Structural Change Within Versus Across Firms: Evidence from the United States*

Xiang Ding
Harvard University†

Teresa C. Fort
Tuck School of Business at Dartmouth, CEPR, and NBER‡

Stephen J. Redding
Princeton University, CEPR, and NBER§

Peter K. Schott
Yale School of Management and NBER¶

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Abstract

From 1977 to 2012, the share of US manufacturing employment fell from 26 to 11%, with half of the change occurring among continuing firms. We develop a model of structural transformation within and between firms and examine the contribution of trade towards this reallocation. Our model highlights the role of intangible knowledge capital that can be redeployed across disparate sectors within the firm and complementary design and production activities. As reductions in trade barriers lower the price of intermediate inputs and reduce production costs, this complementarity increases the share of design in overall firm costs. Using separate data on firm input and output shocks, we provide empirical evidence in support of this prediction.

JEL CLASSIFICATION: L11, L21, L25, L60

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†Littauer Center 1805 Cambridge Street, Cambridge, MA 02138. Email: xiangding@g.harvard.edu

‡Tuck School of Business, 100 Tuck Hall, Hanover, NH 03755. Email: teresa.fort@dartmouth.edu

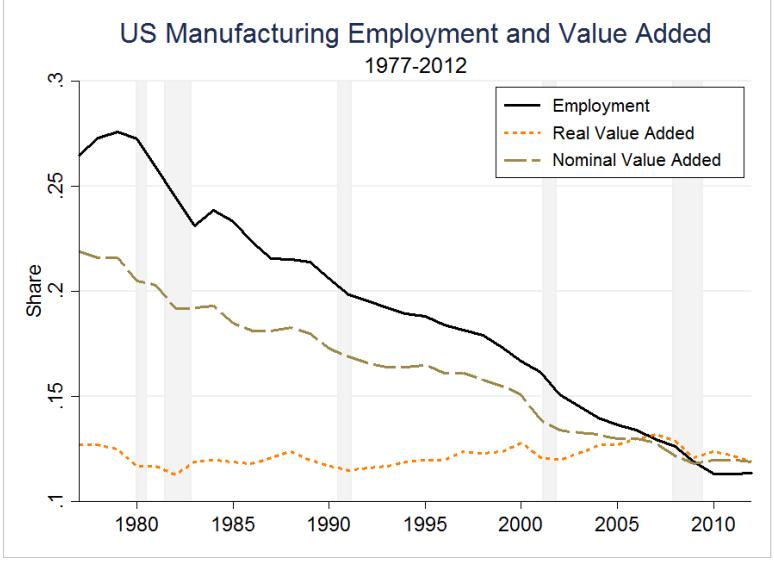
§Julis Romo Rabinowitz Building, Princeton, NJ 08544. Email: reddings@princeton.edu.

¶Yale School of Management 165 Whitney Avenue New Haven, CT 06511. Email: peter.schott@yale.edu.

1 Introduction

The US economy has undergone substantial structural change over the past few decades, transitioning from a manufacturing employment share of 26 percent in 1977 to less than half that level – 11 percent – in 2012. A similar decline has occurred with respect to manufacturing's share of nominal GDP, as illustrated in Figure 1. This contrasts with real manufacturing's output share, which is flat over the period, highlighting the fact that the constant real share is driven by rapidly falling prices in certain industries rather than increases in physical output.[1]

Figure 1: US Manufacturing and Service Employment, 1977-2012



Source: Longitudinal Business Database, US Bureau of Economic Analysis and author's calculations. Figure displays manufacturing employment as a share of total employment, as well as manufacturing GDP as a share of overall GDP, in both real and nominal terms.

At the same time, recent research documents a considerable increase in the share of aggregate US activity accounted for by large, old firms (Decker, Haltiwanger, Jarmin, and Miranda (2014)). Macroeconomists have suggested that this change in the firm size-age distribution is a factor in secular declines in both the start-up rate and in job reallocation across firms (Decker, Haltiwanger, Jarmin, and Miranda (2016); Pugsley and Sahin (2019)), increasing variable mark-ups among publicly traded firms (De Loecker and Eeckhout (2017)), and falling labor shares across sectors (Autor, Dorn, Katz, Patterson, and Reenan (2017)). While these trends appear related, there is considerable debate about their underlying causes, and in particular on the extent to which higher concentration may be due to a rising importance of fixed costs and intangible investments. Structural change may relate to an increase in concentration if the large, old

[1]This trend is particularly notable in the computer and electronics sector, which accounts for the majority of real value added growth over this period. See Houseman, Bartik, and Sturgeon (2018) for a discussion of the role of price indices in semiconductors in manufacturing real value added. The authors note that these falling prices "...largely reflects product and process improvements from research and development..." (abstract).

firms in shrinking industries drive the economy's expansion into new sectors. Fort, Pierce, and Schott (2018), for example, show that 75 percent of the decline in US manufacturing employment between 1977 and 2012 takes place within continuing firms, and that these firms exhibit sizeable increases in services[2] employment over the same period.

