

# Breaking Up Is Hard To Do: Why Firms Fragment Production Across Locations

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## Abstract

This paper assesses the role of communication technology, relative to wage differences and transportation costs, in a firm's decisions to (i) break up its production process; and (ii) source its fragmented production offshore. Using an original dataset of U.S. manufacturing plants' decisions to contract for manufacturing services from domestic or foreign suppliers, I uncover a new set of stylized facts about fragmentation. I develop a theoretical framework consistent with these facts in which firms fragment production to access cheaper labor, but incur communication and transportation costs in doing so. Additional tests support the theory. Plant use of communication technology is associated with an 18 percentage point increase in the probability of fragmentation, and a ten point increase in the probability of locating fragmented production offshore. While wage differences and distance to suppliers are also significant factors in plants' decisions to fragment and offshore, communication technology accounts for five times more of the explained variation than wages and distance combined. In contrast, for the decision about how *much* to offshore, wage differences are relatively more important than distance, and technology explains almost none of the observed variation.

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# 1 Introduction

There is increasing interest in firms' decisions to break up or fragment parts of their production processes. The importance of fragmenting across countries, i.e., offshoring, is evidenced by the large share of intermediate inputs in international trade (Yeats, 2001; Hummels et al., 2001), and is frequently attributed to new communication technology.<sup>1</sup> However, there is little systematic evidence of the impact of communication technology on offshoring, or of its importance relative to traditional trade or labor cost saving motives. In addition, much of the discussion has centered on offshoring because of its potential to harm domestic employment and wages, but some of these potential costs would be absent, or at least mitigated, by domestic rather than foreign fragmentation. We have even less evidence on firms' decisions to fragment domestically, though it may be an alternative to offshoring with very different implications for national welfare.

In this paper I assess the role of technology, relative to wage differences and transportation costs, in a firm's decisions to break up its production across foreign and domestic locations. Using original micro data from the 2007 U.S. Census of Manufactures (CM), I uncover novel facts about the fragmentation of inputs that are customized to meet a firm's specific production criteria. This type of customized fragmentation requires communicating specifications across locations so that the data are uniquely suited to assess the role of communication technology in fragmentation. I develop a theoretical framework that incorporates the new facts and delivers predictions about the trade-off that firms face between labor cost savings and fragmentation costs. Additional tests support the theory and suggest that communication technology is the most important factor in a firm's decision about whether or not to fragment or offshore, while wage differences matter most in the determining the extent to which it does so.

The new CM data identify whether a plant purchased contract manufacturing services (CMS) from other plants (within its company or from another company) to process its inputs; and if so, whether the plant primarily purchased these services domestically or abroad. I combine these data with additional information from the CM, the Longitudinal Business Database (LBD), and firm-level imports, to document a number of new facts about plants that fragment their customized production process. First, a substantial share

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<sup>1</sup>For example, Grossman and Rossi-Hansberg (2008) state "Revolutionary advances in transportation and communications technology have weakened the link between labor specialization and geographic concentration, making it easier to separate tasks in time and space" (p. 1978); Rodríguez-Clare (2010) says, "Falling costs of coordination and communication have allowed firms in rich countries to fragment their production process and offshore an increasing share of the value chain to low-wage countries" (abstract); and Baldwin and Venables (2010) attribute fragmentation of production to " ...revolutionary advances in information and communications technology that massively lowered the cost of organising complex activities over distances" (p. 1).

of plants do not fragment production across locations. In addition, despite the increase in imported inputs, the majority of plants that fragment primarily source from domestic suppliers. The share of plants that fragments production domestically is 13 times higher than the share of plants that offshores, and they employ almost nine times more workers. The data also show that plants that fragment production to any location are larger and more productive, particularly so if they offshore.<sup>2</sup> These aggregate patterns also hold within industries and reveal substantial heterogeneity in firms' sourcing strategies that are not explained by sectoral differences in production requirements. Finally, I find considerable differences in the geographical distribution of fragmenting plants. Most importantly, 22 percent of plants in low wage states fragment domestically, compared to 30 percent in high wage states.

I incorporate the stylized facts into a model of heterogeneous firms that can fragment production across domestic and foreign locations. The model extends Grossman and Rossi-Hansberg (2008) to incorporate domestic fragmentation and non-participation within industries, two key findings in the data. More specifically, firms make their final good from a set of production tasks, and these tasks can be performed in foreign or *domestic* locations in which labor costs are lower. However, breaking up production is hard to do because firms must incur a fixed cost to establish a supply network and per-task costs to communicate product specifications and transport output.<sup>3</sup> The model predicts that per-task fragmentation costs are decreasing in firms' communication technology and proximity to suppliers. In addition, firms in high wage states have the largest number of lower cost sourcing options, while firms in low wage states must offshore to access cheaper labor. Firms also differ in the efficiency of their final good production, so that the fixed costs of fragmentation lead to standard productivity sorting predictions. While the productivity sorting is similar to Antràs and Helpman (2004) and Helpman et al. (2004), heterogeneity in firms' per-task costs and potential for labor cost savings is entirely new.

Guided by the theory, I estimate the relative importance of labor cost savings, communication technology, and transportation costs in plants' decisions to fragment production and offshore. The estimates suggest that plant use of electronic networks to coordinate shipments (as a measure of communication technology) increases the probability of fragmentation by 18 percentage points, comparable to the effect of doubling the home wage. Conditional on fragmenting, the probability that a plant will offshore is ten percentage

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<sup>2</sup>The finding of a productivity premia for offshorers is consistent with Kurz (2006) who analyzes U.S. plant-level data on foreign purchases of materials by manufacturers in 1987 and 1992; and Tomiura (2007) who creates productivity rankings for Japanese firms' sourcing choices. This paper extends those findings by showing they hold for fragmentation of customized inputs.

<sup>3</sup>In Antràs et al. (2006) and Antràs et al. (2008), communication technology affects how heterogeneous agents sort into international production teams. In those papers, the focus is on the interaction of skill and technology differences, and all offshoring takes place within the boundary of the firm. I do not model skill differences and offshoring can take place within or outside the firm.

points higher for plants that use electronic networks. This effect is similar in magnitude to the 12 point decrease in the probability of offshoring fragmented production associated with a doubling of the plant's home wage. The negative relationship between a fragmenting plant's home wage and the probability it will offshore is consistent with the theoretical prediction that plants fragmenting production in lower wage states search for cheaper labor offshore. Plants that are farther away from foreign entry ports are also less likely to fragment offshore, supporting the premise that transportation costs affect plants' sourcing strategies.

Using the linked census-import data, I also examine the intensive margin of offshoring. As expected, I find that conditional on positive offshoring, the share of offshored production is decreasing in the relative foreign wage and firms' distance to ports. This extends Hanson et al. (2005), who find that U.S. multinationals offshore more from low wage countries, and when transport costs are low. The analysis here adds a measure of communication technology and includes fragmentation that is outside the boundary of the firm. More importantly, this paper compares key determinants' impact on the extent of offshoring, to their impact on whether or not to offshore in the first place. While the estimated coefficients suggest that communication technology, wages, and distance are all important factors in a firm's decision to fragment and offshore, the observed variation in producers' electronic network use accounts for five times more of the explained variation than wages and distance combined. In contrast, for firms' decision about how *much* to offshore, wage differences are relatively more important than distance, and technology explains almost none of the observed variation.

A plant's use of communication technology may depend upon the fragmentation strategy it plans to adopt.<sup>4</sup> To address this issue, I focus on electronic networks' ability to lower fragmentation costs by facilitating communication about production requirements. If this mechanism is at work, the effect of communication technology will depend upon a firm's ability to codify its product specifications in an electronic format. Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) software enables plants to codify specifications in an electronic format that can be sent to suppliers, but the extent to which plants can use CAD/CAM depends upon their industry's production process characteristics.<sup>5</sup> I find that plants using networks in the most CAD/CAM intensive industries are about 20 percentage points more likely to fragment production than plants using networks in the least CAD/CAM intensive industries. Exploiting differences in communication and information technology is similar to Bloom et al. (2011) who estimate the differential effect

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<sup>4</sup>See Bustos (2011) for a model in which firm technology is an endogenous choice that affects the firm's export decision.

<sup>5</sup>Conversations with contract manufacturing suppliers at the Mid-Atlantic Design-2 Part Show in April 2011 suggest that communication technology makes fragmentation easier when it can be used in conjunction with CAD/CAM software.

of communication technology and CAD/CAM, on firms' hierarchy structure. While those authors argue that CAD/CAM empowers local managers thereby decentralizing decision-making, I show that it increases communication technology's effectiveness in transmitting information and thus facilitates production fragmentation.<sup>6</sup>

Although plants that use electronic networks in CAD/CAM intensive industries are more likely to fragment, the results also show that they are *less* likely to locate their fragmented production offshore. A potential explanation is that the effectiveness of plants' communication technology also depends upon suppliers' ability to receive and process electronic communications. Consistent with this hypothesis, estimates from firm-country level import data show that firm communication technology and industry CAD intensity are associated with a larger increase in the probability of sourcing from more technologically advanced countries. This analysis extends Yeaple (2003) who finds that FDI in skill intensive industries is more likely to occur in skill abundant countries.<sup>7</sup> The results support the premise that technology facilitates production fragmentation, but uncover substantial heterogeneity in its effectiveness across firms, industries, and sourcing locations.

The primary contribution of this paper is to document an empirical relationship between communication technology and firms' fragmentation and offshoring decisions. To my knowledge, this is the first systematic evidence on a relationship that is assumed in much of the existing theory, and which has the potential to affect a number of the theory's policy implications. The results suggest that improvements in communication technology matter more than wage differentials and distance to suppliers in U.S. producers' decisions about whether to fragment and offshore. In contrast, labor cost savings are the most significant factor in their decision about how much to offshore. The analysis also shows that the impact of communication technology varies significantly across industries and countries. Incorporating this variation into existing theory may lead to nuanced, but also richer and more informative, predictions about offshoring. Another contribution of the paper is to show, theoretically and empirically, that domestic fragmentation is a viable sourcing option chosen by a significant share of U.S. manufacturing producers. While domestic fragmentation and offshoring may both entail significant employment changes, their national welfare implications are potentially quite different. Finally, the paper highlights the importance of geographic heterogeneity in producers' fragmentation costs and benefits and shows how this variation is related to firms' organization of production.

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<sup>6</sup>The complementarity I find between electronic communication and CAD/CAM may explain why Bloom et al. (2011) do not obtain statistically significant estimates on their measure of electronic communication.

<sup>7</sup>The results also relate to Head et al. (2011) who show that Chinese cities tend to import from multiple countries, but cities vary in their propensity to source from a given country. The authors posit that the nationality of foreign affiliates may drive a city's orientation towards a given country. This paper suggests an alternative explanation. Firms differ in their technological capabilities, and this variation may drive their compatibility with different sourcing locations.

In the next section, I describe the new data and explain why fragmentation is a difficult but important activity to measure. In Section 3, I present new stylized facts about plants and firms that fragment their production and describe the main phenomena the model should capture. I develop the model in Section 4 and outline the empirical predictions. In Section 5 I assess the model's predicted equilibrium relationships along both the extensive and intensive margins. Section 6 concludes with a summary of the paper's main implications and ideas for future work.

## 2 Plant level fragmentation data

The fragmentation data are based on a new question in the 2007 Census of Manufactures (CM). The question asks: "Did this establishment purchase contract manufacturing services from other companies or other establishments or your company to process materials or components that this establishment owns or controls?" Establishments that answer yes are also asked whether they primarily purchase these services domestically or abroad.<sup>8</sup> I cannot provide any actual examples of firms or contract manufacturing service (CMS) purchases in the Census data because the data are confidential and respondents' identities cannot be revealed. However, hypothetical examples of CMS purchases include the manufacturing of company A's MP-3 player components as instructed by company A; the assembly of company B's computer processing chips in B's overseas plants using specified inputs and a precise design criterion; and the production of company C's shoes in non-affiliated factories using soles provided and materials specified by company C. In each case, the purchaser furnishes production specifications to the manufacturing service provider.

The CMS question was designed to identify manufacturing establishments that do not perform all of the physical transformation activities required to complete their final good. When an establishment pays another firm to perform some of its manufacturing activities, that establishment is both fragmenting and "outsourcing" production. If multiple plants within the same firm perform different stages of production, that firm is not outsourcing, but it is fragmenting production. According to the Office of Management and Budget (OMB), accurate measures of economic activity require identifying fragmentation both within and outside the firm, because "When producers subcontract portions of the production process to separate affiliated or unaffiliated units, the production function changes at the establishment level" (OMB (2009), p. 766).<sup>9</sup> Fragmentation is also important because it is a

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<sup>8</sup>An establishment denotes a single physical location where business transactions take place and for which payroll and employment records are kept. It is synonymous with a plant. The question as it appeared on the Census form is presented in the online data appendix, available here: [http://econweb.umd.edu/~fort/Data\\_Appendix.pdf](http://econweb.umd.edu/~fort/Data_Appendix.pdf).

<sup>9</sup>The OMB (2011) notes that fragmentation and the resulting changes in the production function affect

necessary step for firms that relocate part of their production process overseas, or “offshore.” Offshoring takes place within and outside the boundaries of the firm and has received ample attention in the literature. There are numerous ways in which offshoring has been measured, but to my knowledge, none are comparable to the CMS data analyzed here.

The CMS data provide new information about fragmentation since they differ from existing measures along several dimensions. First, the data include a comprehensive domestic fragmentation measure. Much of the existing literature on fragmentation focuses only on offshoring, but ignoring domestic fragmentation may confound factors that affect breaking apart the production process with factors that affect locating a portion of production overseas. Second, the data are collected at the plant level and reveal substantial intra-industry heterogeneity in plants’ and firms’ fragmentation decisions. Third, the data contain both outsourced and integrated production, unlike measures of foreign direct investment that consist only of the latter. The inclusion of both types of fragmentation is important since, as noted in Feenstra (1998), “looking within multinational firms alone does not give a full perspective on what is happening” (p. 36).<sup>10</sup> Fourth, the data do not rely on imported intermediates as a measure of foreign fragmentation. Identifying intermediate trade often relies on input-output tables that are relatively coarse and therefore unlikely to identify intermediate inputs exclusively or entirely.<sup>11</sup> Imports of intermediates are also a limited measure since they exclude final goods that are assembled overseas and then re-imported into the home country. Finally, imported inputs can include raw commodities and standardized “off-the-shelf” inputs. Commodity trade is generally not considered offshoring, and it is unclear whether intermediate goods sold in the marketplace represent production fragmentation. While the degree of specificity needed to classify input trade as fragmentation is ambiguous, the data I use clearly identify trade in inputs (of goods and services, such as assembly) that are specialized for the purchaser, and therefore warrant classification as fragmentation.

The CMS data only capture fragmentation of production that is customized to meet buyers’ specifications, and in that sense may represent a subset of overall production fragmentation. Since this type of fragmentation requires communicating product specifications and coordinating input production so that all components fit together, it is especially relevant for assessing the effect of technology on coordination and communication costs across separate production locations. Understanding customized fragmentation is also valuable since it is a

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industry and sector classifications which in turn have an impact on measures such as the Bureau of Labor Statistics producer price index, productivity indices, employment, and wages; and the Bureau of Economic Analysis industry accounts, national income accounts, and regional accounts. Houseman et al. (2011) also discuss how ignoring fragmentation may lead to systematic productivity mismeasurement in the U.S economy.

<sup>10</sup>A limitation of the data is that they do not distinguish between fragmentation that takes place within or outside the firm so that it is not possible to assess theory about optimal firm boundaries.

<sup>11</sup>Two new approaches for identifying intermediate trade are proposed by Sitchinava (2008) and Wright (2011).

relatively new phenomenon;<sup>12</sup> disruptions in the supply of customized inputs are extremely costly;<sup>13</sup> and recent trends in U.S. manufacturing suggest customized production will form an increasingly significant part of economic activity.<sup>14</sup>

## 2.1 Description of the CMS sample

The CM is conducted in years that end in 2 and 7. It covers the universe of manufacturing establishments in the U.S, though not every establishment is asked the CMS question. While all large plants and all plants that belong to multi-unit firms were asked the CMS question, only a random sample of small and medium-sized plants was asked the question. Data for the smallest manufacturing plants, generally those with less than five employees, are based only on administrative records and therefore do not include any information about those plants' CMS purchases.<sup>15</sup> Since the administrative records are often based on imputed data, have no information about CMS purchases, and account for only 1.5% of sales and three percent of employment in the manufacturing sector, I exclude them from the entire analysis. All establishments that receive a census form in the mail are legally required to return the completed form. Despite the legal requirement, a fraction of establishments did not respond to the CMS question.

I assess the observable characteristics of plants outside the CMS sample to address potential issues from sample selection. While the CMS sample covers 54 percent of manufacturing establishments (excluding the administrative records), it includes 75 percent of sales and 71 percent of employment. The online data appendix provides information on the plants outside the CMS sample. To correct for differences between the sample and the population of potential respondents, I estimate the probability that an observation is in the CMS sample. Following Cameron and Trivedi (2005), I use the inverse probability as a weight in the empirical analyses.<sup>16</sup> Details of the missing data and weights estimation are in the online data appendix.

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<sup>12</sup>Trade in standardized inputs, and especially commodities, has been common for hundreds of years. For example, see chapters six and seven in Findlay and O'Rourke (2007).

<sup>13</sup>The recent earthquake in Japan provides a stark example.

