha}\xi_z^\alpha\left(\frac{(1-z)\alpha\phi}{w^N}\right)^{(1-z)\alpha}\left(\exp\left[\int_0^\mu \log m(s)ds\right]\right)^{\alpha z}\left(\frac{(1-\phi)z\alpha}{w^S\Gamma}\right)^{(1-\mu)\alpha z}, \tag{34}$$

with $\xi_z^\alpha = (1-z)^{-(1-z)}z^{-z}$.

Solving for the level of non-contractible headquarter activities h:

Reinserting revenues R in the first order condition of headquarter acitivities gives

$$h^{1-\alpha(1-\mu z)} = \lambda^{1-\alpha}\alpha\xi_z^{\alpha}\left(\exp\left[\int_0^{\mu}\log m(s)ds\right]\right)^{\alpha z}\left(\frac{\phi(1-z)}{w^N}\right)^{1-\alpha(1-\mu)z}\left(\frac{(1-\phi)z}{w^S\Gamma}\right)^{\alpha(1-\mu)z}. \tag{35}$$

Solving for the level of non-contractible manufacturing activities $\mathbf{m(s)}$ $\mathbf{s} \in (\mu, \mathbf{1}]$:

Reinserting revenues R in the first order condition of manufacturing activities gives

$$m(s)^{1-\alpha(1-\mu z)} = \lambda^{1-\alpha}\alpha\xi_z^{\alpha}\left(\exp\left[\int_0^{\mu}\log m(s)ds\right]\right)^{\alpha z}\left(\frac{\phi(1-z)}{w^N}\right)^{\alpha(1-z)}\left(\frac{(1-\phi)z}{w^S\Gamma}\right)^{1-\alpha(1-z)}. \tag{36}$$

Solving for the level of contractible activities on behalf of the manufacturing firm:

The headquarter offers the manufacturing firm a contract that satisfies the participation constraint:

$$(1-\phi)R - w^S\int_0^{\mu} m(s)ds - w^S\Gamma\int_{\mu}^{1} m(s)ds + T \geq 0. \tag{37}$$

The participation constraint is satisfied with equality and the final good producer chooses a contract that maximizes its payoff $\phi R - w^N h - T$:

$$\max_{\{m(s)\}_0^{\mu}} \pi = R - w^N h - w^S\int_0^{\mu} m(s)ds - w^S\Gamma\int_{\mu}^{1} m(s)ds. \tag{38}$$

This can be rewritten as:

$$\max_{\{m(s)\}_0^{\mu}} \pi = R - w^N h - w^S\int_0^{\mu} m(s)ds - w^S\Gamma(1-\mu)m(s). \tag{39}$$

Plugging in the first order conditions characterizing non-contractible investments yields:

$$\max_{\{m(s)\}_0^{\mu}} \pi = [1-(1-z)\phi\alpha - z(1-\mu)(1-\phi)]\, R - w^S \int_0^{\mu} m(s)ds. \tag{40}$$

The first order condition of the profit maximization problem is given by:

$$\frac{\partial \pi}{\partial m(s)} = [1-(1-z)\phi\alpha - z(1-\mu)(1-\phi)]\,\frac{\partial R}{\partial m(s)} - w^S = 0\ ,\ s \in [0,\mu]\,, \tag{41}$$

where

$$\frac{\partial R}{\partial m(s)} = \frac{\alpha z}{1-\alpha(1-\mu z)} m(s)^{-1} R\ ,\ s \in [0,\mu]\,. \tag{42}$$

Contractible investments can then be expressed by:

$$m(s) = \frac{[1-\alpha\phi(1-z) - \alpha(1-\phi)(1-\mu)z]}{1-\alpha(1-\mu z)}\frac{\alpha z}{w^S}R. \tag{43}$$

Inserting revenues R from equation (34), solving for $m(s)$ with $s \in [0,\mu]$ and rearranging finally gives the level of contractible investments in manufacturing:

$$m(s) = \left\{ \frac{(1-\alpha\phi(1-z) - \alpha(1-\phi)(1-\mu)z}{1-\alpha(1-\mu z)} \right\}^{\frac{1-\alpha(1-\mu z)}{1-\alpha}} \left\{ \alpha\lambda^{1-\alpha}\xi_z^{\alpha} \left(\frac{\phi(1-z)}{w^N}\right)^{\alpha(1-z)} \left(\frac{(1-\phi)z}{w^S\Gamma}\right)^{\alpha(1-\mu)z} \right\}^{\frac{1}{1-\alpha}} \left(\frac{z}{w^S}\right)^{\frac{1-\alpha(1-\mu z)}{1-\alpha}}. \tag{44}$$

Solving for profits:

From equation (40) profits can be rewritten as

$$\pi = [1-(1-z)\phi\alpha - z\,(1-\mu)\,(1-\phi)]\, R - w^S \mu m(s)\ ,\ s \in [0,\mu]\,. \tag{45}$$