This paper provides new theory and evidence on the extent to which US structural change takes place within versus across firms. First, we use detailed microdata to decompose the 1977 to 2012 change in the share of US employment in services into within versus across firm components. Motivated by this decomposition, we develop a theoretical framework that highlights the role of intangible knowledge capital that can be used in different sectors within the firm and a complementarity between design and production activities. As technology or trade shocks reduce profitability in some sectors and raise profitability in others, the firm drops those sectors in which variable profits fall below fixed costs, and adds others in which variable profits rise above fixed costs. Additionally, trade shocks that reduce the price of intermediate inputs and lower production costs induce structural transformation within the firm towards design activities, because of the complementarity between design and production. Consistent with these predictions, we present empirical evidence of such reallocations within and between U.S. manufacturers in response to the rise of China between 1997 and 2007.

To quantify the importance of structural change within firms, we exploit detailed data from the US Census Bureau on all private, non-farm establishments from 1977 to 2012. Using longitudinal links proved by Census, we follow Fort, Pierce, and Schott (2018) in defining manufacturing firms broadly to be any firm that ever has an establishment that is ever classified in manufacturing over this period. These data reveal several striking trends. First, manufacturing firms account for 28 percent of the overall growth in US non-manufacturing employment. These firms' non-manufacturing employment growth is highest in retail and in business services. For the latter, manufacturing firms account for 38 percent of the within-firm growth over the period.[3] Second, while we find that most continuing manufacturing firms experience declining manufacturing employment, consistent with increased import competition in their product markets over this period, a sizeable share of manufacturing firms exhibit concomitant increases in service workers. For some manufacturing firms, these increases in non-manufacturing employment are so large that the firm's total employment increases despite its substantial contraction of manufacturing employment. Nonetheless, the occupational and geographical incidence of the decline in manufacturing employment and increase in non-manufacturing employment are quite different. The increases in manufacturing employment are strongest for professional and technical workers and occur in geographically distinct local labor markets from the declines in manufacturing employment. Finally, we calculate that just over half of the increase in the share of US labor devoted to services between 1977 to 2012 – from 76 to 89 percent – takes place within manufacturing firms present in 1977. These patterns highlight the importance

[2]Here and throughout the paper, we define services broadly to refer to any activity outside manufacturing.
[3]We define business services to be NAICS sectors 51-56.

of within-firm transformation and are consistent with incumbent firms exploiting existing assets across sectors in response to shocks.

Motivated by these facts, we develop a theoretical framework in which structural change can take place within as well as across firms. Firms are heterogenous in terms of both design and production efficiency, and combine "design capability", i.e., non-rivalrous intangible capital that can be deployed across sectors, with physical (i.e., manufactured) inputs and labor to produce goods. Trade liberalization affects firms via two channels: by increasing competition in their output markets and by reducing the cost of physical inputs. The degree to which structural change occurs within versus across firms is governed by the elasticity of substitution between design and manufacturing. We show that when design and manufacturing inputs are complementary, declines in the cost of a firm's physical inputs increases both the cost share and labor share of design in its production. Moreover, this elasticity of substitution can interact with design capability such that firms with higher levels of intangible capital grow disproportionately more from input shocks.

In the final section of the paper, we assess the empirical support for complementarity between design and manufactured inputs. To do so, we undertake a more detailed examination of structural change within firms by analyzing US manufacturing firms' manufacturing and non-manufacturing employment responses to the "rise" of China. One innovation of our analysis relative to prior research in this area is to examine the response of manufacturing firms' manufacturing as well as non-manufacturing activities to this shock. The second is to construct two distinct measures of Chinese import exposure that allow us to separate the impact of increased Chinese import penetration in a firm's outputs from increased import penetration in its inputs. Following Antràs, Fort, and Tintelnot (2017), and in the spirit Autor, Dorn, and Hanson (2013), we instrument for changes in industry-level import penetration from China using China's market share gains across industries in Europe. By using market shares rather than level growth in Chinese imports, we avoid capturing correlated demand shocks that might occur across countries and instead exploit China's comparative advantage gains due to changes in trade policy – its entry into the WTO and receipt of permanent normal trade relations status from the United States – as well as its rapid productivity growth.

We find that increased Chinese import penetration in a firm's inputs re-orients firms towards services: that is, it induces a reduction in the firm's manufacturing employment share, and an increase in employment at headquarter and professional and technical services establishments in terms of shares *and* levels. These results are consistent with the premise in the model that design and manufacturing employment are complementary. In contrast, increased import penetration in a firm's product markets leads the firm to shrink its overall and manufacturing employment, consistent with prior work on the effect of Chinese imports on US manufacturing employment (Autor, Dorn, and Hanson (2013), Pierce and Schott (2016)) Examination of firms' trading behavior over this period provides further insight. Greater output exposure to China leads to a decline in export growth rates, the number of countries to which firms exports, and

the number of products they exports. Higher input exposure, on the other hand, coincides with increase along all three of these margins.

This paper contributes to three broad literatures. First, it relates to a large literature in macroeconomics on structural change, nicely summarized in Herrendorf, Rogerson, and Valentinyi (2014), and the substantial debate over whether its ultimate cause is non-homothetic demand (Comin, Lashkari, and Mestieri (2018)), asymmetric technological progress (Ngai and Pissarides (2007)), or both (Herrendorf, Rogerson, and Valentinyi (2013)). Here, our contribution is two-fold. First, we develop a model of structural change in response to globalization that captures the essence of both of these forces. That is, US integration with China causes US comparative disadvantage industries to decline relative to comparative advantage industries (asymmetric demand shock), while greater access to Chinese inputs reallocates US factors towards services (asymmetric supply shock). Second, we assess the relative importance of these mechanisms among US manufacturing firms, focusing on how and why they might occur within rather than across firms. In this sense, the paper relates to recent work focusing on firms' that transition from manufacturing into services (Bernard and Fort (2015), Bernard, Smeets, and Warzynski (2017), Bernard, Fort, Smeets, and Warzynski (2018), Breinlich, Soderbery, and Wright (2018)) and on how differential entry rates across sectors can help explain the US transition (Dent, Karahan, Pugsley, and Sahin (2016), Pugsley and Sahin (2019)).