<sup>14</sup>According to of Forrester Research, "We're entering a new era in which mass customization will lead a number of consumer product categories..." Gowdner (2011).

<sup>15</sup>The CM uses both short and long form questionnaires, and only the long forms ask the CMS purchase questions. While all large and multi-unit firm establishments receive the long form, only a random sample of small, single-unit firms receive the long form. Data for the smallest establishments is imputed from Federal tax returns and industry averages.

<sup>16</sup>Cameron and Trivedi recommend using weights ("that are inversely proportional to the probability of inclusion in the sample") for a descriptive or data summary approach. They note that if a regression model is correctly specified then sample weighted and unweighted estimates should have the same probability limit, Cameron and Trivedi (2005) pp. 817-21.

## 2.2 Aggregating to the firm level

To assess firm-level sourcing decisions, I aggregate the plant data to the firm level.<sup>17</sup> I classify firms with at least one offshoring plant and no domestic fragmenters as “Offshore Purchases.” Firms with at least one domestic fragmenting plant and no offshoring plants are classified as “Domestic Purchases.” Firms with at least one plant that purchases domestic CMS and at least one plant that purchases foreign CMS are classified as “Domestic and Offshore Purchases.” Finally, firms that have no plants that purchase CMS, and have at least one plant that reported no purchases of CMS are designated as “No Purchases.” Note that, due to the question design, an establishment can only source primarily domestically or primarily offshore, while multi-unit firms can potentially do both.

## 2.3 Additional plant-level variables

I supplement the production fragmentation data with plants’ total value of sales, number of employees and industry from the CM. I match the census data to the LBD to obtain the firms’ employment in all other sectors; and to the Business Register to identify plants’ latitude and longitude.<sup>18</sup> By linking the firm-level data to the U.S. Customs import transactions data, I also identify the value, country, and product of firms’ imports.<sup>19</sup> I restrict the import data to imports of manufactured products since imports of inputs that correspond to fragmented production should be classified in manufacturing.

I construct a value-added labor productivity measure for plant  $i$  as  $vap_i = va_i/te_i$ , where  $va$  denotes value-added and  $te$  denotes total employment. plant sales, employment, and productivity all vary significantly across industries. To make meaningful comparisons of these variables across plants in different industries, I calculate a relative measure  $x_{i,g}/\bar{x}_g$ , where  $\bar{x}_g$  is the mean of variable  $x$  in the six digit NAICS industry  $g$ . I use the relative productivity measures to construct firm-level productivity. In Section 3, I also use these relative measures to compare plant characteristics across CMS purchase types.

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<sup>17</sup>The census data have a variable, *firmid*, that identifies the firm to which a given establishment belongs. This variable is superior to the employer identification number (EIN) used in other datasets to identify ownership. Since a single firm can use multiple EINs to file its tax returns, EINs may only identify part of a large firm.

<sup>18</sup>The LBD is a longitudinal panel of every private, non-farm establishment with at least one employee in the U.S. See Jarmin and Miranda (2002) for details on the LBD.

<sup>19</sup>It is not possible to link the trade transactions data to individual establishments for multi-unit firms. See Bernard et al. (2009) for a detailed description of the import data.

### 3 New empirical facts

The census data provide new information about which plants and firms fragment their production. The data also highlight within industry patterns about producers' sourcing decisions. The linked firm-import data show the relationship between importing and offshoring and provide evidence on the foreign locations from which firms purchase CMS. This section presents the new information summarized in ten stylized facts.

#### 3.1 Plant and firm-level participation shares

Table 1 presents plant participation shares by CMS purchase status. The first column shows that 27 percent of plants fragment primarily domestically, while only two percent fragment primarily offshore. The majority of plants do not purchase CMS, and of those that do, only a small fraction primarily offshore.<sup>20</sup> Columns 2 and 3 provide the share of sales and employment respectively by plants' CMS purchase status, weighted by the inverse probability of being in the CMS sample. The percentages of sales and employment at plants that offshore doubles to four percent, while the percent of sales and employment at plants that fragment domestically jumps to 39 percent and 35 percent respectively. These findings are summarized as the following facts:

*Fact 1: The majority of plants do not fragment their production process for customized inputs, even on a sales or employment-weighted basis.*

*Fact 2: Domestic fragmentation is far more prevalent than offshoring.*

Although most plants are single-unit firms, approximately 40 percent of the plants in the CMS sample belong to multi-unit firms. Table 2 illustrates important differences between the plant and firm-level shares. While a majority of sales and employment take place at plants that do not purchase CMS, columns 2 and 3 show that firms that do not purchase CMS account for only 31 percent of sales and 42 percent of manufacturing employment. The differences between the plant and firm level results are largely driven by the high sales and employment shares of firms with some plants that source domestically and others that

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<sup>20</sup>Low participation shares are consistent with Hillberry and Hummels (2008) who examine the 1997 Commodity Flow Survey data and find that most U.S. manufacturing plants do not ship goods across large distances. Limited offshore sourcing for customized production is in line with results in Tomiura (2007), who finds that only 2.68 percent of Japanese manufacturing firms outsource production offshore. There is almost no existing evidence on plants' domestic fragmentation, but Fally (2011) uses aggregate input-output tables to calculate the average number of sequential stages of domestic production, weighted by each stage's value-added. He finds the average number of manufacturing stages is less than two. See Appendix Section A for a discussion about the potential of substituting CMS purchases with standardized inputs.

source offshore. These firms account for only one percent of manufacturing firms, but cover 24 percent of sales and 16 percent of manufacturing employment.<sup>21</sup>

Table 2 provides additional support for *Fact 2*. Domestic fragmentation is more prevalent than offshoring at both the plant and firm level. Firms with plants that purchase CMS primarily domestically account for 55 percent of manufacturing employment, while firms with at least some offshoring plants account for 19 percent. In contrast, employment and sales participation shares differ between the plant and firm-level measures. Activity-weighted firm participation shares suggest that production fragmentation is a significant phenomenon in economic activity. While not all plants within a firm fragment production, large firms are more likely to have one or more plants that fragment. This finding is summarized by:

*Fact 3: The majority of U.S. manufacturing sales and employment takes place at firms with at least one plant that purchases CMS.*

### 3.2 Plant characteristics by CMS purchase status

Table 3 presents weighted means for plant sales, employment and the log of value-added labor productivity by CMS purchase status. Columns 1 and 2 show that the average plant that fragments production is larger in terms of both sales and employment than the average non-fragmenting plant. In addition, plants that fragment production offshore are larger than domestic fragmenters. The average sales at manufacturing plant with no CMS purchases is approximately \$19 million, while the average sales at an offshoring plant is over \$50 million. Column 3 shows a similar pattern for productivity. Domestic purchasers are more productive than plants with no fragmentation, while offshorers are the most productive. Columns 4-6 present averages by CMS purchase status for relative industry measures. As described in Section 2.3, the relative measures capture within industry heterogeneity and ensure that patterns across categories are not driven by industry compositional differences. The same patterns hold for the within-industry measures. Plants with no purchases are smaller and less productive than plants that purchase CMS domestically; and offshoring plants are the largest and most productive plants. These results lead to two more stylized facts:

*Fact 4: Plants that fragment production are larger and more productive than non-fragmenters.*

*Fact 5: Plants that fragment production offshore are larger and more productive than domestic fragmenters.*

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<sup>21</sup>The online data appendix decomposes this table into firms with and without wholesale establishments.

### 3.3 Industry distribution of CMS purchases

To explore variation in fragmentation within industries, Table 4 presents the industry distribution of the share of plants that purchase CMS domestically and offshore. I calculate participation shares within each of the 86 four digit North American Classification System (NAICS) manufacturing industries. The first column shows that there are two industries in which no plants offshore production. In one of these non-offshoring industries, 10-20 percent of the plants purchase CMS domestically, while in the other industry 20-35 percent of plants do. The first striking observation from Table 4 is that all industries have a positive share of plants that purchase domestic CMS. At least five percent of the plants in every industry fragment domestically. Table 4 also shows substantial non-participation in every industry. The highest observed share of fragmenting plants is almost 60 percent.<sup>22</sup> These findings are summarized by:

*Fact 6: There is substantial within industry heterogeneity in plants' sourcing strategies.*

Examining the diagonal of Table 4, it is evident that every industry has a higher share of domestic fragmenters than offshoring plants. This finding provides additional support for *Fact 2*. Domestic sourcing is more prevalent than offshoring within all NAICS 4 industries.

### 3.4 Geographic distribution of CMS purchases

Plant participation shares also vary across U.S. states. I calculate the average production worker wage per state and classify states as low wage, medium wage, and high wage depending upon the tercile to which their wage corresponds.<sup>23</sup> Table 5 presents the average share of plants within each wage category by CMS purchase status. While two percent of plants offshore in all wage categories, domestic fragmentation varies substantially. Only 22 percent of plants purchase CMS domestically in low wage states, while 30 percent fragment domestically in high wage states. This finding leads to an additional stylized fact:

*Fact 7: Domestic fragmentation is more prevalent in high wage states.*

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<sup>22</sup>See the online data appendix for summary statistics about plant participation shares within six digit NAICS industries.

<sup>23</sup>See the online data appendix for details on the wage measure.

### 3.5 Firm import patterns

The CMS data capture the subset of fragmentation in which inputs are customized to meet buyers' specifications. To compare this customized offshoring to measures based on imports, Table 6 shows the share of manufacturing firms' imports of manufactured goods, by firms' CMS purchase status. Column 1 indicates that firms with one or more plants that purchase CMS account for 67 percent of imports. Domestic fragmenters import 36 percent of imports, while offshoring firms import 31 percent. Columns 2 and 3 show that average imports by domestic fragmenters are \$7.2 million, compared to \$18.7 million for offshorers and \$429 million for firms with a mix of plants that fragment domestically and abroad. While it is impossible to measure the exact extent to which imports correspond to CMS purchases, offshoring firms' high share of imports and large average imports suggest that offshore CMS purchases constitute an important trade activity.

Table 6 also presents the average extent to which firms offshore, measured as firms' imports over sales.<sup>24</sup> Column 4 shows that domestic fragmenters source a relatively small share of their production offshore. Their average imports over sales is only three percent, compared to 20 percent for firms that primarily offshore. Somewhat surprisingly, firms with no CMS purchases import an average of nine percent of their sales. To assess whether this high share may result from industry compositional differences or sales in other sectors, I calculate firms' share of imports over sales relative to the average share of their modal industry. Excluding firms with employment outside of manufacturing, the relative shares are 0.67, 0.68 and 3.9 for non-purchasers, domestic fragmenters, and offshorers respectively. Offshoring firms' share of imports over sales is almost four times their industry average, while non-purchasers and domestic fragmenters' share is less than their industry mean. This leads to an additional fact:

*Fact 8: Firms that source customized inputs primarily offshore have a disproportionately high share of imports over sales.*

Although the CMS data lack specific details about the products and locations from which firms fragment, the trade data provide information about the products and countries of firms' imports. Column 1 in Table 7 shows that about 40 percent of firms that do not purchase CMS import manufactured goods. Imports by firms that do not purchase CMS may reflect purchases of standardized materials, inputs, or final goods that are sold in the marketplace; or they may reflect imports that relate to activities in other sectors in which

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<sup>24</sup>Since a significant portion of manufacturing firms that import have wholesale establishments, I include firms' sales in manufacturing and wholesale in the denominator. Firms may have sales in other sectors, but these data are not readily available. The online data appendix provides a decomposition between firms with and without wholesale establishment.

the firm is active. About half of all firms that purchase domestic CMS import goods, while 90 percent of offshoring firms import. Firms that purchase CMS offshore but do not import may be offshoring the final assembly of goods that they sell overseas.<sup>25</sup> Nearly all firms that purchase CMS both domestically and offshore import manufactured goods. Table 6 also shows firms' share of imports from low-income countries. I classify countries as low income if they are in the bottom two per-capita GDP terciles.<sup>26</sup> Column 2 shows that firms with no CMS purchases and domestic CMS purchases import 28 and 19 percent of their manufactured good imports from low-income countries respectively. In contrast, offshorers source almost half of their imports from low-income countries. This leads to the following fact:

*Fact 9: Offshoring firms import relatively more from low-income countries than domestic fragmenters and non-fragmenters.*

Table 7 also provides information about the products and countries from which firms import. Column 2 shows that the median count of distinct ten digit Harmonized System (HS) codes imported by firms is zero for firms with no CMS purchases and one for domestic fragmenters. In contrast, firms that purchase CMS offshore import a median of eight distinct products, and firms with both domestic and offshore purchasing plants import a median of 123 products. Column 3 shows that this pattern holds for the subset of importing firms in each category. Columns 4 and 5 provide the same statistics for the number of countries from which a firm imports. Firms with no CMS purchases import from a median of zero countries, domestic fragmenters import from a median of one, and offshorers import from a median of three. Firms with a mix of plants that source domestically and others that source offshore import from a median count of 20 countries. Conditional on importing, firms that source primarily offshore still import from more countries than firms that fragment domestically or not at all.

The firm-level import patterns in Tables 6 and 7 provide a reassuring validation of the CMS data. The vast majority of firms that purchase CMS primarily offshore import manufactured goods. In addition, these firms import a wider range of products from a greater number of countries compared to firms that purchase CMS primarily domestically or not at all. Table 7 also shows that firms that purchase CMS offshore tend to source from multiple countries. These findings are summarized by a final stylized fact:

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<sup>25</sup>Almost all of these firms export goods. It is also possible that some firms are erroneously classified as non-importers due to an inability to link the import data to the census data. This should not be a big issue, however, as I match 92 percent of the transactions and 91 percent of the value of imports.

<sup>26</sup>I obtain countries' per-capita GDP in 2007 from the International Monetary Fund. The GDP data are unavailable for a small number of countries that represent less than one percent of imports in each CMS category.

*Fact 10: Offshoring firms are more likely to source multiple goods and from multiple countries than domestic fragmenters and non-fragmenters.*

### 3.6 Summary of important findings

The new CMS data provide key insights into plant and firm level fragmentation strategies. A substantial share of plants and firms do not break apart their production of customized inputs, and the vast majority of those that do primarily source domestically. Plants that fragment production are larger and more productive than non-fragmenters; and plants that source offshore are the largest and most productive. These patterns persist within industries, indicating substantial within industry heterogeneity in firms' sourcing strategies. In addition, high wage states have the largest share of plants that fragment production domestically. Finally, offshoring firms import a disproportionate share of their production, in a greater range of products and from a higher fraction of low income countries.

## 4 Model of Production Fragmentation

In this section, I develop a static partial equilibrium model of firms' production fragmentation decisions. It is a model of heterogeneous firms with an exogenous wage similar to Helpman et al. (2004) and Antràs and Helpman (2004), but incorporates the concept of task production with costly fragmentation originally introduced by Grossman and Rossi-Hansberg (2008). The model incorporates the stylized facts presented in Section 3 and provides a framework to assess the costs and benefits associated with fragmenting production across different locations.

### 4.1 Demand

Consumers are identical with preferences represented by

$$U = \prod_{j=1}^J Q_j^{\lambda_j}, \quad \sum_j \lambda_j = 1,$$

where  $Q_j$  is an index of aggregate consumption in industry  $j$ , and  $\lambda_j$  is an exogenous share of income spent on industry  $j$ . Aggregate consumption in industry  $j$  is a constant elasticity

of substitution function

$$Q_j = \left( \int_{i \in j} q(i)^\sigma di \right)^{1/\sigma},$$

where  $\varepsilon = \frac{1}{1-\sigma} > 1$  denotes the elasticity of substitution between goods in a given industry. For now I drop the  $j$  subscripts with the understanding that all industry variables refer to industry  $j$ .

These CES preferences lead to demand for a particular variety  $i$  in a given industry,

$$q(i) = Ap(i)^{-\varepsilon}, \quad A = \frac{\lambda E}{\int_{i \in j} p(i)^{1-\varepsilon} di} \quad (1)$$

where  $p(i)$  is the price of variety  $i$  and  $E$  is aggregate expenditure.

## 4.2 Production

There is an exogenous mass of producers,  $N_{jh}$ , in each industry and geographic home state  $h$ . In the model, producers' location is exogenous to their sourcing arrangement. In the empirical section, I consider the possibility that producers choose their location based on their anticipated sourcing strategy and use several approaches to address the potential biases that could result.

Labor is the only factor of production and is supplied inelastically. Producers use one unit of labor to produce one unit of task output. Production in each industry requires a continuum of tasks, normalized to one and indexed by  $k$ . Producers combine task output via a Leontief production function to produce a single composite input  $M$ . More formally,  $M = \min_k \{m_k\}$ ,  $k \in [0, 1]$ , where  $m_k$  denotes the output of task  $k$ .<sup>27</sup>

Producers have heterogeneous productivity denoted by  $\varphi > 0$ . They transform the composite input  $M$  into their product via:  $q = M/\varphi$ . Productivity can therefore represent production efficiency (same quality at lower cost) or product quality (higher quality at equal cost). The key assumption here is that productivity heterogeneity affects the transformation of the input  $M$  into output  $q$ , but does not alter firms' ability to convert labor into task output.<sup>28</sup>

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<sup>27</sup>The assumption of single composite input with a Leontief production function is based on the set-up in Rodríguez-Clare (2010). The assumption of no substitutability between tasks that use the same factor of production is common in the literature and simplifies the analysis. The model could be extended so that the composite input is produced via a constant elasticity of substitution technology that depends on the intensity with which each task is performed.