Plugging in contractible investments from equation (43):

$$\pi = (1-\alpha)\left(\frac{1-(1-z)\phi\alpha - z(1-\mu)(1-\phi)}{1-\alpha(1-\mu z)}\right) R. \tag{46}$$

Profits can now be derived by combining contractible investments from equation (44) with revenues R given by equation (34). Revenues R are then given by:

$$R = \lambda\alpha^{\frac{1}{1-\alpha}} (1-\phi)^{\frac{\alpha z(1-\mu)}{1-\alpha}} \phi^{\frac{\alpha(1-z)}{1-\alpha}} w_S^{\frac{-\alpha z(1-\mu)}{1-\alpha}} w_N^{\frac{-\alpha(1-z)}{1-\alpha}} \Gamma^{\frac{-\alpha z(1-\mu)}{1-\alpha}} \left[\frac{1-\alpha\phi(1-z)-\alpha(1-\mu)(1-\phi)z}{1-\alpha(1-\mu z)}\right]^{\left(\frac{\alpha(1-z)+\alpha z(1-\mu)}{(1-\alpha)(1-\alpha(1-\mu z))}\right)}. \tag{47}$$

Combining this with equation (46) and setting $\theta = (1-\mu z)$ finally yields:

$$\pi = (1-\alpha)\lambda \left[\alpha^{\alpha} w_N^{-\alpha(1-z)} w_S^{-\alpha z} \Gamma^{-\alpha z(1-\mu)} \frac{(1-\phi)^{\alpha(1-\mu)z}\phi^{\alpha(1-z)} \left(1-\alpha\phi(1-z)-\alpha(1-\mu)(1-\phi)z\right)^{(1-\alpha\theta)}}{(1-\alpha\theta)^{(1-\alpha\theta)}}\right]^{\frac{1}{1-\alpha}}. \tag{48}$$

Outsourcing:

- $\phi = 0.5$

$$\pi^O = (1-\alpha)\lambda \left[\alpha^{\alpha} w_N^{-\alpha(1-z)} w_S^{-\alpha z} \Gamma^{-\alpha z(1-\mu)} \frac{0.5^{\alpha\theta} \left(1-\alpha 0.5\theta\right)^{(1-\alpha\theta)}}{(1-\alpha\theta)^{(1-\alpha\theta)}}\right]^{\frac{1}{1-\alpha}}. \tag{49}$$

Vertical Integration:

- $\phi = 0.5\left(1+\delta^{\alpha}\right)$

$$\pi^{VI} = (1-\alpha)\lambda \left[\alpha^{\alpha} w_N^{-\alpha(1-z)} w_S^{-\alpha z} \frac{0.5^{\alpha\theta} \left(1-\delta^{\alpha}\right)^{\alpha(1-\mu)z} (1+\delta)^{\alpha(1-z)} \triangle^{(1-\alpha\theta)}}{(1-\alpha\theta)^{(1-\alpha\theta)}}\right]^{\frac{1}{1-\alpha}}, \tag{50}$$

with $\triangle = \left[1-\alpha 0.5\left(\theta+\delta^{\alpha}\left(1-z\left(2-\mu\right)\right)\right)\right]$.

Location Choice: The $A(z,\mu,\Gamma)$-curve

Comparing profits in North π^N and South π^S, production takes place in South if

$$\frac{\pi^N}{\pi^S} \leq 1, \tag{51}$$

which can be rearranged to get

$$\frac{w^N}{w^S} \geq \left(\frac{(1-\alpha\theta)^{(1-\alpha\theta)}}{0.5^{\alpha\theta}\,(1-\alpha 0.5\theta)^{(1-\alpha\theta)}} \right)^{\frac{1}{z}} \Gamma^{(1-\mu)} \equiv A(z,\mu,\Gamma). \tag{52}$$

$A(z, \mu, \Gamma)$ is a decreasing function of z since

$$\lim_{z\to 0} \left(\frac{(1-\alpha(1-\mu z)^{(1-\alpha(1-\mu z))}}{0.5^{\alpha(1-\mu z)}(1-\alpha 0.5\,(1-\mu z))^{(1-\alpha(1-\mu z))}} \right) = \frac{(1-\alpha)^{(1-\alpha)}}{0.5^{\alpha}\,(1-\alpha 0.5)^{(1-\alpha)}} > 1, \tag{53}$$

from where

$$\lim_{z\to 0} A(z,\mu,\Gamma) = +\infty, \tag{54}$$

follows. Moreover, note that

$$\begin{aligned} &\lim_{z\to 1} \left(\frac{(1-\alpha(1-\mu z)^{(1-\alpha(1-\mu z))}}{0.5^{\alpha(1-\mu z)}(1-\alpha 0.5\,(1-\mu z))^{(1-\alpha(1-\mu z))}} \right) \\ &= \frac{(1-\alpha\,(1-\mu))^{(1-\alpha(1-\mu))}}{0.5^{\alpha(1-\mu)}\,(1-\alpha 0.5\,(1-\mu))^{(1-\alpha(1-\mu))}} > 1 \end{aligned}, \tag{55}$$