This paper also adds to an extensive literature studying the impact of low-wage imports on worker, firm, and regional outcomes. A growing body of work documents relationships between low-wage import competition and firms' product mix (Bernard, Jensen, and Schott (2006), Bernard, Jensen, Redding, and Schott (2011) and technological and quality upgrading (Khandelwal (2010), Bloom, Draca, and Van Reenen (2016). Other work emphasizes the impact of imported inputs and offshoring on firm productivity, employment levels and composition, and the firm-size distribution(Amiti and Konings (2007), Goldberg, Khandelwal, Pavcnik, and Topalova (2010), Halpern, Koren, and Szeidl (2015), Antràs, Fort, and Tintelnot (2017), Boehm, Flaaen, and Pandalai-Nayar (2017), Magyari (2017), Bloom, Handley, Kurmann, and Luck (2019)). Most recently, the negative impact of Chinese import competition on US manufacturing employment (Autor, Dorn, and Hanson (2013), Pierce and Schott (2016)) has received considerable attention. Here, our contribution is to differentiate the impact of rising low-wage country imports in firms' outputs versus inputs, and to show that separately identifying these channels provides a more complete understanding of the impact of international trade.

Finally, our analysis relates to the voluminous literature examining the boundaries of the firm. Existing theories focus on firms as vehicles for reducing transactions costs (Williamson (1981)) or resolving incomplete contracting problems (Grossman and Hart (1986), Hart and Moore (1990)).[4] Here, we emphasize firms' role in the accumulation and leveraging of intangible assets. In that sense, our approach is most closely related to Atalay, Hortacsu, and Syverson (2014), who argue that the transfer of intangibles across plants may be an important motive for integration, and Foster, Haltiwanger, and Syverson (2008), who

[4]See Lafontaine and Slade (2007) and Hart (2011)for extensive reviews of this literature.

document significant *revenue* productivity advantages of large, old firms relative to small, young firms, even though the latter tend to have higher physical productivity. Our contribution is to emphasize the role of intangibles in firm production in our model, and to show empirically that firm responses to integration with China are consistent with complementarities between these intangibles and manufacturing inputs.

The remainder of the paper proceeds as follows. Section 2 describes the data and provides a novel set of facts about the role of manufacturing firms in the US structural transformation, and the extent to which it has occurred within firms. In section 3 we present a framework to rationalize in which firms have intangible assets that they can leverage across sectors, and which used in a complementary fashion with manufacturing inputs. We exploit the China shock in section 4 to document the impact of specific demand and input shocks on structural change within the firm. The last section concludes.

2 New facts on US Structural Change from 1977 to 2012

This section provides a set of new descriptive facts on how the US economy has evolved across sectors and geography from 1977 to 2017.

2.1 Data

Our principal source of data is the the US Longitudinal Business Database (LBD), which links all private, non-farm employer establishments and firms over time starting in 1977 (Jarmin and Miranda (2002)). Each establishment is assigned a single industry code in each year based on its predominant activity.[5] The LBD makes a useful distinction between an "establishment", which is a single physical location where business transactions take place and for which payroll and employment records are kept, and a "firm", an organizational structure that can include one or more establishments.

In this paper, as in official statistics, employees are classified into industries based on the classification of the establishment at which they work. As a result, all employees in a manufacturing plant are classified as manufacturing employees, regardless of their occupation. A firm may span more than one industry if it has multiple establishments and these establishments do not have the same industry code.

The LBD is unique in its identification of the entire firm ownership structure. To address the fact that there is considerable merger and acquisition activity over time, we follow Haltiwanger, Jarmin, and Miranda (2013) and classify firm death as instances in which all the establishments in a firm exit forever. Firm birth is likewise classified as instances in which all the establishments in a firm are new.[6] While this definition may miss certain firm births in which existing establishments are all taken over by new

[5] We identify manufacturing plants based on an assignment of time-consistent NAICS codes developed by Fort and Klimek (2016) that ensure that the transition from SIC to NAICS does not result in spurious changes in the number of manufacturing workers based on changes in the set of activities considered "manufacturing." Our analysis drops records that are outside the scope of the County Business Patterns data, such as agriculture, and observations that are clearly erroneous, for example because of implausible payroll and employment numbers.

[6] Though the LBD contains firm identifiers, they are are not longitudinally valid. In fact, by construction they change whenever a single-unit firm transitions to a multi-unit firm, or vice versa.

ownership, we believe it is the most appropriate choice given that an establishment is associated with a physical location where intangibles are accumulated. Moreover, classifying all M&A as births and deaths would clearly overstate the amount of firm turnover. For example, when two firms merge, the assets of both firms, including their intangibles, persist.