<sup>28</sup>This assumption is similar to Antràs and Helpman (2004) where a firm's productivity does not affect the productivity of its input suppliers. See Appendix Section B.3 for additional discussion.

### 4.3 Profits within an integrated plant

With CES preferences, the optimal final goods' price is a mark-up over marginal cost and is given by  $p_i(\varphi) = C_i/\varphi\sigma$ , where  $C_i$  denotes the marginal cost of the input  $M$  for firm  $i$ . Let  $w_h$  denote the wage in the producer's home state. Because producers make  $m_k$  one to one from labor, the cost of one unit of  $M$  at the integrated producer is  $C_i = w_h$  and its profits are:

$$\pi_I = \frac{(1 - \sigma)A}{\sigma^{(1-\varepsilon)}} \left[ \frac{\varphi}{w_h} \right]^{(\varepsilon-1)}. \quad (2)$$

As is standard in this class of models, the most productive producers are also the biggest producers.

### 4.4 Production with fragmentation across locations

When fragmentation is possible, final good producers can purchase task output from manufacturing service providers (MSPs) in different locations.<sup>29</sup> MSPs specialize in the production of a single task that they customize for multiple final good producers. By specializing, the MSP is more efficient at the production of a given task than an integrated plant.

#### 4.4.1 Benefits from fragmentation

The MSP efficiency gain is captured by its use of  $\alpha < 1$  units of labor to produce one unit of  $m_k$ .<sup>30</sup> MSPs are located in a domestic state,  $D$ , or offshore,  $O$ . There is free entry and perfect competition among MSPs so that the price of a task purchased from an MSP in sourcing location  $s$  is simply equal to its local production cost:

$$P_s(m_k) = \alpha w_s, \text{ where } s \in \{D, O\}. \quad (3)$$

By purchasing tasks from an MSP, a final good producer benefits from the gain in specialization,  $\alpha$ , and can access potentially cheaper labor in the MSP's location.

<sup>29</sup>MSP is the term used by practitioners and by the U.S. Census Bureau to describe these specialized suppliers.

<sup>30</sup>The model could be extended to allow  $\alpha$  to vary across sourcing locations. Grossman and Rossi-Hansberg (2009) argue that countries may differ in their productivities for given activities due to external economies of scale. Lafontaine and Sivadasan (2009) find that differences in labor market institutions across countries affect within firm labor productivity.

#### 4.4.2 Costs of fragmentation

Although purchasing tasks from MSPs allows a final good producer to enjoy efficiency gains and access cheaper labor, it also entails certain costs. Establishing a supply network incurs a fixed cost  $f_D$  when the MSP is domestic and  $f_O$  when the MSP is foreign, with  $f_D \leq f_O$ . These costs are paid in the final good producer's home wage.

Fragmentation also incurs a task specific cost due to the additional transportation and coordination needs associated with breaking up the production function across locations. The fragmentation cost for firm  $i$  in industry  $j$  to source task  $k$  from location  $s$  is represented by the function:

$$\tau(\delta_{is}, \omega_k, \eta_i, \eta_s, \rho_j) \geq 1 \quad (4)$$

which I assume is continuously differentiable in all its arguments.  $\delta_{is}$  denotes the distance between the final good producer and the sourcing location  $s$ . Transportation costs are increasing in distance so that  $\frac{\partial \tau}{\partial \delta} > 0$ .  $\omega_k$  represents an inherent characteristic, such as weight, of the output from task  $k$ .  $\frac{\partial \tau}{\partial \omega} > 0$  reflects task-specific differences in fragmentation costs attributable to these inherent differences.  $\eta_i$  captures producer  $i$ 's information technology, while  $\eta_s$  reflects the state of technology in the sourcing location. I assume technology lowers fragmentation costs so that  $\frac{\partial \tau}{\partial \eta} < 0$ .  $\rho_j$  represents the extent to which production technology in industry  $j$  is amenable to electronic communication. In the empirical section, I assume that electronic communication about the production process lowers fragmentation costs so that  $\frac{\partial^2 \tau}{\partial \eta \partial \rho} < 0$ . In addition, firms with better technology enjoy greater fragmentation cost savings when they source from locations with better technology so that  $\frac{\partial^2 \tau}{\partial \eta_i \partial \eta_s} < 0$ .

Final good producers pay the task specific fragmentation costs in units of labor from sourcing location  $s$ .<sup>31</sup> The per-unit cost to final good producer  $i$  for task  $k$  purchased from an MSP in location  $s$  is then:

$$c_{kis} = \alpha w_s \tau(\delta_{is}, \omega_k, \eta_i, \eta_s, \rho_j). \quad (5)$$

#### 4.5 Profits with fragmentation

Final good producers perform all tasks within a single integrated plant,  $I$ , or they can source an endogenous share of tasks from an MSP in another domestic state,  $D$ , or offshore location,  $O$ . To determine which sourcing strategy maximizes total profits, producers first maximize variable profits for each strategy. They then compare total profits across strategies by subtracting the respective fixed costs associated with fragmentation to a given location.

<sup>31</sup>Payment of fragmentation costs in units of foreign labor is based on the offshoring cost set-up in Grossman and Rossi-Hansberg (2008).

Fragmenting only maximizes variable profits if it results in lower costs of task production. Order tasks such that fragmentation costs are strictly increasing in the index  $k$ .<sup>32</sup> A necessary, though not sufficient, condition for fragmentation is then

$$w_h > \alpha w_D \tau_D(0) \text{ or} \tag{6a}$$

$$w_h > \alpha w_O \tau_O(0), \tag{6b}$$

where  $D$  and  $O$  denote the lowest cost domestic and offshore locations respectively, and  $\tau(0)$  denotes the fragmentation cost of task  $k = 0$ . Equation (6) simply states that the task with the lowest fragmentation cost must be cheaper to fragment, either domestically or offshore, than to produce in an integrated plant. Whenever Equation (6a) holds, then for offshoring to be potentially viable, it must also be the case that

$$\frac{w_O}{w_D} < \frac{\tau_D(0)}{\tau_O(0)}. \tag{7}$$

In this case, the decision to offshore is independent of the home wage and depends only the relative costs and benefits of sourcing from the lowest cost domestic location relative to the lowest cost foreign location. I assume that the distance to an offshore location is greater than the distance to a domestic location, and/or that domestic technology is superior to foreign technology so that  $\tau_D(k) < \tau_O(k) \forall k$ . From Equation (7), this assumption means that  $w_O < w_D$  for offshoring to occur. I also assume that  $\frac{\partial \tau_D(\cdot)}{\partial k} \leq \frac{\partial \tau_O(\cdot)}{\partial k}$ . As domestic fragmentation costs increase in the task index,  $k$ , offshoring costs increase at least as much.

Equations (6) and (7) highlight the role of relative wages and costs in determining whether fragmentation and offshoring take place. If the wage differential is not sufficiently high relative to fragmentation costs, then producers will not fragment and non-participation arises without any role for fixed costs and productivity. The other potential corner solution is  $w_h > \alpha w_s \tau_s(1)$ , where  $s \in \{D, O\}$ . In this case, producers fully fragment. Since the focus of this paper is on U.S. manufactures that still perform some fraction of their physical transformation activities, I assume  $w_h$  is sufficiently low so that full fragmentation does not occur.

If a producer only sources from one location  $s$ , then its optimal share of fragmented production,  $\bar{k}_s$ , is implicitly defined by

$$w_h = \alpha w_s \tau_s(\bar{k}_s), \text{ where } s \in \{D, O\}. \tag{8}$$

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<sup>32</sup>For this ordering to hold across locations, the task-specific component of fragmentation costs,  $\omega_k$ , can interact with distance or technology, but not both. Under this assumption, the ordering is without loss of generality and tasks' fragmentation cost order, though not their absolute size, is the same across locations. See the appendix for further discussion. Assuming costs are strictly increasing in  $k$  is not without loss of generality. The appendix in Grossman and Rossi-Hansberg (2006) addresses the possibility of flat portions in the offshoring cost function in a model of homogeneous firms and perfect competition.

With sourcing from one location, the cost of the composite input  $M$ , for producer  $i$  sourcing from  $s$  is now:

$$C_{is} = (1 - \bar{k}_s)w_h + \alpha w_s \int_0^{\bar{k}_s} \tau_{is}(k) dk, \text{ where } s \in \{D, O\}. \quad (9)$$

If a producer sources domestically and offshore, then its share of offshored production is  $\bar{k}_O$  which is implicitly defined by

$$\frac{w_O}{w_D} = \frac{\tau_D(\bar{k}_O)}{\tau_O(\bar{k}_O)}, \quad (10)$$

while  $\bar{k}_D$  is given by Equation (8). In this case, the producer's home wage has no effect on its share of offshored production. When a producer sources domestically and offshore, the cost of the composite input  $M$  is then

$$C_i = (1 - \bar{k}_D)w_h + \alpha w_O \int_0^{\bar{k}_O} \tau_O(k) dk + \alpha w_D \int_{\bar{k}_O}^{\bar{k}_D} \tau_O(k) dk, \quad (11)$$

where  $\bar{k}_O$  is the share of production offshored and the is  $\bar{k}_O - \bar{k}_D$  is the share fragmented domestically.

This new cost for the composite input  $M$  results in the following profits for producer  $i$ :

$$\pi_{is} = \frac{(1 - \sigma)A}{\sigma^{(1-\varepsilon)}} \left( \frac{\varphi}{C_{is}} \right)^{(\varepsilon-1)} - \sum_s w_h f_s, \text{ where } s \in \{D, O, DO\}. \quad (12)$$

## 4.6 Equilibrium sourcing strategy

In equilibrium, final good producer  $i$  chooses the sourcing location  $s$  that maximizes profits  $\max_s \{\pi_{is}\}$ , where  $s \in \{I, D, O, DO\}$ . Since fragmentation entails a fixed cost, it will never occur if Equation (6) does not hold. In this section, I determine the optimal fragmentation strategy for the subsets of producers in a state for whom: (i) domestic fragmentation maximizes variable profits; (ii) offshoring maximizes variable profits; and (iii) a mixed strategy of domestic and offshore fragmentation maximizes variable profits. I first determine producers' optimal share of fragmented production, and then identify those producers' profit maximizing decision.

Producers who face costs  $c_{kiD} < c_{kiO} \forall k$  represent the subset of producers for whom domestic fragmentation maximizes variable profits,  $N_D$ . Figure 1a illustrates this cost scenario.

In the figure,  $C_D$ , the cost of the composite  $M$  defined in Equation (9), is simply the area under the bold line. Because domestic fragmentation entails an additional fixed cost, Figure 1b depicts the optimal sourcing strategy for firms with these wage and cost conditions. Fragmentation lowers marginal costs and therefore results in a steeper profit function, but the fixed cost to fragment means that, of the producers in the set  $N_D$ , only those with productivity above the threshold,

$$\tilde{\varphi}_D = \left[ \frac{\sigma^{1-\varepsilon}}{(1-\sigma)A} \left( \frac{w_h f_D}{C_D^{1-\varepsilon} - w_h^{1-\varepsilon}} \right) \right]^{\frac{1}{\varepsilon-1}}, \quad (13)$$

find it optimal to fragment domestically.

*Empirical prediction 1: Holding all else constant, firms with productivity above an endogenous threshold will fragment production domestically.*

Under these cost conditions, ignoring the domestic fragmentation option will over predict the amount of offshoring, while it under predicts total fragmentation. Figure 1a shows that when offshoring is the only option, the share of fragmented production is lower ( $\bar{k}_O < \bar{k}_D$ ), as are the production cost savings. As a result, producers for whom variable profits are maximized by offshoring will face a higher productivity threshold and therefore be less likely to fragment.

The subset of producers for whom domestic fragmentation maximizes variable profits,  $N_O$ , face costs  $c_{kiD} > c_{kiO} \forall k$ . Figure 2a depicts this situation.  $C_O$ , the cost of the composite input  $M$  is the area under the bold line. The cost of  $M$  under offshoring is clearly lower than the cost with domestic fragmentation, which is the lower than the cost from integrated production. If the relative fixed costs are small compared to the relative costs of  $M$  under domestic versus offshore fragmentation, then optimal profits are similar to those in Figure 1b, except here only integrated production or offshoring take place. However, if relative fixed costs are large compared to relative savings, or

$$\frac{f_O}{f_D} > \frac{C_O^{1-\varepsilon} - w_h^{1-\varepsilon}}{C_D^{1-\varepsilon} - w_h^{1-\varepsilon}},$$

then integrated production, domestic fragmentation, and offshoring are all possible profit maximizing strategies. Figure 2b depicts this case. Producers in the subset  $N_O$ , with productivity between  $\tilde{\varphi}_D$  and  $\tilde{\varphi}_O$  fragment domestically, while those with productivity above  $\tilde{\varphi}_O$  offshore, where

$$\tilde{\varphi}_O = \left[ \frac{\sigma^{1-\varepsilon}}{(1-\sigma)A} \left( \frac{w_h(f_O - f_D)}{C_O^{1-\varepsilon} - C_D^{1-\varepsilon}} \right) \right]^{\frac{1}{\varepsilon-1}}. \quad (14)$$

*Empirical prediction 2: Holding all else constant, firms with productivity above an endogenous threshold will offshore production.*

In this case, excluding the domestic fragmentation margin also over predicts the amount of offshoring and under predicts fragmentation. Let  $\hat{\varphi}_O$  denote the offshoring threshold in a world with no domestic fragmentation. Figure 2b shows that  $\tilde{\varphi}_D < \hat{\varphi}_O < \tilde{\varphi}_O$ . As a result, producer  $i$  with productivity  $\tilde{\varphi}_D < \varphi_i < \hat{\varphi}_O$  no longer fragments, while producer  $l$  with productivity  $\hat{\varphi}_O > \varphi_l < \tilde{\varphi}_O$  now offshores instead of fragmenting domestically.

A third potential scenario may lead to domestic and offshore fragmentation by the same producer. If the difference between the domestic versus offshore cost is not the same for each task (i.e.,  $\partial\tau_D(\cdot)/\partial k < \partial\tau_O(\cdot)/\partial k$ ), then a single producer may find both offshoring and domestic fragmentation optimal. Figure 3a depicts this case. The lowest cost for the composite input is attained by offshoring  $\bar{k}_O$ , and fragmenting  $\bar{k}_D - \bar{k}_O$  domestically. The bold line is the graphical equivalent of Equation (11), where the area underneath the line represents the cost of  $M$  with this mixed strategy. If fixed costs are high relative to fragmentation cost savings, then integrated production, domestic fragmentation, offshoring, and a mix of domestic and foreign sourcing are the four possible profit maximizing strategies. Figure 3b depicts these profit functions. Here, producers in the subset  $N_{DO}$  with productivity above  $\tilde{\varphi}_{DO}$  fragment domestically and offshore, where

$$\tilde{\varphi}_{DO} = \left[ \frac{\sigma^{1-\varepsilon}}{(1-\sigma)A} \left( \frac{w_h f_D}{C_{OD}^{1-\varepsilon} - C_O^{1-\varepsilon}} \right) \right]^{\frac{1}{\varepsilon-1}}. \quad (15)$$

In this scenario, excluding the domestic fragmentation option also over predicts the extent of offshoring and under predicts total fragmentation. Let  $\hat{k}_O$  denote the share offshored production with no domestic fragmentation, where  $w_h = \alpha w_O \tau_O(\hat{k}_O)$  implicitly defines  $\hat{k}_O$ . Figure 3a shows that for each producer that would have fragmented domestically and offshore,  $\hat{k}_O < \bar{k}_D$  (recall from Equation (11) that  $\bar{k}_D$  represents total fragmented production). In addition, there is no longer a domestic fragmentation profit function, so the new productivity threshold is once again  $\tilde{\varphi}_D < \hat{\varphi}_O < \tilde{\varphi}_O$ . More producers offshore, but fewer fragment.

## 4.7 The likelihood of fragmentation

The model provides a framework in which to assess how changes in producer technology, distance to suppliers, and labor cost differences affect the decision to fragment production. This section assesses how these factors affect: (i) whether or not fragmentation is potentially feasible (i.e., the impact on variable profits) and; (ii) total profits.

#### 4.7.1 Variation in producer's technology

The model predicts that plants with better communication technology,  $\eta$ , will face lower fragmentation costs. In particular, the cost of the composite input  $M$  for a producer fragmenting from location  $s$  is decreasing in technology according to:

$$\frac{\partial C_s}{\partial \eta} = \frac{\partial \bar{k}_s}{\partial \eta} [\alpha w_s \tau(\bar{k}_s) - w_h] + \alpha w_s \int_0^{\bar{k}_s} \frac{\partial \tau(k)}{\partial \eta} dk < 0. \quad (16)$$

The term in square brackets in Equation (16) is equal to zero from Equation (8).<sup>33</sup> The second term represents the inframarginal savings that result from better technology. Holding distance and wage differences constant, an improvement in communication technology decreases fragmentation costs. This decrease means that fragmentation is now potentially viable for a larger set of firms.

Producers for whom fragmentation already maximized variable profits are also more likely to fragment production in response to improvements in their communication technology. The change in fragmentation profits from an improvement in technology  $\eta$  is:

$$\frac{\partial \pi_s}{\partial \eta} = (1 - \varepsilon) B[C_s]^{-\varepsilon} \frac{\partial C_s}{\partial \eta}. \quad (17)$$

Plugging in Equation, (16), better technology increases fragmentation profits. Since  $\pi_I$  is unaffected by the change, this is equivalent to a lowering of the productivity threshold above which fragmentation is optimal. An individual firms is now more likely to exceed that threshold so that:

*Empirical prediction 3: All else equal, plants with better communication technology will be more likely to fragment production.*

#### 4.7.2 Variation in the home wage

For fragmentation to occur, the home wage must be sufficiently high so that some tasks are cheaper to purchase from another location. In particular, Equation (6) is more likely to hold when  $w_h$  is large. As a result, the measure of producers for which fragmentation has the potential to maximize total profits is increasing in the state wage.