for which reason

$$\lim_{z\to 1} A(z,\mu,\Gamma) = \left(\frac{(1-\alpha\,(1-\mu))^{(1-\alpha(1-\mu))}}{0.5^{\alpha(1-\mu)}\,(1-\alpha 0.5(1-\mu))^{(1-\alpha(1-\mu)}} \right) \Gamma^{1-\mu} > 1, \tag{56}$$

since $\Gamma > 1$. Most importantly, note that $f(b) = (1-ab)^{1-a}\,b^a$ is increasing in b for $b \in (0,1)$ and $a \in (0,1)$. Hence, the $A(z,\mu,\Gamma)$-curve is downwardsloaping. As long as the relative wage $\frac{w^N}{w^S}$ is large enough, a cutoff $\bar{z} \in (0,1)$ emerges such that for $z < \bar{z}$ profits with Northern manufacturing are larger than profits with Southern manufacturing $\pi^N > \pi^S$. Thus, for any $z > \bar{z}$ manufacturing in South is more profitable $\pi^N < \pi^S$.

Mode of Organization: The $A^*(z,\mu,\Gamma)$-curve

Comparing profits with vertical integration and outsourcing, the headquarter firm opts for integration if

$$\frac{\pi^{VI}}{\pi^{O}} \geq 1, \tag{57}$$

which can be rearranged to obtain

$$A^*(z,\mu,\Gamma) \equiv \left(\frac{(1-\delta^{\alpha})^{\alpha z(1-\mu)}\,(1+\delta^{\alpha})^{\alpha(1-z)}\,\triangle^{(1-\alpha\theta)}}{(1-\alpha 0.5\theta)^{(1-\alpha\theta)}} \right)^{\frac{1}{\alpha z}} \Gamma^{1-\mu} \geq 1, \tag{58}$$

with $\triangle = [1-\alpha 0.5\,(\theta + \delta^{\alpha}\,(1-z\,(2-\mu)))]$.

$A^{\star}(z,\mu,\Gamma)$ is a decreasing function of z since

$$\begin{aligned} \lim_{z\to 0} & \frac{(1-\delta^{\alpha})^{\alpha z(1-\mu)}(1+\delta^{\alpha})^{\alpha(1-z)}\,[1-\alpha 0.5\,(\theta+\delta^{\alpha}\,(1-z\,(2-\mu)))]^{(1-\alpha\theta)}}{(1-\alpha 0.5\theta)^{(1-\alpha\theta)}} \\ & = \frac{(1+\delta^{\alpha})^{\alpha}\,(1-\alpha 0.5\,(1+\delta^{\alpha}))^{(1-\alpha)}}{(1-0.5\alpha)^{(1-\alpha)}} > 1 \end{aligned}, \tag{59}$$

which implies that

$$\lim_{z\to 0} A^*(z,\mu,\Gamma) = +\infty, \tag{60}$$

and

$$\begin{aligned} \lim_{z\to 1} & \frac{(1-\delta^{\alpha})^{\alpha z(1-\mu)}(1+\delta^{\alpha})^{\alpha(1-z)}\,[1-\alpha 0.5\,(\theta+\delta^{\alpha}\,(1-z\,(2-\mu)))]^{(1-\alpha\theta)}}{(1-\alpha 0.5\theta)^{(1-\alpha\theta)}} \\ & = \frac{(1-\delta^{\alpha})^{\alpha(1-\mu)}\,(1-\alpha 0.5\,(1-\delta^{\alpha})\,(1-\mu))^{(1-\alpha(1-\mu))}}{(1-\alpha 0.5\,(1-\mu))^{(1-\alpha(1-\mu))}} < 1 \end{aligned}, \tag{61}$$

which implies that

$$\lim_{z\to 1} A^{*}(z,\mu,\Gamma) = \left(\frac{\left(1-\delta^{\alpha}\right)^{\alpha(1-\mu)} \left(1-\alpha 0.5\left(1-\delta^{\alpha}\right)\left(1-\mu\right)\right)^{(1-\alpha(1-\mu))}}{\left(1-\alpha 0.5\left(1-\mu\right)\right)^{(1-\alpha(1-\mu))}} \right)^{\frac{1}{\alpha}} \Gamma^{1-\mu} < 1, \quad (62)$$

if Γ is not too large. Again, note that this is because $f(b) = (1-ab)^{1-a}\, b^{a}$ is increasing in b for $b \in (0,1)$ and $a \in (0,1)$. Hence, $\exists\, z \in (0,1)$ such that $\pi^{O}\left(z^{*}\right) = \pi^{VI}\left(z^{*}\right)$.