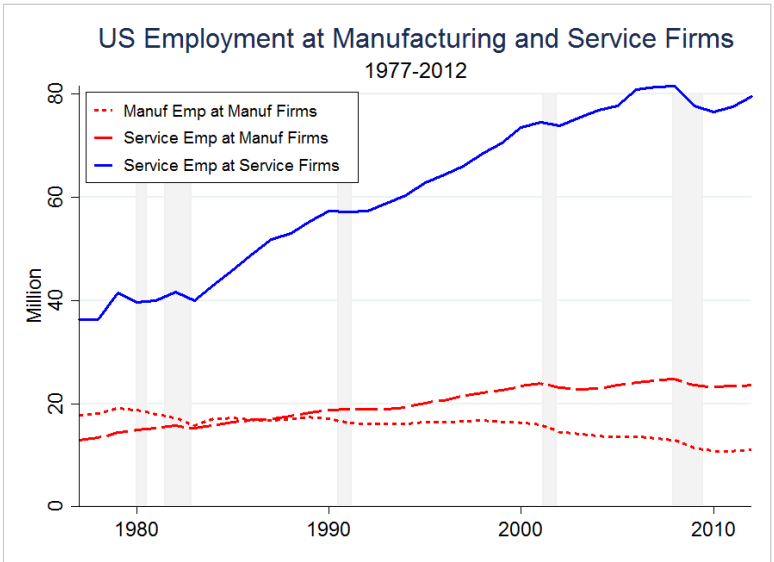
In addition to the LBD, we use data from the US Census Bureau's Census of Manufactures (CM) to measure firms' output and input usage across sectors. The CM surveys all manufacturing establishments quinquennially in years ending in "2" and "7" (hereafter referred to as "census years"). In contrast to the LBD, the CM provides a rich portrait of establishment activity, including detailed information on their sales and material inputs purchases, and employment and wages by production versus non-production worker status.

2.2 Manufacturing to Services

We focus on the decline of manufacturing employment and the rise of service employment from 1977 to the present, where the start date is dictated by the availability of the LBD data described above. To analyze the extent to which the transformation from manufacturing to services occurs within firms, we follow Fort, Pierce, and Schott (2018) in defining a manufacturing firm to be any firm that ever owns an establishment that is ever classified as manufacturing during this period. It is important to emphasize that this definition is quite broad, and that it may capture firms not traditionally thought of as manufacturers. Starting with such an expansive definition is useful, however, in that it provides the most complete picture of the types of firms that engage in both manufacturing and services. (In future drafts, we plan to compare the results below to those based on more restrictive definitions of manufacturing firms by, for example, excluding firms whose manufacturing employment shares fall below some threshold over the sample period.)

Figure 2 depicts total private non-farm employment from the LBD, broken out into three categories: manufacturing employment (at manufacturing firms), non-manufacturing employment at manufacturing firms, and non-manufacturing employment at non-manufacturing firms. This figure highlights two noteworthy trends. First, it reveals that manufacturing employment peaks in 1979, never fully recovers from the recessions in the 1980s and 1990s, and then falls substantially after the 2000 and 2007 recessions. Second, manufacturing firms contribute significantly to the growth of service employment. Between 1977 and 2012, service employment increased from 49 million to 86 million, with nearly a third of this increase – 28 (=11/37) percent – taking place within manufacturing firms.

Figure 2: US Manufacturing and Service Employment, 1977-2012



Source: Longitudinal Business Database and author's calculations. Figure displays US employment by type of firm. Manufacturing firms are defined as any firm that ever has an establishment ever classified as manufacturing during the sample period. Service firms are all other firms. Manufacturing firms can have both manufacturing and service employment depending on their mix of establishments, as the sector of employment is identified at the establishment level.

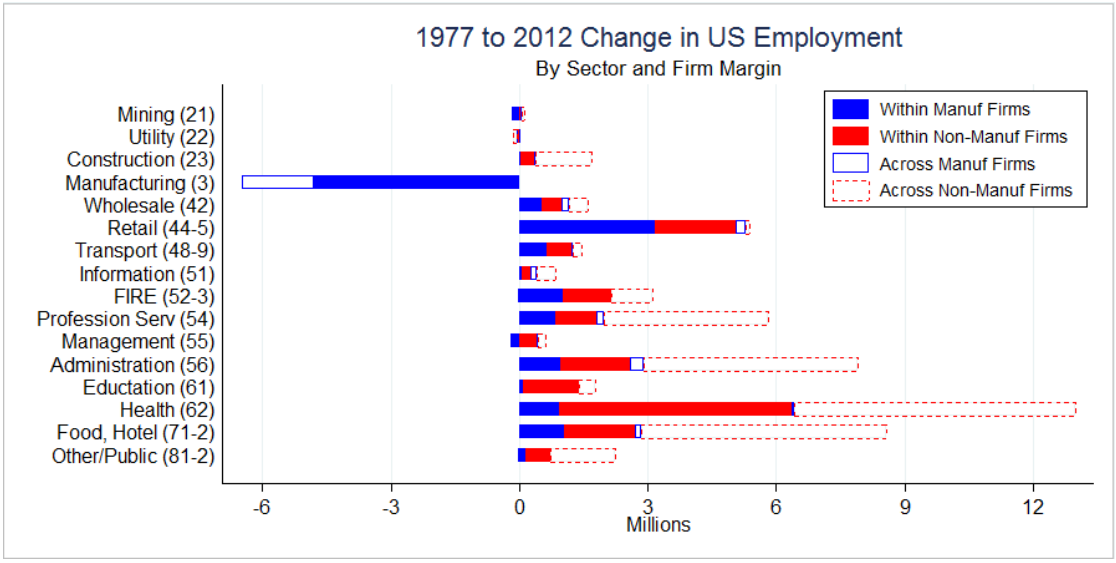
2.3 Sectoral Employment Growth Within versus Across Firms