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<sup>33</sup>This is essentially the envelope condition, where the change in fragmented production is small since the initial share minimizes costs. As is true for all derivatives, this expression holds for small changes in  $\eta$ . Figure 1a shows that the derivative may not capture the effect of large changes in  $\eta$  on task production costs.

An increase in the home wage may also make fragmentation relatively more profitable for the subset of producers for whom fragmentation maximizes variable profits. Consider the effect of a change in the producer's home wage,  $w_h$ . The change in integrated profits relative to fragmented profits is

$$\frac{\partial \pi_I / \partial w_h}{\partial \pi_s / \partial w_h} = \frac{[w_h]^{-\varepsilon}}{(1 - \bar{k}_s)[C_s]^{-\varepsilon} + f_s / (\varepsilon - 1)B}. \quad (18)$$

where

$$B \equiv \frac{(1 - \sigma)A}{(\sigma\varphi)^{1-\varepsilon}}.$$

For a producer that is indifferent between integrated and fragmented production before the wage change, the relative decrease in integrated profits exceeds the decrease in fragmented profits as long as:

$$f_s < B \left( \frac{\varepsilon - 1}{\varepsilon} \right) C_s^{-\varepsilon} \left[ \frac{1}{\tau(\bar{k}_s)} \int_0^{\bar{k}} \tau(k) dk \right].$$

This condition reflects the fact that fixed costs are paid in the home wage. If fixed costs are greater than this threshold, an increase in the home wage results in additional fixed costs that swamp the marginal cost benefits from fragmentation. This result leads to the following prediction:

*Empirical prediction 4: All else equal and assuming fixed costs are not too large, the profitability of fragmentation is increasing in producers' home wage.*

#### 4.8 Domestic versus offshore sourcing

Of the firms that fragment production, only those with productivity above  $\tilde{\varphi}_O^{\varepsilon-1}$  do so offshore. Since the slope of the offshoring profit function depends upon fragmentation costs, the likelihood of exceeding  $\tilde{\varphi}_O^{\varepsilon-1}$  is also decreasing in the distance between a firm and its potential offshore sourcing locations. More formally

$$\frac{\partial \tilde{\varphi}_O^{\varepsilon-1}}{\partial \delta} = \left[ \frac{\partial C_O}{\partial \delta} - \frac{\partial C_D}{\partial \delta} \right] \left( \frac{w_h(f_O - f_D)}{[C_O^{1-\varepsilon} - C_D^{1-\varepsilon}]^2} \left( \frac{\sigma^{2-\varepsilon} A}{(1 - \sigma)^2} \right) (C_O^{-\varepsilon} - C_D^{-\varepsilon}) \right). \quad (19)$$

The terms in the parentheses are positive, so the effect on the offshoring threshold depends upon the sign of the terms in the square brackets. If a decrease in distance to foreign suppliers does not affect plants' distance to domestic suppliers, then the second term is zero and Equation (19) is negative. The offshoring threshold is therefore lower, leading to the following prediction:

*Empirical prediction 5: All else equal, plants that are closer to potential offshore sourcing locations will be more likely to offshore.*

The offshoring threshold also depends upon communication technology. Specifically, the effect of changes in technology on the productivity threshold is given by

$$\frac{\partial \tilde{\varphi}^{\varepsilon-1}}{\partial \eta} = \left[ \frac{\partial C_O}{\partial \eta} - \frac{\partial C_D}{\partial \eta} \right] \left( \frac{w_h(f_O - f_D)}{[C_O^{1-\varepsilon} - C_D^{1-\varepsilon}]^2} \left( \frac{\sigma^{2-\varepsilon} A}{(1-\sigma)^2} \right) (C_O^{-\varepsilon} - C_D^{-\varepsilon}) \right) \quad (20)$$

The terms in parentheses are positive, so the offshoring threshold is decreasing in technology as long as  $\frac{\partial C_O}{\partial \eta} < \frac{\partial C_D}{\partial \eta}$ . Plugging in Equation (16) shows that an improvement in communication technology will make offshoring relatively more profitable than domestic fragmentation if the inframarginal cost savings from offshored production exceed the inframarginal cost savings of domestic fragmentation. Consider the case depicted in Figure 2a where  $c_{iD} > c_{iO}$ . In this case, offshoring maximizes variable profits, but the higher fixed cost to offshore induces non-participation. Under these conditions, the terms in the first set of brackets can be expressed as

$$\alpha w_O \int_{\bar{k}_D}^{\bar{k}_O} \frac{\partial \tau_O(k)}{\partial \eta} dk + \alpha w_O \int_0^{\bar{k}_D} \frac{\partial \tau_O(k)}{\partial \eta} dk - \alpha w_D \int_0^{\bar{k}_D} \frac{\partial \tau_D(k)}{\partial \eta} dk. \quad (21)$$

The first term is always negative, while the second two terms offset each other if the technology shock affects all tasks and domestic and offshore costs equally. When this occurs, a technology improvement will lower a firm's offshoring threshold making it more likely that the firm offshores. In contrast, if the technology shock lowers domestic fragmentation costs relatively more than offshoring costs, the offshoring threshold may rise, thereby decreasing the likelihood that a given firm will exceed the threshold.

*Empirical prediction 6: All else equal, communication technology affects the likelihood of offshoring, but its impact depends upon technology's effect on domestic versus offshore costs.*

Finally, the home wage affects the likelihood that a fragmenting producer sources offshore. To see why, suppose there is one high wage state, one low wage state and one offshore location, where  $w_O < w_L < w_H$ . For simplicity, assume that  $\tau_O(\cdot) = \tau_L(\cdot) = \tau_H(\cdot)$  so that  $\alpha w_O \tau_O(\cdot) < \alpha w_L \tau_L(\cdot) < \alpha w_H \tau_H(\cdot)$ . With this set-up, all producers in the high wage state face the scenario depicted in Figure 2a. Offshoring maximizes variable profits, but only those producers with productivity above  $\tilde{\varphi}_O$  will source offshore, while those with  $\tilde{\varphi}_D < \varphi < \tilde{\varphi}_O$  will fragment domestically. In contrast, no producers in the low wage state will fragment domestically, while those with  $\varphi > \tilde{\varphi}_O$  will offshore.<sup>34</sup> This leads to a final

<sup>34</sup>If the gain from specialization is sufficiently high, firms in low wage states may still fragment in their

prediction about fragmenting producers' decision to offshore:

*Empirical prediction 7: All else equal, the likelihood a fragmenting plant will offshore is decreasing in its home wage.*

#### 4.9 Share of fragmentation

In equilibrium, the share of production a final good producer fragments depends on the relative wage differences across locations. If a producer only sources from one location, then Equation (8) shows that the share fragmented by producers for whom  $\pi_s > \pi_I$  is increasing in their relative home wage. More formally,

$$\frac{d\bar{k}}{d(w_s/w_h)} = -\frac{\alpha\tau_s(\bar{k}_s)^2}{\partial\tau_s(\bar{k})/\partial\bar{k}}. \quad (22)$$

It is important to note, however, that for a producer sourcing from multiple locations, Equation (10) shows that the share of production offshored is independent of the home wage and depends only the wage differences between sourcing alternatives. This leads to the following prediction:

*Empirical prediction 8: The share of tasks purchased from location  $s$  is decreasing in the location's wage relative to alternate sourcing location wages.*

A decrease in fragmentation costs will also result in an increased share of fragmentation (i.e.,  $\frac{dk}{d\delta} < 0$  and  $\frac{dk}{d\eta} < 0$ ).<sup>35</sup> This yields the additional prediction:

*Empirical prediction 9: The share of tasks producer  $i$  fragments will be increasing in the producer's technology and decreasing in its distance to suppliers.*

#### 4.10 Summary of empirical predictions

The model makes predictions about the extensive and intensive margins of producers' equilibrium fragmentation strategies. More productive producers with better information technology and located in higher wage states are more likely to fragment production. Of these fragmenting producers, the most productive that are relatively closer to foreign sourcing locations are more likely to offshore. In contrast, fragmenting producers' propensity to offshore is decreasing in their home wage since other domestic locations are less likely to

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own state.

<sup>35</sup>See appendix sections B.1 and B.2 for full derivatives.

provide lower labor costs. Finally, the degree to which producers fragment their production depends upon the relative wages in their sourcing sites and the fragmentation costs they incur.

## 5 Testing the model’s predictions

In this section, I use the census data to test the equilibrium relationships predicted by the model. First I focus on the extensive margin and estimate determinants of the probability that a plant purchases contract manufacturing services (CMS), as well as the probability that a fragmenting plant will offshore. I then use the linked import data to assess the relationship between firm characteristics and the share of offshore production. Finally, I disaggregate the firm import data by country to determine whether the effects of firm characteristics on sourcing strategies depend upon location specific factors.

### 5.1 The fragmentation decision

I evaluate the relative importance of technology, distance and labor cost savings in a plant’s decision to fragment its production process by estimating:

$$Pr(y_{i,j,h} = 1|X_{i,j,h}) = \beta_J + \beta_T Tech_i + \beta_w wage_h + \sum \beta_D Dist_i + \sum \beta_P Prod_i, \quad (23)$$

where  $y_{i,j,h}$  equals one if plant  $i$  in industry  $j$  and home state  $h$  purchases CMS.  $Tech_i$  is a plant level measure of communication technology.  $wage_h$  is the producer’s home state wage,  $Dist_i$  is a set of distance measures from plant  $i$  to ports and borders, and  $Prod_i$  denotes plant productivity terciles. I include a full set of six digit NAICS industry dummies as controls.

I measure plants’ local labor costs with state-industry level U.S. wages constructed from the Bureau of Labor Statistics’ Occupation Employment Statistics (OES). To minimize any potential bias arising from the relationship between wages and skill, the wage measure is based solely on production worker occupations and the mix of these occupations for a given industry is fixed across states. As a result, the variation in wages across states is attributable to differences in states’ wages for detailed occupations.<sup>36</sup> Averaged over industry, the mean state wage is \$14.58, with a standard deviation of \$1.08. The lowest wages are \$12.44 and \$12.96 in South Dakota and Mississippi respectively, while the highest wage is \$17.97 in Alaska, followed by Delaware, Washington, Michigan and Connecticut, all with average

<sup>36</sup>Additional information on the wage data is presented in the online data appendix.

wages above \$16.

I construct three measures to capture the distance between an individual plant and foreign sourcing locations. First, I calculate the distance between each plant and the closest deep water port. I also calculate the distances between each plant and the closest border crossing with Mexico and the closest crossing with Canada.<sup>37</sup> Table 8 presents the average distance, by CMS purchase status, between a plant and the closest deep water port and border crossings. On average, plants that purchase CMS primarily offshore are 50 miles closer to a deep water port than plants that purchase CMS domestically. Offshoring plants are also 78 miles closer to Mexican border crossings relative to domestic fragmenters. In contrast, domestic fragmenters are over 50 miles closer to border crossings with Canada.

I construct productivity terciles using the log of plants' value-added labor productivity. I use terciles to follow the model's prediction that producers must exceed a productivity threshold for profits from fragmentation to exceed profits from integrated production. One implication of the model is that a plant for which fragmentation is optimal will be larger if it fragments.<sup>38</sup> Since the productivity measure is based on revenue, it may be subject to reverse causality. Plants that fragment production are larger, as a result of fragmentation, and therefore have higher measured productivity. To address this issue, I instrument for plant productivity in 2007 using lagged values from 2002. I discuss the IV strategy in more detail below.

I measure a plant's use of communication technology with an indicator variable equal to one if the plant used electronic networks to control or coordinate its shipments in 2007. Specifically, the indicator identifies plants that negotiate the price or terms of sale for their shipments over an Internet, Extranet, Electronic Data Interchange (EDI) network, electronic mail, or other online system. Although this measure directly relates to shipments rather than input purchases, it is a useful proxy for plants' general use of communication technology. Using data collected in the 1999 Annual Survey of Manufactures (ASM) Computer Survey Network Use Supplement (CNUS), the U.S. Department of Commerce (DOC) 2001 *E-Stats report* finds that just over half of the manufacturing plants that used networks to coordinate shipments in 1999 also used networks to make input purchases. Additional calculations from the CNUS show that 32 percent of plants that sold goods over networks also used networks to provide information about their design specifications to external suppliers, compared to only 16 percent of plants that did not sell goods over networks.<sup>39</sup>

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<sup>37</sup>Details for the port and border crossing locations are in the online data appendix.

<sup>38</sup>Recall that for fragmentation to be optimal, the marginal cost of fragmented production must be less than the marginal cost of integrated production. With price set to a constant mark-up over marginal cost and downward sloping demand, a plant with the same underlying productivity parameter will therefore be larger if it fragments.

<sup>39</sup>Plants that do not use networks to control or coordinate shipments may still use the internet. For

An obvious problem with estimating Equation (23) is that a plant's communication technology may be endogenous to its sourcing strategy. If a plant installs a technology platform and adapts its business processes to use electronic networks because it is planning to fragment production, an unobserved shock favoring fragmentation may increase electronic network use. If this occurs, the estimated coefficient on technology will be biased. Since a plant's use of electronic networks to control or coordinate its shipments is driven by multiple factors, some of which are unrelated to fragmentation, one way to address the potential reverse causality problem is to instrument for plants' use of networks in 2007 with lagged values of their use in 2002. Table 9 presents the shares of plants that used these networks by plants' 2007 CMS purchase status. 36 percent of non-fragmenters, 51 percent of domestic fragmenters, and 61 percent of offshorers used electronic networks in 2007. In 2002, these shares are lower by a factor of roughly half for each CMS category.

For the lagged instrument to be valid, plants' use of networks in 2002 must be determined by factors other than their decision to fragment production in 2007. For example, the instrument can identify a causal relationship if plants that used networks in 2002 to facilitate sales decide to fragment in 2007 because their existing communication technology makes fragmentation relatively more profitable. There are concrete reasons to believe that factors other than fragmentation play an important role in plants' use of networks to control or coordinate shipments. According to the DOC (2001), almost half of the plants that used networks to control or coordinate shipments in 1999 did not use networks to purchase inputs. McElheran (2010) also investigates the relationship between E-buying and E-selling and finds that, although both processes share the same technology platforms, E-selling generally entails more complex organizational changes. Finally, Table 9 shows that in 2007, 36 percent of plants that did not fragment production used electronic networks.

To identify a causal relationship using lagged values as instruments, it is also necessary for plants' fragmentation status in 2007 to differ from their fragmentation status in 2002. In particular, the instrument's power to identify a causal relationship depends upon the existence of plants that used networks in 2002 but did not fragment production. Although the 2002 CM did not ask the 2007 CMS purchase question, I use two similar questions from 2002 to assess differences between plants' 2002 and 2007 fragmentation strategies. The 2002 CM asked an establishment: 1) whether it contracted with another firm for any of its production using materials owned by the respondent; and 2) whether it sent any partially completed products to a foreign facility for processing that were then returned to the respondent. Respondents had the option to check YES or NO to both of these

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example, the DOC (2001) shows that approximately 87 percent of manufacturing plants in the 1999 ASM sample used an electronic network at their plant. In contrast, only 31 percent and 33 percent of the ASM plants accepted or placed orders online respectively. These data are only available in 1999. Additional details on the electronic network use data are provided in the online data appendix.

questions. I compare the 2007 fragmentation status of single-units to their 2002 contract purchases.<sup>40</sup> Table 10 decomposes plant shares for each 2007 CMS category according to 2002 electronic network use and fragmentation status. Columns 3 and 4 in the second row show that 14 percent of plants that purchase CMS domestically in 2007 used networks in 2002, and almost half of these plants did not fragment production in 2002. The third row shows that 28 percent of plants that offshore in 2007 used networks in 2002, and half of these plants did not fragment in 2002. Table 11 presents similar shares for 2002 electronic network use and offshore CMS purchase status. The third row shows that 31 percent of offshoring plants in 2007 used networks in 2002, though less than 20 percent of these plants offshored in 2002. These tabulations suggest the data contain sufficient variation in fragmentation status across electronic network use for the lagged values to be suitable instruments.

### 5.1.1 Main results for fragmentation

Table 12 reports results from estimating Equation (23). Column 1 provides OLS estimates from a regression on all plants in the CMS sample, weighted by the inverse probability of inclusion in the sample.<sup>41</sup> The second column reports OLS results for the IV sample. Since the instruments are lagged 2002 values, the IV sample consists of plants that existed in the same physical locations in 2002. I estimate a linear probability model (LPM) rather than logit or probit because of the large number of industry fixed effects, and so that the results are more comparable to the IV estimates; however, the online data appendix shows that marginal effects from probit estimation are quite similar.<sup>42</sup> Column 3 presents results for the IV estimation. I focus on these results since they correspond to the preferred specification.

The estimated coefficient on electronic networks suggests that plants using electronic networks are 18 percentage points more likely to fragment. The coefficient is larger than the OLS estimate, consistent with the measure of network use to coordinate shipments being a noisy proxy for plant communication technology that facilitates communication with input suppliers. The estimated coefficient on the state wage is positive and significant and suggests that a plant in Washington state is 4.7 percentage points more likely to fragment than the “same” plant in Mississippi, where average production worker wages are almost 30 percent lower. Productivity also has the expected positive relationship. Relative to plants

<sup>40</sup>I limit the comparison to single unit firms since the 2002 question asks only about contract purchases from another firm.

<sup>41</sup>The weighted and unweighted estimates are almost identical.

<sup>42</sup>Because the endogenous technology variable and productivity measures are discrete, the IV regression cannot be estimated via IV probit. In addition, probit fixed effect estimates are inconsistent due to the incidental parameters problem. While it is possible to estimate a conditional logit model with fixed effects, estimating partial effects on the response probabilities with this specification requires plugging in values for the industry indicators (p. 492 Wooldridge (2002)). This exercise would not be practical in the analysis here.

in the lowest productivity tercile, plants in the second and third terciles are 12 and 16 points more likely to fragment respectively. Hillberry and Hummels (2008) detect significant non-linearities in the role of distance in shipments between plants, so I create indicators for different distance categories. Plants that are 51-200 miles from a deep water port, or more than 50 miles from a border crossing with Mexico, face a 1.5 and 2.8 percentage point decrease in the probability of fragmentation respectively, relative to plants that are within 50 miles of each foreign access point.

There are three first stage regressions, two for productivity terciles two and three, and one for the electronic networks variable. The first three columns in the top panel of Appendix Table A.1 present the estimated coefficients and standard errors for the instruments in each first stage regression. The lagged instrument is always significant in its own first stage regression, with the expected positive coefficient. Each column reports Shea's partial R-squared for that column's endogenous variable, which range from 0.03 to 0.11.<sup>43</sup> Each column also reports the F-Statistic for the null hypothesis that the instruments are jointly equal to zero. These F-statistics are well above the threshold of 10 proposed in Stock et al. (2002).

### 5.1.2 Differential impact of communication technology across industries

In this section, I take an additional step towards identifying the causal effect of technology on the probability of fragmentation by focusing on a specific mechanism through which technology lowers fragmentation costs. In the model, technology lowers fragmentation costs by making it easier to communicate design criteria and production specifications across locations. In practice, a plant's use of electronic networks for these purposes depends upon its ability to codify the design and production requirements in an electronic format. If this ability varies across industries, electronic networks will lower fragmentation costs more in those industries in which the production process is amenable to electronic codification. The interaction between a plant's communication technology and its industry electronic codifiability identifies the marginal benefit of communicating design criteria and production specifications electronically.<sup>44</sup>

I measure variation in industry electronic codifiability as the share of plants in a NAICS 6 industry that used Computer Aided Design (CAD) and Computer Aided Manufacturing

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<sup>43</sup>See Shea (1997) for a discussion of the partial R-squared as an indicator of weak instruments.

<sup>44</sup>This approach is similar to the identification strategy in Rajan and Zingales (1998) who assess the effect of financial development on country growth by estimating the differential impact financial development has on growth in industries that are dependent on external financing. Those authors note "One way to make progress on causality is to focus on the details of theoretical mechanisms through which financial development affects economic growth, and document their working" (p.560).

(CAM) software in 1999.<sup>45</sup> This software allows plants to codify their input design criteria and the requisite physical transformation processes in an electronic format. Use of CAD/CAM software varies substantially across industries. The variation is driven by the complexity and extent to which the physical transformation process can be codified electronically. There is little benefit to creating a CAD file for a non-complex product whose specifications can be described in a simple text file, while certain production processes are simply not amenable to electronic codification in CAM software.<sup>46</sup> Industry CAD intensity ranges from almost zero to one, with a mean of 0.44 and standard deviation of 0.25. The least CAD intensive industries are food manufacturing and textiles, while automotive, aerospace and machinery manufacturing are all CAD intensive.

Column 4 in Table 12 reports results from estimating Equation (23) with an additional interaction term between plant use of electronic networks and industry CAD intensity. I do not include the CAD variable directly because it is fully absorbed by the industry fixed effects. The interaction term has a positive and statistically significant coefficient, supporting the hypothesis that electronic communication lowers fragmentation costs more in industries in which plants are better able to specify production requirements electronically. To gauge the magnitudes and implied economic significance of the coefficients, Figure 4a plots the full effect of electronic networks evaluated at different levels of CAD intensity. The figure depicts a strong increasing relationship. Relative to plants that do not use electronic networks, plants that use networks in “other apparel” manufacturing (CAD intensity of 4 percent) are 4.8 percentage points more likely to fragment, while plants using networks in the “semiconductor machinery” manufacturing (CAD intensity of 98 percent) are 24 percentage points more likely to fragment. The differential impact of electronic networks between these two industries is thus almost 20 percentage points. The coefficients on wage and distance are largely unchanged in this specification.

The right panel in Appendix Table A.1 presents the estimated coefficients and standard errors for the instruments in each first stage regression. The lagged instrument is always significant in its own first stage regression, with the expected positive coefficient. Shea’s partial R-squared measure ranges from 0.03 to 0.14, while F-statistics for the null hypothesis that the instruments are jointly equal to zero are well above 10.

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<sup>45</sup>Conversations with various manufacturing service providers and their customers at the Mid-Atlantic Design-2-Part Show in Phoenixville, PA on April 14, 2011 suggest that electronic communication facilitates fragmentation most when it can be used in conjunction with CAD/CAM software. The CAD/CAM data were collected by the U.S. Census Bureau as part of the 1999 CNUS. Additional details are in the online data appendix.

<sup>46</sup>For example, spring and wire manufacturing requires a continuous physical transformation process that cannot be performed by machines run by CAM software.

### 5.1.3 Additional controls

There are several additional concerns that arise when estimating Equation (23). First, the model assumes that aggregate expenditure is identical across locations, though in reality this is clearly not the case. Since firm size depends upon aggregate expenditure, firms in areas with higher demand might be more likely to overcome the fixed costs of fragmentation. If demand and wages are correlated, then the estimated wage coefficient will be biased. I assess this potential issue by controlling for personal income in the plant’s economic area, as defined by the Bureau of Economic Analysis (BEA) economic areas.<sup>47</sup> Column 5 in Table 12 shows that controlling for local demand does not affect the estimated coefficients.

Another potential concern is that the wage estimate is biased by differences in worker skill across states. Although the wage measure is based on wage differences within detailed occupation codes across states, it may still reflect skill heterogeneity. To assess the extent to which the wage estimate is biased by skill, I construct skill measures that vary by state. Column 6 in Table 12 presents estimates of Equation (23) controlling for the state share of workers with a college degree and the share of production workers with a high school degree. The inclusion of these skill measures does decrease the estimated wage coefficient, but it is still positive and statistically significant. It now implies that, compared to the “same” plant in Mississippi, a plant in Washington state is 3.3 percentage points more likely to fragment.<sup>48</sup>

In the model, producer’s location is exogenous to their sourcing strategy. This assumption is plausible if firms’ location is based on historic patterns. In the long-run, however, producers’ location may depend upon their anticipated sourcing strategy. While the IV regressions are based on plants that existed in a given location for at least five years, this time frame could still include firms that chose their location with a fragmentation strategy in mind. I therefore repeat the analysis using the subsample of plants that existed in their 2007 location for at least ten years. The estimated coefficients are largely unchanged, though I do not report them here to avoid potential disclosure avoidance issues in future drafts. Finally, I re-estimate Equation (23) excluding plants in the automotive industry. The automotive industry has the highest share of domestically fragmented plants and is often considered a leader in the new methods for fragmenting production. I do not report the results in this draft, but these estimated coefficients are also largely unchanged.

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<sup>47</sup>There are 179 BEA economic areas. These areas are designed to capture relevant regional markets surrounding metropolitan or micropolitan statistical areas.

<sup>48</sup>I have also estimated Equation (23) controlling for the share of state workers with an associate’s degree and a high school degree, and the share of production workers with a college degree and an associate’s degree. In all cases, the estimated coefficients on the variables of interest are largely unchanged.

## 5.2 Domestic versus offshore fragmentation

I now analyze a plant's decision to locate its fragmented production offshore. I estimate a variant of Equation (23), where the dependent variable is equal to one if plant  $i$  in industry  $j$  and home state  $h$  purchases CMS primarily offshore. I restrict the analysis to plants that fragment production so that the estimated coefficients reflect the impact of covariates on the probability of offshoring, relative to domestic fragmentation. The estimates for the probability of fragmentation therefore capture the determinants of breaking up the production process, while results in this section reflect the costs and benefits of locating fragmented production offshore.

### 5.2.1 Main results for offshoring

Table 13 reports the results from estimating Equation (23) on the subset of fragmenting plants. As before, columns 1 and 2 provide OLS estimates for the full and IV samples respectively, while column 3 reports the IV estimates. The IV estimates suggest that plants using electronic networks to coordinate shipments are ten percentage points more likely to locate their fragmented production offshore. Based on the prediction from the model, this suggests that electronic communication has a differential impact of fragmentation costs that is increasing in distance. The estimated wage coefficient also has the expected negative sign. The probability that a fragmenting plant in Mississippi will purchase CMS offshore is 3.7 percentage points higher than the probability that a fragmenting plant in Washington state will do so. Consistent with the model, plants in the top productivity tercile are 3.8 percentage points more likely to offshore relative to the least productive plants.

Distance to international entry ports is also an important factor in plants' decision to offshore production. The IV estimates show that plants over 50 miles from a border crossing with Mexico are 9.5 percentage points less likely to source their fragmented production from a foreign country relative to plants that are within 50 miles of the border. In contrast, being close to Canada does not have a statistically significant relationship with the probability a fragmenting plant will source offshore. Plants that are over 200 miles away from a deep sea port are 2.4 percentage points less likely to fragment, relative to plants within 50 miles of the closest port.<sup>49</sup>

The bottom panel of Appendix Table A.1 presents the estimated coefficients, standard errors and weak instrument tests for all instruments in each first stage regression. The lagged

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<sup>49</sup>I performed the analysis with much finer bins but found no statistically significant differences between them.

instrument is always positive and significant and the F-Statistic for the null hypothesis that the instruments are jointly equal to zero is well-above the threshold of 10 for each first stage regression.

### 5.2.2 Differential impact of communication technology across industries

I also estimate the differential impact of electronic networks across industries on the probability of offshoring. As in Section 5.1.2, I allow the effect of electronic networks to vary by industry CAD intensity. Column 4 in Table 13 presents the estimates. In stark contrast to results for the probability of fragmentation, the interaction between plant use of electronic networks and CAD industry intensity is negative. Figure 4b depicts the full effect of networks, evaluated at different levels of CAD intensity. While electronic network use is associated with a higher probability of fragmentation for all levels of CAD intensity, networks' impact appears to decrease with CAD intensity. The full effect is imprecisely estimated at low and intermediate levels of CAD, but the negative relationship is still present in the high CAD industries. A likely explanation for this result is that the average state of technology in foreign sourcing locations is below the average U.S. level. Receiving CAD/CAM files and using them correctly requires sophisticated equipment and workers. As a result, CAD software's potential to reduce coordination and communication costs across locations when used in conjunction with electronic communication cannot be realized if a given location does not have the ability to use it. Below, I investigate this possibility using the import data disaggregated by country.

The finding that electronic communication has a differential impact on the probability of relocating fragmented production offshore adds a new dimension to our understanding of the determinants of offshoring. Rather than treating technology as a single parameter that affects all firms and industries the same way, the results in Tables 12 and 13 uncover heterogeneous responses within and across industries. In addition, technological change does not necessarily make offshoring more likely. Technological improvements that facilitate domestic fragmentation may render offshoring less profitable if foreign sourcing locations are not properly equipped to exploit new infrastructure or techniques.

### 5.2.3 Additional controls

As in the fragmentation regressions, I ensure that the results are robust to controlling for local expenditure and state skill measures. Column 5 in Table 13 shows that controlling for the level of personal income in the plant's economic area does not affect the estimated

coefficients. When I control for skill, the coefficient on the share of production workers in a state with at least a high school degree is negative and significant and the wage coefficient decreases slightly. While these results suggest skill may play a role in plants’ decision to source their fragmented production offshore, the qualitative relationships predicted by the model are robust to controlling for observed skill heterogeneity.<sup>50</sup> I also estimate the probability of offshoring on the subsamples of plants that existed for at least ten years, and excluding the auto industry. In both cases, the estimated coefficients are largely unchanged.

### 5.3 Share of fragmented production

In this section, I turn to the intensive margin of firms’ fragmentation decision. To assess the relationship between producer characteristics and the share of fragmented production, I estimate:

$$\ln(\text{share}_f) = \beta_J + \beta_T \text{Tech}_f + \beta_w \text{wage}_{f,s/US} + \sum \beta_D \text{Dist}_f + \beta_P \ln(\text{Prod}_f) + \varepsilon_{i,j,h}, \quad (24)$$

for firm  $f$  in industry  $j$ . The data do not provide information about the total share of fragmented production, and the import data are only available at the firm level, so I use firm imports over sales as a proxy of the share of production sourced offshore.

As discussed in Section 2, a firm’s imports do not necessarily reflect fragmented production. To maintain the focus on firms that fragment customized production processes, I limit the analysis to the subsamples of manufacturing firms with positive import values that purchase CMS primarily offshore and primarily domestically.<sup>51</sup> I estimate Equation (24) separately for the offshoring and domestic fragmenters to allow the estimated coefficients to vary by firm sourcing strategy. Separate estimations for each sample are appropriate since firms that purchase CMS primarily offshore have less scope for their intensive margin to vary. For the estimates to be consistent, I rely on the assumption that, conditional on being in the sample, the log share of offshored production follows a classical linear model. This assumption underpins a “hurdle” or “two-tiered” model that is often used to address corner solution outcomes such as those present here. Using this methodology, the probability of offshoring is estimated in the first step, and the log share of offshored production is estimated in a second, independent step via OLS. The estimates presented in this section therefore correspond to estimates of the second step in a hurdle model.<sup>52</sup>

<sup>50</sup>This is true for the six variants of state skill measures I constructed.

<sup>51</sup>I limit the analysis to manufacturing firms without wholesale establishments so that the empirical analysis tracks the theory more closely. There are not enough manufacturing firms with both domestic and offshore purchases to disclose those regression results.

<sup>52</sup>The total impact of an independent variable on the share of fragmented production is then a combination of the its effect on the probability of offshoring and its effect on the share of offshoring. Wooldridge (2002)

Multi-unit firms may span multiple industries, so I control for industry using the firm’s share of employment in each four digit NAICS code. I construct an import-weighted average relative foreign wage for each firm using country-industry-occupation wages from the International Labor Organization (ILO).<sup>53</sup> This wage measure is clearly endogenous to firms’ sourcing choices, so the estimates provide an assessment of the model’s prediction about the relationship between wages, fragmentation costs and the share of offshored production, but do not uncover any causal effect. Although the model does not specify a role for productivity in determining the share of offshored production, I include the log of value added firm productivity as a control to ensure that the electronic network use indicator is not biased by its correlation with productivity. As before, I measure firms’ distance to foreign entry ports, using the minimum distance over all establishments for multi-unit firms. In the specification that includes the electronic networks and CAD intensity interaction, I measure firm CAD intensity as an employment-weighted share of each firm’s industry CAD intensity. Because the industry controls are no longer fully co-linear with the CAD industry measure, I include the level of CAD intensity by firm. To ensure the CAD intensity measure is not confounded by the extent to which an industry uses more complex or differentiated inputs, I also control for the share of differentiated inputs for a firm’s industry mix using the industry measure from Nunn (2007).<sup>54</sup>

Columns 1 and 2 in Table 14 report results from estimating Equation (24) on the subsets of firms that source offshore and domestically respectively. Firm use of electronic networks does not have a statistically significant relationship with the share of offshored production for firms that primarily offshore. In contrast, for firms that primarily source domestically, use of electronic networks is associated with an 8.5 percent increase in their share of offshored production. For both samples, adding an interaction between electronic networks and CAD intensity results in a statistically insignificant relationship between communication technology and the degree of offshoring.

The estimated coefficients also suggest that the share of production offshored by firms that primarily source from foreign locations is independent of firms’ distance to a deep water port or border crossing. Although three of the four distance coefficients have the expected negative sign, they are all imprecisely estimated and therefore not statistically different from zero. It is important to interpret these results in context of the estimates in Section 5.2. Firms that source primarily offshore are closer to deep water ports and Mexican border crossings, but their share of offshored production is independent of these distances. In contrast, the share of offshored production by firms that primarily source from domestic

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pp. 536-7 describes the hurdle model in detail. See Appendix Section C for a discussion about the limitations and benefits of a hurdle model in this analysis relative to Tobit or Heckman selection models.

<sup>53</sup>Details about the data and wage construction are in the online data appendix.

<sup>54</sup>I use the liberal definition of the fraction of inputs not sold on an exchange and not reference priced.

locations is decreasing in their distance from a deep water port. Relative to firms that are 50 miles from a port, the share of offshored production by firms that are 50 to 200 miles away is 15 percent lower, and the share for firms over 200 miles away is 27 percent lower. The share of offshored production by firms that primarily fragment domestically is also 34 percent lower for firms that are more than 50 miles from a Canadian border crossing.

The relative foreign wage has the expected negative sign and is statistically significant for firms that primarily offshore and firms that primarily source domestically. For offshoring firms, a ten percent increase in their average relative foreign wage is associated with a 1.8 percent lower share of offshored production. For firms that source primarily domestically, a ten percent increase in their average relative foreign wage is associated with a 2.7 percent decrease in their share of offshored production. This relationship is consistent with the model's prediction, but as explained above, should not be interpreted as providing any causal information about firms' sourcing decisions.