In this section, we examine the extent to which continuing firms contribute to the aggregate US decline in manufacturing employment and rise of non-manufacturing employment. We find that a substantial share of employment growth across sectors occurs among continuers, i.e., firms that operate over the entire 1977 to 2012 sample period. Specifically, we decompose the change in employment in each broad sector k by type of firm and two margins of employment adjustment: (i) the change due to net firm birth and death, and (ii) the change that occurs within incumbents:

$$\begin{aligned} \Delta Emp_k = (\Delta Emp_M^{FB} - \Delta Emp_M^{FD}) + (\Delta Emp_M^{CF^+} - \Delta Emp_M^{CF^-}) \\ +(\Delta Emp_{NM}^{FB} - Emp_{NM}^{FD}) + (\Delta Emp_{NM}^{CF^+} - \Delta Emp_{NM}^{CF^-}). \end{aligned} \tag{1}$$

The first line in this equation contains the margins of manufacturing firms (subscript M), while the second row focuses on non-manufacturing (NM) firms. Within each line, the first two terms capture the net contribution of firm birth (FB) and firm death (FD), while the second two terms summarize the net contribution of continuing firms (CF).

Figure 3: Reallocation of US Employment Across Sectors, 1977-2012



Source: Longitudinal Business Database and author's calculations. Each bar records the 1977 to 2012 change in employment for the noted 2-digit NAICS sector, by type of firm and margin of adjustment. Manufacturing firms are defined as any firm that ever has an establishment ever classified as manufacturing during the 1977 to 2012 sample period. The first margin of adjustment represents the change in employment within continuing firms, either at their continuing establishments or due to plant birth and death. The second margin of adjustment captures the change in employment from firm birth and death.

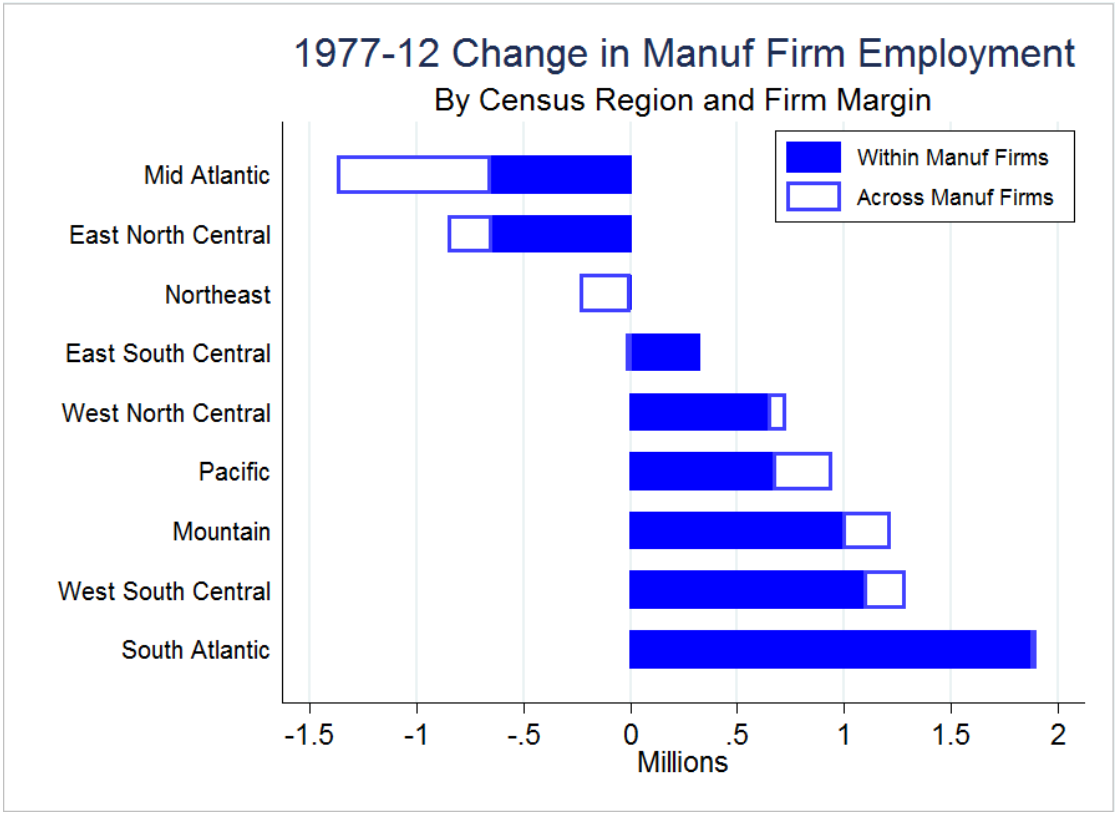
Figure 3 displays the results, where changes at continuing firms are captured by solid bars and changes due to firm turnover are noted by hollow bars. Three trends stand out. First, given our definition of manufacturing firms, a change in manufacturing employment can only occur among manufacturing firms. The solid portion of the bar for this sector indicates that 75 percent of the decline in US manufacturing employment from 1977 to 2012 occurs within continuing manufacturing firms, with the remaining 25 percent due to net manufacturing firm death. Second, comparison of the relative contributions of manufacturing and service firms reveals that the former are particularly important for retail, and also make sizable contributions to business services, i.e., sectors whose NAICS codes begin with "5". Third, while net firm birth is the main contributor of employment in business services, manufacturing firms comprise a significant portion (38 percent) of within firm growth in these sectors.