Thus far, the empirical results are consistent with many of the model's predicted equilibrium relationships. Labor cost saving motives are evident in producers' decision about whether or not to fragment production and offshore, as well as the extent to which they offshore, conditional on fragmentation. Distance to foreign entry points is also an important factor in whether or not a producer offshores the majority of its fragmented production. For firms that fragment primarily domestically, distance is also related to the extent to which firms offshore production.

The role of technology is more nuanced. Technology facilitates communication between producers and suppliers about inputs' design and production requirements, thereby increasing the probability a producer will fragment production. However, producers' ability to leverage the communication advantages that technology confers appears to be higher when sourcing from domestic rather than foreign locations. This relationship is evident in the extensive margin results where, conditional on fragmenting, plants that use electronic networks in CAD intensive industries are less likely to offshore. The intensive margin results in this section also suggest that communication technology has a limited impact on the degree to which a firm offshores its production. In the next section, I use firm-country level import data to assess whether the the apparent decreased effectiveness of communication technology in sourcing from offshore relative to domestic locations may be driven by heterogeneity in foreign locations' technology.

## 5.4 Location selection

In this section, I re-assess firms' decision about where to locate their fragmented production using variation in firms' sourcing locations. I aggregate the import data to the firm-country level and construct an indicator equal to one if a firm sources from a given country. The dataset includes an observation for every potential firm-country import combination. I regress the indicator on firm characteristics ( $X_F$ ), country characteristics ( $X_S$ ), and firm-country interactions ( $X_F \times X_S$ ):

$$Pr(y_{i,s} = 1|X_{i,s}) = \theta + \beta_F X_F + \beta_S X_S + \beta_{FS}(X_F \times X_S), \quad (25)$$

where  $y_{i,s} = 1$  if firm  $i$  imports from country  $s$ . The firm variables,  $X_F$ , include the log of value added productivity, electronic network use, the interaction between electronic networks and industry CAD intensity, and the industry share of differentiated inputs.<sup>55</sup> The country variables,  $X_S$ , include relative wages, human capital, and a country technology measure. I interact the firm level technology variables with country technology to assess whether the impact of firm technology on the probability of sourcing from a given location depends upon that country's level of technology. The interaction terms,  $X_F \times X_S$ , also include the minimum distance between each firm and country.

I measure country technology as the number of secure internet servers in 2007 in each country from the World Bank World Development Indicators (WDI). This variable is similar to one used by Freund and Weinhold (2002), who find an important role for a country's internet penetration in explaining variation in countries' growth of U.S. services trade. The number of internet servers in a country represents a measure of countries' communication technology infrastructure. In this dimension, an assessment of its importance in trade complements Limão and Venables (1999) who show that transportation infrastructure is a significant determinant of trade flows.<sup>56</sup> I calculate the minimum distance between a firm and each country using latitudes and longitudes from the CEPII.<sup>57</sup> The relative foreign wage comes from the same data described in Section 5.3, but here each firm faces the same wage for a given industry-country combination. Because the model assumes homogeneous labor, I control for country human capital with an updated version of the Hall and Jones (1999) measure.<sup>58</sup>

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<sup>55</sup>Since the focus of this analysis is on the interaction terms, I use a continuous productivity measure to facilitate the disclosure analysis.

<sup>56</sup>The measure of country communication technology also relates to Golub et al. (2007) who document a role for countries' technology infrastructure in exports and FDI.

<sup>57</sup>The data are available here: [www.cepii.fr/anglaisgraph/bdd/distances.htm](http://www.cepii.fr/anglaisgraph/bdd/distances.htm). I use latitude and longitude for the largest city in each country. Firm latitude and longitude is based on the closest manufacturing plant in the firm.

<sup>58</sup>I use the education data from Barro and Lee (2000) to construct a measure for 2000 since this is the most recent data available. Human capital measures tend to be correlated over time, but this measure is

Since the objective of this section is to assess whether the effectiveness of firm level technology depends upon the level of technology in a given country, I use country or firm fixed effects and focus on the interaction terms. This approach controls for all possible omitted country or firm characteristics and is therefore less susceptible to reverse causality and spurious correlation problems. As in Section 5.1, I estimate Equation (25) using a linear probability model.<sup>59</sup>

Table 15 presents results from estimating Equation (25) on the subset of firms that primarily purchase CMS from offshore and domestic locations respectively. Columns 1 and 2 report estimates using country fixed effects which allow for a quantification of the role of firm technology in the probability of sourcing from a given country. The interactions between firm and country technology are positive and significant for both samples. Figure 5a plots the full effect of electronic network use for offshoring firms evaluated at different levels of country technology. While using electronic networks does not increase the probability of sourcing from countries with a small number of servers, such as Bangladesh, their use increases the probability of sourcing from a high technology country like Japan by over two percentage points. Figure 5b depicts a similar relationship between industry CAD intensity and country technology. To illustrate magnitudes, increasing CAD intensity from the level in the “other apparel” industry to the level in the “semi-conductor machinery” industry is associated with no increase in the probability of sourcing from a country with Bangladesh’s technology, but a 6.6 percentage point increase in the probability of sourcing from a country with Japan’s level of technology.

Columns 3 and 4 in Table 15 report estimates of Equation (25) with firm fixed effects. The firm-country interactions are positive and statistically significant in this specification as well. Figure 6 shows the differential impact of country technology on firms’ sourcing strategies. The probability a firm will source from a given country is increasing in its servers, but the effect of servers is larger for firms that use electronic networks and is increasing in industry CAD intensity. While an increase in country technology equivalent to bringing Bangladesh’s number of servers on par with Japan’s is associated with a 14 percentage point increase in the probability a firm in the “other apparel” industry sources from that country, it is associated with a 25 percentage point increase for a firm in the “semi-conductor machinery” industry.

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more relevant than the original Hall and Jones (1999) variable based on 1989 data.

<sup>59</sup>OLS is preferable in this context due to the inclusion of firm and country fixed effects. Probit estimates with fixed effects are inconsistent. In addition the marginal effects for interaction terms vary by observation making them difficult to summarize (see Ai and Norton (2003)). Finally, both probit and logit models suffer from perfect separation that occurs when a firm or country dummy predicts an outcome perfectly. There is no appealing solution for the separation problem in the analysis here with fixed effects. See Zorn (2005) for a discussion of this issue.

The results presented in Table 15 are also consistent with an important role for distance. The estimates with country fixed effects, presented in columns 1 and 2, exploit differences in firms' distance to a given country that arise from variation in firms' geographic distribution across the U.S. They suggest that doubling the firm-specific distance to a country is associated with 2.6 or 1.9 percentage point decrease in the probability of sourcing from that country for offshoring and domestic fragmenters respectively. The estimates with firm fixed effects exploit the variation in distance to different countries for a given firm. Although the coefficients have the expected negative sign, they are not statistically significant.

## 5.5 Assessing the relative importance of technology, distance and wages

In this section, I assess the relative importance of wages, technology, and distance in firms' fragmentation and offshoring decisions. To perform the analysis, I calculate the share of the explained variation attributable to each of these key determinants. For example, to assess the importance of wage variation in a given estimation, I first calculate  $\hat{y}$ , the predicted value of the dependent variable for each observation; using actual values of independent variables. Next, I re-calculate predicted values using the actual wage values for each observation, but holding all other independent variables at their sample means. Letting  $\hat{y}_{iw}$  denote this predicted value for observation  $i$ , the share of the explained variation accounted for by the actual wage variation in the data is then  $VAR(\hat{y}_{iw})/VAR(\hat{y}_i)$ . When multiple variables capture the effect of distance or technology, I calculate the predicted values with all distance or technology variables evaluated at actual values and all other independent variables held at their means. Since these calculations do not incorporate covariances between independent variables, they do not represent a perfect decomposition and the fraction of the variation explained by each variable will not necessarily add to one. However, the analysis provides an informative quantification of the relative importance of the key explanatory variables.

Table 16 presents results of this variance decomposition for the main results from each set estimations. The top panel corresponds to the IV estimates for the probability a plant will fragment production (Table 12) and the probability it will offshore (Table 13). The first row shows that wage variation accounts for two percent of the explained variation in both fragmentation and offshoring decisions. Technology, measured by plant use of electronic networks, accounts for 27 percent of the explained variation in plants' fragmentation decision and 24 percent of the explained variation in offshoring. While distance explains practically none of the variation in the fragmentation decision, it accounts for two percent of the explained variation of offshoring.<sup>60</sup> The second row shows that when the effect of

<sup>60</sup>The distance measure is more relevant for the relative costs of foreign sourcing. The low share of explained variation may simply reflect the limitation of the distance measures for domestic sourcing.

electronic networks is allowed to vary by CAD intensity, technology accounts for 36 and 47 percent of the explained variation in fragmentation and offshoring respectively. Variation in communication technology accounts for much larger share of the explained variation in plants' decision to break up their production process or source from overseas, relative to both distance and labor cost savings motives.

The bottom panel of Table 16 presents shares of the explained variation of firms' imports over sales for the four specifications in Table 14. The left hand side shows variance shares for firms' that purchase CMS primarily domestically, while the right hand side has shares for firms that primarily offshore. For both types of firms, the wage variation accounts for the largest share of variation. Depending upon the specification, wages' share of the explained variation ranges from .11 to .17. Variation in distance between a firm and the closest foreign entry points is also important, accounting for approximately 5 percent of the explained variation in all specifications. Technology only accounts for a non-trivial portion of the explained variation when it includes the electronic networks interaction, and since these interactions are statistically insignificant, the share of explained variation is less instructive. These results suggest that while technology is the most relevant determinant in producers' decision about whether or not to fragment and offshore, labor cost differences are most the important factor in explaining the degree to which firms offshore, conditional on fragmentation.

## 6 Conclusion

The organization of production has grown increasingly complex as firms seek to lower production costs by exploiting gains to specialization and accessing cheaper labor. To take advantage of these opportunities, a firm must break up its production process so that different stages of production can be performed in different locations. This paper shows that a majority of firms do not fragment or offshore production of inputs that must be customized to meet specific production requirements. The paper provides a theoretical framework in which the non-participation evident in the data is explained by both fixed and marginal costs of fragmentation, as well as by wage differences across producers' and suppliers' locations.

Communication technology has the potential to lower fragmentation costs by facilitating coordination and communication across locations. Consistent with this cost reducing role, the empirical results show that plant use of electronic networks to coordinate shipments increases the probability of fragmentation by 18 percentage points. To address the possibility of endogenous technology choice, I focus on the ability of communication technology to facilitate fragmentation through improved communication about product specifications and

production processes. Using industry variation in CAD intensity as a measure of a firm's ability to specify its production process in an electronic format, I find evidence consistent with this mechanism. The differential impact of electronic communication on the probability of fragmenting in CAD intensive industries is almost 20 percentage points higher than the impact in low CAD industries.

While the paper documents a strong role for communication technology in a firm's fragmentation decision, it also shows that technology's impact on the probability of offshoring is more nuanced. In particular, firms that use electronic networks in CAD intensive industries are less likely to offshore their fragmented production than firms in low CAD industries. One explanation for this result is that successful use of electronic communication and CAD technology depends upon a sourcing location's technology. Since offshore locations' average technology is lower than U.S. technology, this could drive the lower impact of electronic networks on the probability of offshoring by firms in CAD intensive industries. Consistent with this hypothesis, estimates using disaggregated country-import data show that the effect of firm communication and information technology on the probability of offshoring is increasing in country level technology. As a result, a single parameter is unlikely to capture the true impact of technological improvements since this impact varies substantially across firms, industries, and countries.

This paper also finds that potential labor cost savings are a significant determinant of firms' fragmentation decisions. Plants in high wage locations are more likely to fragment production domestically, while conditional on fragmentation, plants in low wage states are more likely to offshore. These results suggest that plants are geographically differentiated with arbitrage opportunities to purchase labor from other locations. The paper shows that the arbitrage opportunities depend on communication technology. Given the rapid progress in developing communication technology to date, fragmentation is likely to become more common in the future as more firms seek to exploit its potential to lower production costs. To the extent that technological advances require matching technology or skills in the sourcing location, however, these advances will not necessarily displace U.S. jobs, but instead may lead to substantial shuffling of employment across U.S. states.

There are several directions in which to build upon the theory and evidence presented here. First, this paper does not examine the role of skill differences except as controls. Some of the estimates on these controls, however, suggest that skill may be an important factor in determining the extent to which foreign labor can substitute for domestic employment. Understanding the interaction between industry and task skill requirements and countries' human capital endowments could shed new light on the role offshoring may have played in rising wage inequality in the U.S. It could also provide useful guidance about the types of jobs that will be more vulnerable to future offshoring as fragmentation costs continue to

fall.

An obvious extension to the analysis here is to consider the role of trade policy in firms' sourcing choices. The linked firm-import data could be used to assess whether tariff differences across countries or products affect their probability of being sourced from a particular country. These data could also uncover the potential impact of policy uncertainty on how firms organize their production. Handley and Limão (2011) find that membership in a preferential trade agreement leads to additional firm entry into export markets by reducing the uncertainty firms face when deciding whether to pay a sunk entry cost. Fragmented production is likely to magnify the effect of uncertainty since a shock to the costs of fragmented inputs, or a disruption to their supply, may affect all other inputs.

Another avenue for future work is to examine firms that have offshored all their physical transformation activities. The North American Industry Classification System categorizes these firms as wholesalers, even when they design their products and coordinate the production process. Using similar contract manufacturing services data available for this sector, one could assess whether communication technology, distance and wage differences play a similar role in these firms' offshoring decision. In addition, firms' employment over time could provide information about whether these offshoring firms are new; if they used to manufacture domestically and have relocated all production offshore; and how the firms' employment composition in other sectors has changed over time. This evidence would improve our understanding of how firms' production evolves and provide useful information to policy-makers about the types of jobs likely to be created in the future if fragmentation and offshoring continue.

## Appendices

### A Substitutability of CMS purchases and standardized inputs

The CMS data correspond to fragmentation of customized production processes, so plants that report no purchases may perform all the requisite physical transformation activities to make their good, or they may be able to purchase standardized, off-the-shelf inputs. To assess whether CMS purchases can be substituted with standardized inputs, I examine their relationship with plants' purchases of materials. Plants' purchases of CMS are positively correlated with their material purchases, suggesting that CMS purchases are not substitutes

for material inputs. To control for the possibility that standardized inputs are substitutes for CMS purchases in the empirical section, I use six digit NAICS industry fixed effects so that the estimates reflect within industry differences in the probability of fragmentation. The six digit NAICS industry controls represent a very detailed classification that should capture the importance of customized inputs in production. It is possible, however, that some firms within an industry produce higher quality goods that require more customized inputs. In this case, the estimated coefficients on productivity may reflect higher quality, rather than greater production efficiency. In firm-level regressions with multi-unit firms that span multiple industries, I can only control for industry at the four digit level. In these cases, I also include the Nunn (2007) measure of an industry's need for differentiated inputs as a control for industries' demand for customized production processes.

## B Proofs

### B.1 Share of fragmentation and distance

The effect on  $\bar{k}$  from an increase in distance between the firm and its sourcing location is

$$\frac{d\bar{k}}{d\delta} = -\frac{1}{\partial\tau(\bar{k})/\partial\bar{k}} \frac{\partial\tau(\bar{k})}{\partial\delta} < 0, \quad (26)$$

as expected.

### B.2 Share of fragmentation and technology

The effect on  $\bar{k}$  from a change in communication technology is:

$$\frac{d\bar{k}}{d\eta} = -\frac{1}{\frac{\partial\tau(\bar{k})}{\partial\bar{k}}} \left[ \frac{\partial\tau(\bar{k})}{\partial\eta} + \frac{d\rho}{d\eta} \frac{\partial\tau(\bar{k})}{\partial\rho} \right] + \frac{1}{w_s \frac{\partial\tau(\bar{k})}{\partial\bar{k}}} \left[ \frac{1}{\alpha} \frac{dw_h}{d\eta} - \tau(\bar{k}) \frac{dw_s}{d\eta} \right]. \quad (27)$$

If wages are unaffected by technology, then the second set of square brackets are zero (but you see how skill-biased technological change would have interesting effects on offshored production). Here I assume that  $\frac{d\rho}{d\eta} = 0$  which means  $\frac{d\bar{k}}{d\eta} < 0$ .

### B.3 Homogeneous task production

The model assumes that productivity heterogeneity affects the transformation of the input  $M$  into output  $q$ , but does not alter firms' ability to convert labor into tasks. This assumption is similar to Antràs and Helpman (2004), where all suppliers make inputs one-to-one from labor, regardless of the productivity of the firm that owns them. The effect of extending the impact of productivity to task production depends upon firms' sourcing choices. Under integrated production, heterogeneity in task production would amplify the profitability and size differences that productivity heterogeneity induces without changing the model's basic result. The effect of extending task productivity heterogeneity under fragmented production would depend upon whether, and the extent to which, firms transfer their productivity to their input suppliers. With costless transferability regardless of ownership, task heterogeneity would simply amplify the existing results. If firm ownership or supplier industry affect transferability, then firms will weigh these additional fragmentation costs against the benefits described above.<sup>61</sup>

### B.4 Multi-dimensional task costs

When firms can source each task from a different location and fragmentation costs vary along two task-specific dimensions, it is no longer possible to order tasks by their costs. Locations vary in terms of their distance to the firm, relative wage and technological capabilities. Task-specific cost factors, such as weight and complexity, may interact with location-specific variables to induce non-monotonicities in costs across locations and tasks. For example, suppose final good production requires complex plastic screws that are communication intensive but relatively light, and large metal frames that are straightforward to construct but heavy. Plastic screws will be more expensive than frames to fragment from a nearby MSP, but metal frames will be relatively more costly to purchase from a distant supplier. Maximizing variable profits when there are three potential fragmentation strategies therefore entails identifying the lowest cost sourcing location for each task. A firm will prefer to source task  $k$  from location 1 over location 2 if:

$$\frac{w_{s_1}}{w_{s_2}} < \frac{\tau(\delta_{s_2}, \omega_k, \eta_{s_2})}{\tau(\delta_{s_1}, \omega_k, \eta_{s_1})}, \quad (28)$$

conditional on  $w_h > \alpha w_{s_1} \tau_k(\delta_{s_1}, \omega_k, \eta_{s_1}, \rho_j)$ . Equation (7) shows that as long fragmenting is cheaper than integrated production, the decision to source from one location over another depends only the relative costs and benefits of those locations. The share of fragmented

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<sup>61</sup>See Fort (2010) for an analysis of how firms' ability to transfer productivity to new plants varies across industries.

production from a given location  $s$  will simply be the total number of tasks for which  $s$  is the cheapest sourcing location.

## C Hurdle models

Although the hurdle model relies on the assumption that  $\ln(y)$  follows a classical linear model, it is more general than Tobit because it does not constrain the effect of the independent variables on the probability of  $y > 0$  to have the same sign and relative magnitudes as the effect of the independent variables on the size of  $\ln(y)$ . Using a standard hurdle model approach, the  $E(y|x) = \Phi(x\gamma)\exp(x\beta + \sigma^2/2)$ , where  $\gamma$  are the coefficients from a probit of the probability that  $y > 0$ ,  $\beta$  are the coefficients from the OLS regression of  $\ln(y)$  on  $x$  for positive values of  $y$ , and  $\sigma$  are the standard errors from the OLS regression.

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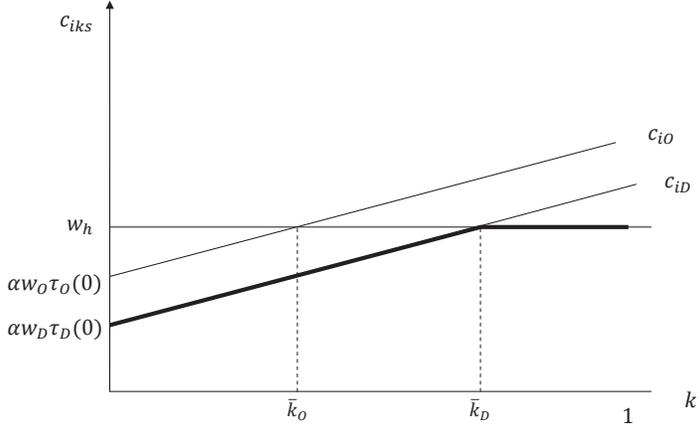
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Figure 1: Integrated production and domestic fragmentation

(a) Variable costs per task



(b) Profits

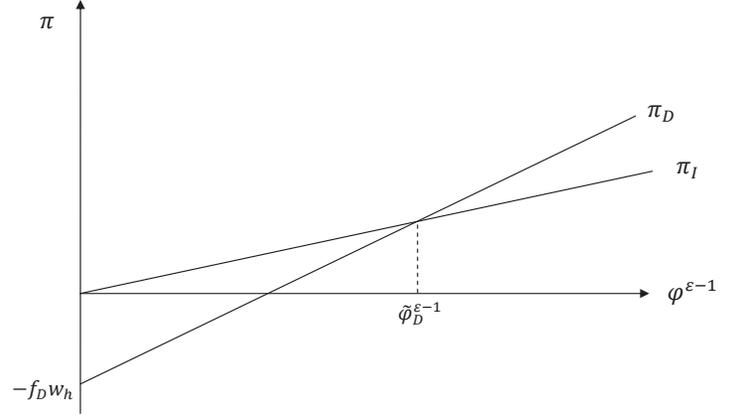
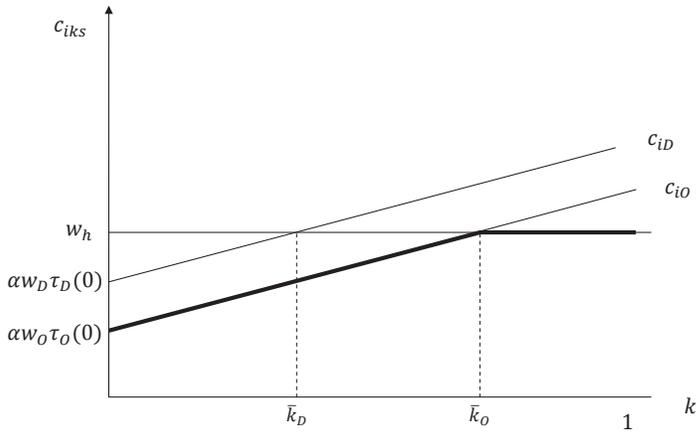


Figure 2: Integrated production, domestic fragmentation, or offshoring

(a) Variable costs per task



(b) Profits

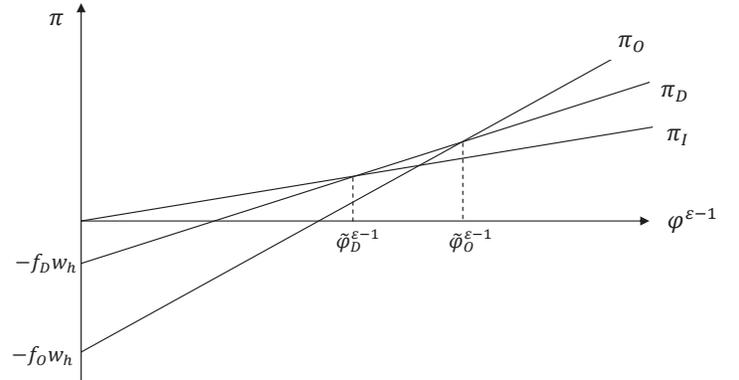


Figure 3: Integrated production, domestic fragmentation and offshoring

(a) Variable costs per task

(b) Profits

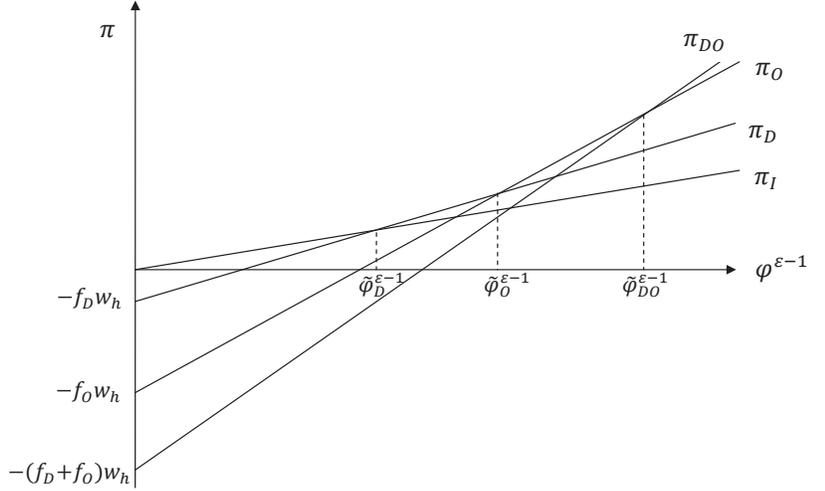
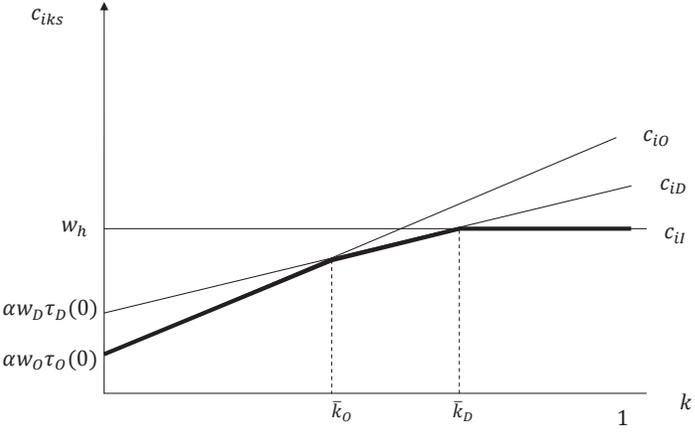
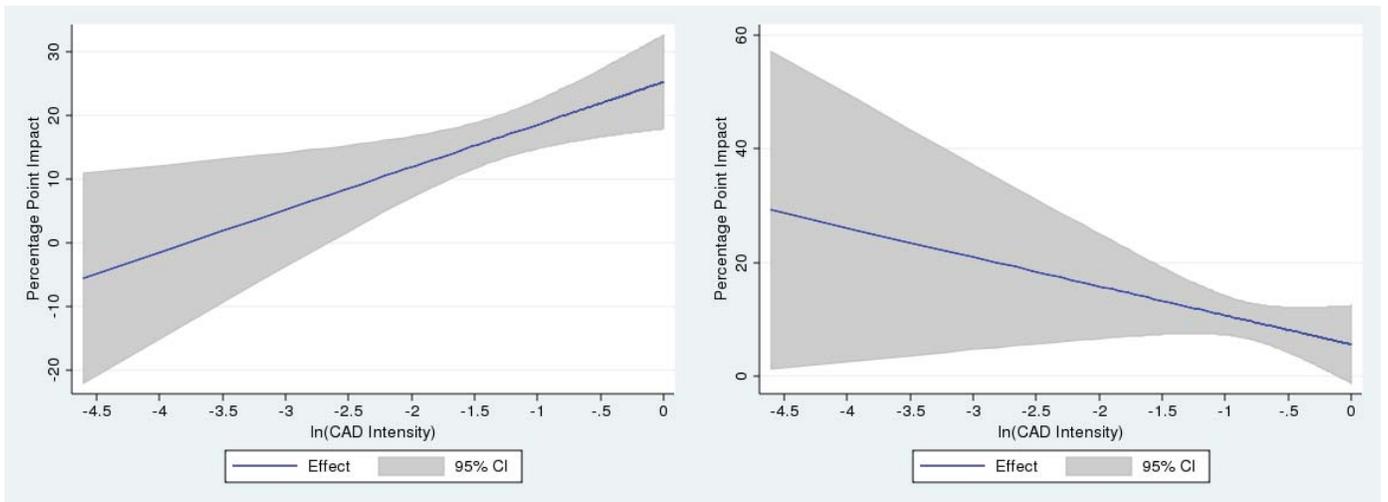


Figure 4: Differential impact of electronic networks, by industry CAD intensity

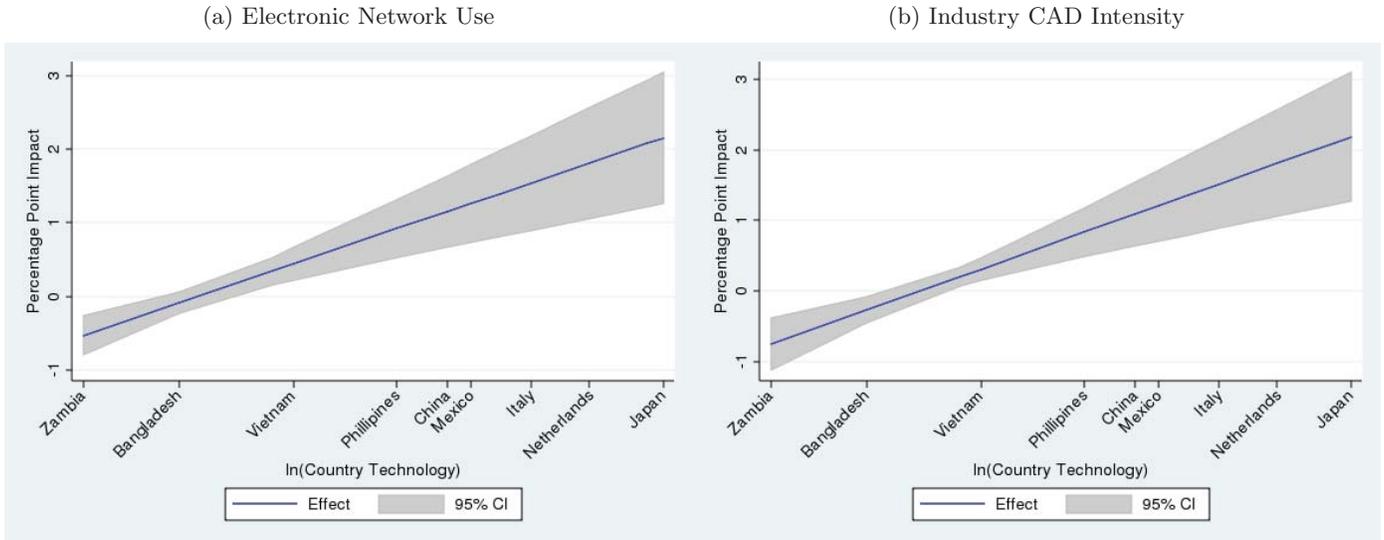
(a) Probability of Fragmentation

(b) Probability of Offshoring



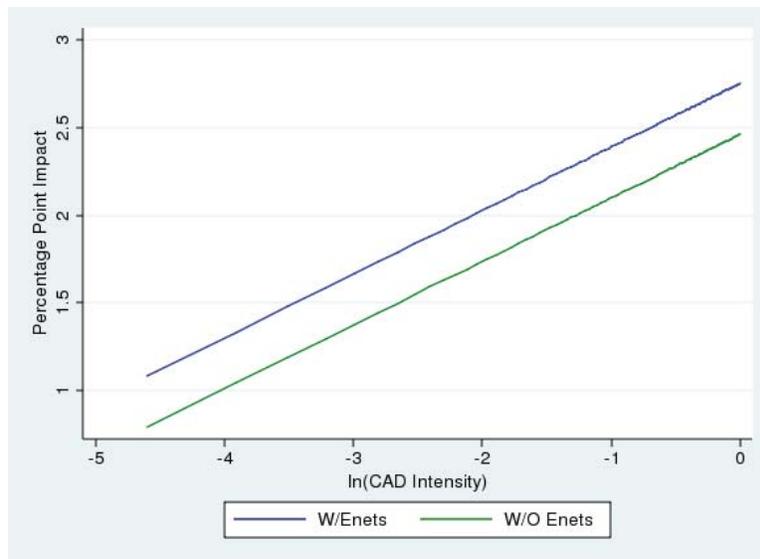
Notes: Estimates based on IV regressions of the probability an establishment fragments and offshores.

Figure 5: Differential impact of firm technology on probability of sourcing from country  $s$ , by country technology



Notes: Estimates based on regressions of the probability a firm imports from a given country.

Figure 6: Differential impact of country technology on probability of sourcing from country  $s$ , by industry CAD intensity



Notes: Estimates based on regressions of the probability a firm imports from a given country.

Table 1: Plant participation shares by contract manufacturing service purchase status

	Plants	Sales	Emp
No Purchases	0.71	0.57	0.61
Domestic Purchases	0.27	0.39	0.35
Offshore Purchases	0.02	0.04	0.04

Notes: Approximately 106,500 manufacturing plants in the CMS sample. Sales and employment shares weighted by the inverse probability of inclusion in the CMS sample.

Table 2: Manufacturing firm participation shares by contract manufacturing service purchase status

	Firms	Sales	Emp
No Purchases	0.69	0.31	0.42
Domestic Purchases	0.28	0.42	0.39
Offshore Purchases	0.02	0.03	0.03
Domestic & Offshore	0.01	0.24	0.16

Notes: Manufacturing firms are all firms in the CMS sample with one or more plants classified in manufacturing. Sales and employment shares weighted by the inverse probability of inclusion in the CMS sample.

Table 3: Plant means by contract manufacturing service purchase status

	Raw Means			Relative Industry Means		
	Sales <sup>a</sup>	Emp	ln(VAP)	Sales	Emp	ln(VAP)
No Purchases	19,487	51.3	4.51	0.87	0.91	-0.03
Domestic Purchases	37,077	79.8	4.63	1.28	1.20	0.07
Offshore Purchases	51,457	137	4.74	2.17	1.69	0.20
All Plants	24,686	60.4	4.55	1.00	1.00	0.00

Notes: Weighted by the inverse probability of inclusion in the CMS sample. <sup>a</sup> Sales in \$000s.

Table 4: Industry distribution of the share of establishments that purchase contract manufacturing services

86 Manufacturing Industries (NAICS 4)					
Domestic Purchases (% of estabs in industry)	Offshore Purchases (% of estabs in industry)				Total
	0%	0-5%	5-10%	10-20%	
5-10%	0	2	0	0	2
10-20%	1	22	2	0	25
20-35%	1	31	6	2	40
35-50%	0	13	4	1	18
50-60%	0	1	0	0	1
Total	2	69	12	3	86

Note: Categories defined such that  $LHS < \%estabs \leq RHS$

Table 5: Plant participation shares within average state wage terciles, by CMS purchase status

	State wage tercile		
	Low	Medium	High
No Purchases	0.76	0.73	0.68
Domestic Purchases	0.22	0.25	0.30
Offshore Purchases	0.02	0.02	0.02

Table 6: Manufacturing firm imports, by contract manufacturing service purchase status

	Total imports (share)	Average imports (millions \$s)	$\frac{Imports}{Sales}$ (mean)
No Purchases	0.33	2.5	0.09
Domestic Purchases	0.36	7.2	0.03
Offshore Purchases	0.07	18.7	0.20
Domestic & Offshore	0.24	428.5	0.16

Notes: Manufacturing firms are all firms in the CMS sample with one or more plants classified in manufacturing. Imports are of manufactured goods only. Measures weighted by the inverse probability of inclusion in the CMS sample.