2.4 Regional Employment Growth Within Manufacturing Firms

The US exhibits substantial reallocation across regions as well as sectors, and here, too, a substantial portion of the growth in manufacturing firm employment across regions occurs within firms. This reallocation can be seen in Figure 4, which provides a decomposition similar to that reported in Figure 3 but with respect to the nine mutually exclusive Census regions that comprise the United States. (This figure currently focuses on manufacturing firms; in a future draft, we intend to include a similar decomposition for service firms.) Here, too, several patterns stand out. First, manufacturing firms' employment declines only in the

three regions most to the north and east of the United States. These are Northeast, Middle Atlantic and East North Central regions, and together they account for a decline of 2.5 million, versus an increase of 6.4 million in the remaining six regions. Second, outside these three regions, the vast majority of manufacturing firm employment growth occurs within continuing firms. Indeed, firm birth and death accounts for just 12 percent of net growth outside the northeast, versus 47 percent within it. The South Atlantic region in particular stands out in this dimension. Of its 1.9 million increase in employment, just 1 percent is due to net firm birth.

Figure 4: US Regional Employment Growth



Source: Longitudinal Business Database and author's calculations. Each bar records the 1977 to 2012 change in overall employment among manufacturing firms, by Census region and margin of adjustment. Manufacturing firms are defined as any firm that ever has an establishment ever classified as manufacturing during the 1977 to 2012 sample period. The first margin of adjustment represents the change in employment within continuing firms, either at their continuing establishments or due to plant birth and death. The second margin of adjustment captures the change in employment from firm birth and death. The mappings of Census regions to states are: New England (CT, ME, MA, NH, RI, VT); Middle Atlantic (NJ, NY, PA); East North Central (IN, IL, MI, OH, WI); West North Central (IA, KS, MN, MO, NE, ND, SD); South Atlantic (DE, DC, FL, GA, MD, NC, SC VA, WV); East South Central (AL, KY, MS, TN); West South Central (AR, LA, OK, TX); Mountain (AZ, CO, ID, MT, UT, NV, WY); and Pacific (AK, CA, HI, OR, WA).

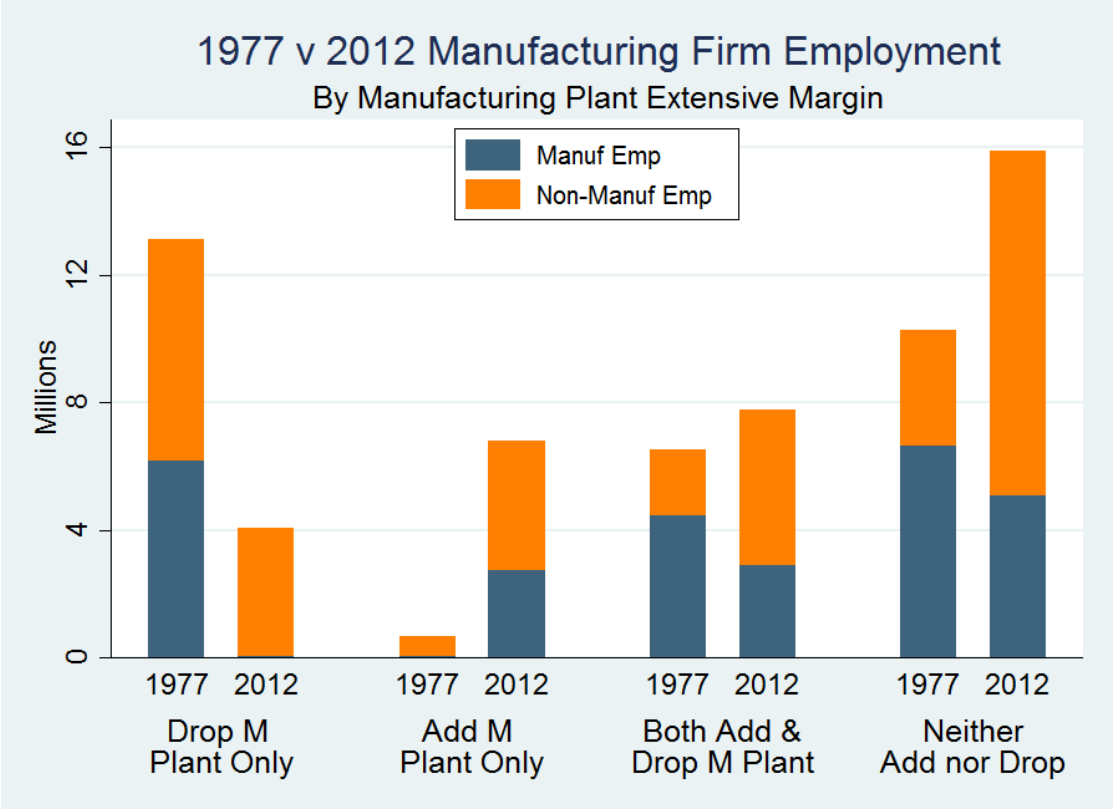
2.5 Employment Reallocation Within Firms

While the data reported in the previous section highlight the importance of continuing manufacturing firms for employment growth across sectors and regions, they provide no information about whether shifts

in employment from one sector to another, or one region to another, take place within the same manufacturing firm. In this section we examine such reallocation. To do so, we examine the extent to which the manufacturing firms simultaneously add and drop manufacturing and non-manufacturing establishments between 1977 and 2012.

We start by classifying manufacturing firms into four mutually-exclusive categories based on their activity with respect to manufacturing plants: 1) firms that only drop manufacturing plants over the 1977 to 2012 period; 2) firms that only add manufacturing plants over the period; 3) firms that both add and drop plants over the period; and 4) firms that neither add nor drop plants. (In a future draft, we plan to compare the results here, which focus on employment changes within coarse plant adding and dropping bins, with more detailed information about changes in the manufacturing employment share at the firm level.) Figure 5 decomposes manufacturing firms' total employment in 1977 and 2012 across these four categories.

Figure 5: Manufacturing Firm Employment by Manufacturing Plant Extensive Margin Changes



Source: Longitudinal Business Database and author's calculations. Each pair of bars compares the 1977 and 2012 employment of manufacturing firms that engage in one of four mutually exclusive activities during that interval: only drop manufacturing plants (bars 1 and 2); only add manufacturing plants (bars 3 and 4); both add and drop manufacturing plants (bars 5 and 6); and neither add nor drop manufacturing plants (bars 7 and 8). The solid and hollow portions of each bar represent manufacturing and service employment, respectively. Manufacturing firms are defined as any firm that ever has an establishment ever classified as manufacturing during the 1977 to 2012 sample period. Manufacturing firms can have both manufacturing and service employment depending on their mix of establishments, as manufacturing versus service employment is identified at the establishment level.

Three facts stand out. First, manufacturing firms that only drop manufacturing plants account for a significant portion of 1977 manufacturing employment, and they shed almost all of it by 2012. By contrast, these firms' non-manufacturing employment is more resilient, declining from 6.9 million in 1977 to 3.9 million in 2012. Second, firms that only add manufacturing plants grow their manufacturing employment considerably, from 0.1 to 2.8 million workers, yet their non-manufacturing employment increases are even larger, from 0.5 to 3.9 million workers. Finally, firms that both add and drop manufacturing plants, as well as those that neither add nor drop them, comprise the majority of manufacturing employment by 2012. Even so, the share of employment in manufacturing among these firms drops from approximately two thirds to one third due to a combination of manufacturing employment declines and non-manufacturing employment increases.

To determine the extent to which manufacturing and non-manufacturing employment may be substitutes or complements, we further decompose manufacturing firms according to their non-manufacturing plant add-drop activity, yielding the 16 mutually-exclusive categories displayed in Table 1. Each cell of this table reports the change in manufacturing employment (top panel) or service (bottom panel) employment among firms engaging in the noted pair of activities, where the last row and column of each panel report totals.[7]

As indicated in the table, there are several sets of activities – M drop only combined with add NM only or both add and drop NM – associated with manufacturing firms shedding manufacturing employment but gaining non-manufacturing employment. In fact, for both of these firm types, non-manufacturing employment growth more than offsets their manufacturing employment decline. Most striking are firms that both add and drop manufacturing plants. These firms decrease their manufacturing employment by 1.72 million (or 25 percent of the total net decline), yet increase their non-manufacturing employment by 2.71 million (25 percent of the net increase). In total, there are four bins in which firms shed manufacturing employment (by -4.6 million workers) but increase non-manufacturing employment (by 5.4 million workers).

Pointing to potential complementarities between manufacturing and non-manufacturing activities, there are also bins – e.g., firms that both add and drop M plants while only adding NM plants – in which firms increase both types of employment. In total, five of the 16 bins exhibit growth in both types of employment (2 of which represent bins that include firm births), while 5 have declines in both (2 of which represent bins that include firm deaths).[8]

[7] In particular, note that the final column of each table reports the employment changes summarized in Figure 5.

[8] Firms that die are captured by two bins: drop M plant only combined with neither adding nor dropping NM plants or dropping NM plants only. Firms that are born are present in two bins: add M plant only combined with either adding NM plants or neither adding nor dropping NM plants.

Table 1: 1977-12 Changes in Manufacturing Firm Employment by Extensive Margin Plant Changes

Panel A: Manufacturing Employment					
	NM Drop Only	NM Add Only	NM Both	NM Neither	Total
M Drop Only	-4.55	-0.25	-1.04	-0.27	-6.11
M Add Only	0.10	1.76	0.47	0.36	2.69
M Both	-0.02	0.14	-1.72	0.01	-1.59
M Neither	-0.07	0.10	0.00	-1.62	-1.59
Total	-4.54	1.75	-2.29	-1.52	-6.60
Panel B: Non-Manufacturing Employment					
	NM Drop Only	NM Add Only	NM Both	NM Neither	Total
M Drop Only	-4.39	0.28	1.16	-0.01	-2.96
M Add Only	-0.03	2.00	1.46	0.01	3.44
M Both	-0.01	0.12	2.71	0.00	2.82
M Neither	-0.75	3.04	3.66	1.27	7.22
Total	-5.18	5.44	8.99	1.27	10.52

Notes: Source: Longitudinal Business Database and author's calculations. Each cell in the top panel reports the 1977 to 2012 change in manufacturing employment among firms engaged in one of 16 mutually exclusive activites defined by their adding and dropping of manufacturing (M) and non-manufacturing (NM) establishments. Four actions are possible with respect to each type of plant: add only, drop only, both add and drop, and neither add nor drop. The second panel reports analogous information for manufacturing firms' non-manufacturing employment. Manufacturing firms are defined as any firm that ever has an establishment ever classified in manufacturing between 1977 to 2012.