Table 7: Manufacturing firms' import behavior, by contract manufacturing service purchase status

	Importer (share)	Low income <sup>a</sup> (share)	Median count of Firm			
			HS Products <sup>b</sup>		Countries <sup>c</sup>	
			All Firms	Importers	All Firms	Importers
No Purchases	0.41	0.28	0	3	0	2
Domestic Purchases	0.53	0.19	1	4	1	2
Offshore Purchases	0.90	0.48	8	11	3	4
Domestic & Offshore	$\approx 1.0^d$	0.19	123	124	20	20

Notes: Manufacturing firms are all firms in the CMS sample with one or more plants classified in manufacturing. Firm imports are limited to manufactured goods. *a* Share of imports from low-income countries, where countries in the bottom two per capita GDP terciles are classified as low income. *b* Count of distinct 10 digit Harmonized System codes a firm imports. *c* Count of distinct countries from which a firm imports. *d* Rounded for disclosure avoidance.

Table 8: Average distance between a plant and the closest port and border crossings, by CMS purchase status

	Deep water	Border Crossings	
	Ports	Canada	Mexico
No Purchases	286	469	992
Domestic Purchases	302	431	1,028
Offshore Purchases	248	483	950
All Plants	290	459	1,001

Table 9: Plant use of electronic networks, by year and 2007 CMS purchase status

	Share of Plants	
	2002	2007
No Purchases	0.17	0.36
Domestic Purchases	0.22	0.51
Offshore Purchases	0.33	0.61

Table 10: Share of plants in each 2007 CMS status, by 2002 electronic network use and 2002 CMS purchase status

2007 CMS Purchases	Networks in 2002=NO 2002 CMS Purchases		Networks in 2002=YES 2002 CMS Purchases	
	No	Yes	No	Yes
None	0.72	0.17	0.08	0.03
Domestic Purchases	0.51	0.34	0.07	0.08
Offshore Purchases	0.41	0.30	0.14	0.14

Note: Table limited to single unit firms in 2007 since 2002 question only includes CMS purchases from another firm.

Table 11: Share of plants in each 2007 CMS status, by 2002 electronic network use and 2002 offshore CMS purchase status

2007 CMS Purchases	Networks in 2002=NO 2002 Offshore Purchases		Networks in 2002=YES 2002 Offshore Purchases	
	No	Yes	No	Yes
None	0.82	0.03	0.14	0.01
Domestic Purchases	0.74	0.06	0.19	0.02
Offshore Purchases	0.57	0.12	0.25	0.06

Table 12: Probability that a plant fragments production

Dependent variable is 1 if plant  $i$  in industry  $j$  and state  $h$  fragments production

	OLS Estimates		IV Estimates			
	All <sup>a</sup> (1)	IV sample (2)	Baseline (3)	CAD (4)	Demand (5)	Skill (6)
<i>Electronic networks<sub>i</sub></i>	0.106*** (0.008)	0.102*** (0.004)	0.181*** (0.019)	0.253*** (0.037)	0.253*** (0.038)	0.253*** (0.037)
× <i>ln(CAD<sub>j</sub>)</i>				0.067*** (0.025)	0.067*** (0.025)	0.067*** (0.025)
<i>ln(wage<sub>h</sub>)</i>	0.159*** (0.055)	0.227*** (0.032)	0.183*** (0.029)	0.176*** (0.030)	0.176*** (0.030)	0.129*** (0.036)
<i>ln(VAProd<sub>i</sub>)</i> Q2	0.039*** (0.007)	0.037*** (0.005)	0.119*** (0.023)	0.123*** (0.023)	0.123*** (0.023)	0.122*** (0.023)
Q3	0.068*** (0.008)	0.074*** (0.008)	0.158*** (0.013)	0.161*** (0.013)	0.161*** (0.013)	0.161*** (0.013)
Distance to port <sup>b</sup>						
51-200 miles	-0.018* (0.010)	-0.008 (0.009)	-0.015*** (0.005)	-0.015*** (0.004)	-0.015*** (0.005)	-0.015*** (0.005)
200+ miles	-0.008 (0.007)	0.008 (0.009)	0.003 (0.005)	0.002 (0.005)	0.003 (0.006)	0.003 (0.006)
50+ miles to border w/						
Mexico	0.013* (0.007)	-0.012 (0.009)	-0.028*** (0.005)	-0.028*** (0.005)	-0.028*** (0.006)	-0.032*** (0.006)
Canada	-0.026 (0.022)	-0.013 (0.023)	-0.007 (0.007)	-0.008 (0.007)	-0.008 (0.007)	-0.008 (0.006)
<i>ln(BEA Personal Income)</i>					0.000 (0.002)	
<i>ln(Share college<sub>h</sub>)</i> <sup>c</sup>						0.033* (0.019)
<i>ln(Share highschool<sub>h</sub>)</i> <sup>d</sup>						0.040* (0.020)
NAICS 6 controls	yes	yes	yes	yes	yes	yes
Adj. R-Squared	0.08	0.09	0.08	0.08	0.08	0.08
N	105,500	71,600	71,600	71,600	71,600	71,600

Notes: Standard errors clustered by state. \*, \*\*, \*\*\* denote 10%, 5% and 1% significance respectively. IV regressions instrument for electronic networks and productivity using lagged 2002 values. *a* Regression for full sample, weighted by the inverse probability of inclusion in sample. *b* Distance between plant  $i$  and closest deep water port; plants within 50 miles is omitted category. *c* Share of all workers in state with at least a college degree. *d* Share of all production workers in state with at least a high school degree. N rounded for disclosure avoidance.

Table 13: Probability that a plant offshores, conditional on fragmentation

Dependent variable is 1 if plant  $i$  in industry  $j$  and state  $h$  offshores its fragmented production

	OLS Estimates		IV Estimates			
	All <sup>a</sup> (1)	IV sample (2)	Baseline (3)	CAD (4)	Demand (5)	Skill (6)
<i>Electronic networks<sub>i</sub></i>	0.023*** (0.004)	0.021*** (0.004)	0.100*** (0.016)	0.055 (0.035)	0.056 (0.035)	0.057* (0.034)
× <i>ln(CAD<sub>j</sub>)</i>				-0.051 (0.037)	-0.051 (0.037)	-0.051 (0.037)
<i>ln(wage<sub>h</sub>)</i>	-0.139*** (0.033)	-0.117*** (0.042)	-0.127*** (0.043)	-0.124*** (0.043)	-0.127*** (0.045)	-0.111** (0.045)
<i>ln(VAProd<sub>i</sub>)</i> Q2	0.004 (0.006)	0.006 (0.004)	-0.001 (0.018)	-0.003 (0.019)	-0.004 (0.019)	-0.004 (0.019)
Q3	0.020*** (0.007)	0.021** (0.009)	0.038*** (0.011)	0.036*** (0.011)	0.035*** (0.011)	0.034*** (0.011)
Distance to port <sup>c</sup>						
51-200 miles	-0.013** (0.006)	-0.007 (0.009)	-0.011 (0.008)	-0.012 (0.008)	-0.010 (0.008)	-0.007 (0.008)
200+ miles	-0.022*** (0.003)	-0.016*** (0.005)	-0.023*** (0.005)	-0.024*** (0.006)	-0.021*** (0.005)	-0.014*** (0.005)
50+ miles to border w/ Mexico	-0.092*** (0.031)	-0.123*** (0.036)	-0.095*** (0.018)	-0.096*** (0.018)	-0.097*** (0.018)	-0.089*** (0.019)
Canada	-0.013** (0.006)	-0.011* (0.005)	-0.010 (0.007)	-0.010 (0.007)	-0.010 (0.007)	-0.011* (0.006)
<i>ln(BEA Personal Income)</i>					0.002 (0.002)	
<i>ln(Share college<sub>h</sub>)</i> <sup>c</sup>						0.025 (0.016)
<i>ln(Share highschool<sub>h</sub>)</i> <sup>d</sup>						-0.051** (0.020)
NAICS 6 controls	yes	yes	yes	yes	yes	yes
Adj. R-Squared	0.09	0.10	0.08	0.07	0.07	0.07
N	30,700	21,500	21,500	21,500	21,500	21,500

Notes: Standard errors clustered by state. \*, \*\*, \*\*\* denote 10%, 5% and 1% significance respectively. IV regressions instrument for electronic networks and productivity using lagged 2002 values. *a* Regression for full sample of fragmenting plants, weighted by the inverse probability of inclusion in the CMS sample. *b* Distance between plant  $i$  and closest deep water port; plants within 50 miles is omitted category. *c* Share of all workers in state with at least a college degree. *d* Share of all production workers in state with at least a high school degree. N rounded for disclosure avoidance.

Table 14: Firm share of offshored production

Dependent variable is  $\ln\left(\frac{\text{imports}}{\text{sales}}\right)$  for firm  $f$  in industry  $j$

	CMS purchases primarily:			
	Offshore		Domestic	
<i>Electronic networks<sub>f</sub></i>	0.070	-0.145	0.085**	0.082
	(0.107)	(0.180)	(0.043)	(0.069)
$\times CAD_j$		-0.232		-0.005
		(0.156)		(0.061)
$\ln(VA Prod_f)$	-0.004	-0.013	-0.043	-0.043
	(0.070)	(0.070)	(0.033)	(0.033)
<i>Distance<sub>f</sub> to port<sup>a</sup></i>				
51-200 miles	0.150	0.154	-0.149**	-0.149**
	(0.151)	(0.150)	(0.066)	(0.065)
200+ miles	-0.053	-0.044	-0.254***	-0.252***
	(0.114)	(0.114)	(0.048)	(0.048)
> 50 miles from border w/ <sup>a</sup>				
Mexico	-0.287	-0.297	-0.232	-0.224
	(0.235)	(0.235)	(0.160)	(0.159)
Canada	-0.194	-0.217	-0.343***	-0.344***
	(0.203)	(0.203)	(0.075)	(0.075)
$\ln(wage_s/US)$	-0.182***	-0.175***	-0.265***	-0.265***
	(0.050)	(0.050)	(0.022)	(0.022)
$\ln(CAD_j)$		0.052		-0.084
		(0.165)		(0.066)
$\ln(Diff\ inputs_j)$		-1.902**		0.910***
		(0.751)		(0.296)
Industry controls	yes	yes	yes	yes
Adj. R-Squared	0.04	0.04	0.07	0.07
N	1,200	1,200	9,300	9,300

Notes: \*, \*\*, \*\*\* denote 10%, 5% and 1% significance respectively. <sup>a</sup> Distance between foreign entry point and the closest manufacturing establishment in the firm; firms with a plant within 50 miles is omitted category. N rounded for disclosure avoidance.

Table 15: Offshore sourcing location selection

Dependent variable is 1 if firm  $f$ , in industry  $j$ , imports from country  $s$

	Firms' CMS purchases are primarily:			
	Offshore	Domestic	Offshore	Domestic
<i>Electronic networks<sub>f</sub></i>	-0.005*** (0.001)	-0.005*** (0.001)		
$\times \ln(CAD_j)$	-0.000 (0.001)	0.000** (0.000)		
$\times \ln(Servers_s)$	0.002*** (0.001)	0.002*** (0.000)	0.003*** (0.001)	0.003*** (0.001)
$\ln(CAD_j)$	-0.008*** (0.002)	-0.004*** (0.001)		
$\times \ln(Servers_s)$	0.003*** (0.001)	0.001*** (0.000)	0.004*** (0.001)	0.002*** (0.000)
$\ln(VA Prod_f)$	0.002*** (0.000)	0.001*** (0.000)		
$Distance_{fs}^a$	-0.026** (0.011)	-0.019** (0.009)	-0.018 (0.030)	-0.026 (0.023)
$\ln(Diff\ inputs_j)$	0.007*** (0.001)	0.002*** (0.000)		
$\ln(w_s/w_{US})$			-0.021 (0.018)	-0.004 (0.005)
$\ln(Human\ Capital_s)$			-0.051 (0.035)	-0.024 (0.017)
$\ln(Servers_s)$			0.025*** (0.007)	0.009*** (0.002)
Country fixed effects	yes	yes	no	no
Firm fixed effects	no	no	yes	yes
Adj. R-Squared	0.21	0.11	0.10	0.09
N	270,000	363,900	103,000	1,382,000

Notes: Standard errors clustered by country. There are 185 country clusters in columns 1 and 2, and 70 country clusters in columns 3 and 4. \*, \*\*, \*\*\* denote 10%, 5% and 1% significance respectively.  $a$  Distance between a country's main city and the closest manufacturing establishment in the firm. N rounded for disclosure avoidance.

Table 16: Variance decomposition results: Contributions of wages, technology, and distance

Plant extensive margin estimations, dependent variable is one if plant						
Specification with:	Fragments			Offshores		
	Wages	Technology	Distance	Wages	Technology	Distance
Electronic networks	0.02	0.27	0.00	0.02	0.24	0.02
and CAD interaction	0.01	0.36	0.00	0.02	0.47	0.02

Firm intensive margin estimations, dependent variable is $\ln(\frac{imports}{sales})$						
Specification with:	Firms' CMS Purchases are Primarily:					
	Domestic			Offshore		
	Wages	Technology	Distance	Wages	Technology	Distance
Electronic networks	0.17	0.00	0.05	0.14	0.00	0.05
and CAD interaction	0.16	0.01	0.05	0.11	0.05	0.04

Notes: The top panel corresponds to the IV estimates for the extensive margin presented in columns 4 and 5 in Tables 12 and 13. In the extensive margin estimations, the dependent variable in the left panel is an indicator for whether a plant fragments production; the dependent variable in the right panel is an indicator for whether a plant that fragments does so primarily offshore. The bottom panel corresponds to estimates from Table 14. In the intensive margin regressions, the dependent variable is the firm  $\ln(\frac{imports}{sales})$ . The left panel provides estimates for the subset of domestic fragmenters; the right panel provides estimates for the subset of offshorers. In both panels, the top row is the specification with electronic networks only, while the bottom row includes networks and their interaction with CAD intensity.

Table A.1: First stage regressions

Each column is the first stage regression for the listed endogenous variable

Probability of Fragmentation Regressions							
Instruments	Electronic networks only			With CAD interaction			
	$\ln(VAP_i)$ Q2	$\ln(VAP_i)$ Q3	$Elec.Nets_i$ Indicator	$\ln(VAP_i)$ Q2	$\ln(VAP_i)$ Q3	$Elec.Nets_i$ Indicator	$\times \ln(CAD_j)$
$\ln(VAP_i)$ Q2	0.156*** (0.006)	0.089*** (0.004)	0.043*** (0.005)	0.089*** (0.004)	-0.059*** (0.007)	0.043*** (0.005)	0.156*** (0.006)
Q3	-0.049*** (0.006)	0.392*** (0.007)	0.062*** (0.005)	0.392*** (0.007)	-0.081*** (0.008)	0.062*** (0.005)	-0.049*** (0.006)
$Elec\ networks_i$	-0.007* (0.004)	0.038*** (0.004)	0.263*** (0.004)	0.042*** (0.006)	-0.088 (0.064)	0.278*** (0.006)	-0.012** (0.006)
$\times \ln(CAD_j)$				0.003 (0.003)	0.171*** (0.056)	0.013*** (0.003)	-0.004 (0.003)
Adj. R <sup>2</sup>	0.08	0.26	0.14	0.26	0.51	0.14	0.08
Shea's Partial R <sup>2</sup>	0.03	0.11	0.04	0.03	0.12	0.04	0.03
F-Statistic <sup>a</sup>	373	1212	1372	936	713	1037	280
Probability of Offshoring Regressions							
$\ln(VAP_i)$ Q2	0.140*** (0.011)	0.097*** (0.007)	0.012 (0.008)	0.140*** (0.011)	0.097*** (0.007)	0.012 (0.008)	-0.059*** (0.007)
Q3	-0.080*** (0.012)	0.399*** (0.011)	0.031*** (0.010)	-0.080*** (0.012)	0.399*** (0.011)	0.030*** (0.010)	-0.081*** (0.008)
$Elec\ networks_i$	-0.014* (0.008)	0.048*** (0.006)	0.241*** (0.006)	-0.030** (0.014)	0.061*** (0.011)	0.267*** (0.012)	-0.088 (0.064)
$\times \ln(CAD_j)$				-0.017 (0.010)	0.013* (0.008)	0.027** (0.012)	0.171*** (0.056)
Adj. R <sup>2</sup>	0.09	0.25	0.12	0.09	0.25	0.12	0.51
Shea's Partial R <sup>2</sup>	0.04	0.11	0.04	0.03	0.11	0.05	0.03
F-Statistic <sup>a</sup>	177	485	567	374	395	455	138

Notes: Each column reports the coefficients and standard errors for the excluded instruments in the first stage regression of the respective endogenous variable. Instruments are 2002 lagged values. Standard errors clustered by state. \*, \*\*, \*\*\* denote 10%, 5% and 1% significance respectively. <sup>a</sup> F-Statistic is for a test of the null hypothesis that the instruments are jointly equal to zero.