2.6 Computing the Within-Firm Contribution of US Structural Change (preliminary)

We conclude this section with a preliminary decomposition of structural change into within- versus across-firm components. As reported implicitly in Figure 1, manufacturing employment's share of total private, non-farm employment in the United States falls from 26 percent in 1977 to 11.4 percent in 2012. Table 2 presents this same information, but reversed to show the economy-wide share of non-manufacturing employment rising from 74 percent to 89 percent. As Table 2 makes clear, this increase in the United States' non-manufacturing share of employment is due to both the decline in manufacturing employment and the increase in service employment.

The second row of Table 2 reports the portion of the 1977 to 2012 change in the US non-manufacturing share that occurs within continuing manufacturing firms. We compute this number by summing the employment changes of bins in Table 1 that capture continuing firms. For example, all firms in categories

that neither add nor drop establishments, as well as those in categories that add one type of establishment while dropping the other, must be continuers. As indicated in the table, the employment changes among firms in these bins raise the US non-manufacturing employment to 82 percent.

The third row of Table 2 displays the changes in manufacturing and service employment located in bins which capture firm births and deaths (see footnote 8). These changes increase the aggregate US NM share by an additional two percentage points, to 84 percent.

Finally, the increase in non-manufacturing employment among non-manufacturing firms raises the economy-wide non-manufacturing employment share to 89 percent. Thus, the decomposition reveals that continuing manufacturing firms account for more than half (8 out of 15 percent) of the rise in the aggregate non-manufacturing employment share over the period.

Table 2: Decomposition of US Structural Change (preliminary)

	Manuf	Non-Manuf	Total	NM Share
1977 Employment (millions)	17.8	49.3	67.1	0.74
+ Changes in Continuing-Man Firm Bins	13.9	62.2	76.1	0.82
+ Changes in Birth/Death Man Firm Bins	11.1	59.8	71.0	0.84
+ Non-Manufacturing Firms	11.1	86.5	97.5	0.89
2012 Employment (millions)	11.1	86.5	97.5	0.89

Notes: Source: Longitudinal Business Database and author's calculations. Table decomposes the overall change in US manufacturing and non-manufacturing (i.e., service) employment between 1977 (top row) and 2012 (bottom row). Second row reports the change in employment among manufacturing firms whose manufacturing and non-manufacturing plant adding and dropping activity indicates that they are continuing firms. Third row reports the change in employment among manufacturing firms whose manufacturing and non-manufacturing plant adding and dropping activity encompasses firm birth and death. These activities are: dropping manufacturing establishments and not adding non-manufacturing establishments (death), or adding manufacturing establishments and not dropping non-manufacturing establishments (birth). Fourth row of table reports the contribution of non-manufufacturing firms. Manufacturing firms are defined as any firm that ever has an establishment ever classified as manufacturing during the 1977 to 2012 sample period.

3 Model

The facts presented in the previous section highlight the importance of continuing manufacturing firms in mediating the US transition from manufacturing to services. The data suggest that some firms substitute away from manufacturing employment and towards service employment as they shut down manufacturing plants and open non-manufacturing establishments. Other firms increase both types of employment, suggesting complementarity. In this section, we develop a model that allows for both substitutability and complementarity in firms' manufacturing and service activities. As a result, structural change, i.e., the transition from manufacturing to services, can occur within or across firms either in response to sector-

specific demand or input shocks. This model combines the specification of firm heterogeneity from Melitz (2003), the formulation of multi-product firms from Bernard, Redding, and Schott (2010), and complementarity between design and production, similar to the complementarity between manufacturing and services in the macroeconomic literature on structural transformation including Ngai and Pissarides (2007).

3.1 Preferences

We consider a world of N countries indexed by $n, i \in N$. Preferences are defined over the goods supplied by a set of sectors indexed by $j \in J$. Time is discrete and denoted by $t \in T$. Each county is endowed with inelastic supplies of design workers ($\bar{L}_t^D$) and production workers ($\bar{L}_t^P$). We assume that the representative consumer has CES preferences across firm varieties in each sector and market. Using CES demand, sales for firm f in industry j in market n at time t are:

$$X_{fjnt} = p_{fjnt}^{1-\sigma_j} X_{jnt} P_{jnt}^{\sigma_j - 1}, \tag{2}$$

where X_{jnt} is aggregate expenditure in sector j in market n at time t; P_{jnt} is the price index in sector j in market n at time t; and σ_j is the elasticity of substitution across firms within sector j. Total firm sales are the sum of sales across all markets and sectors served by the firm:

$$X_{ft} = \sum_{n \in N_f} \sum_{j \in J_{nf}} X_{fjnt} = \sum_{n \in N_f} \sum_{j \in J_{nf}} X_{jnt} P_{jnt}^{\sigma_j - 1} p_{fjnt}^{1-\sigma_j}, \tag{3}$$

where N_f is the set of markets for firm f and J_{nf} is the set of industries for firm f in market n.

3.2 Pricing and Profits

Firms compete under conditions of monopolistic competition, taking as given the aggregate demand shifter ($X_{jnt} P_{jnt}^{\sigma_j - 1}$) in each sector j in each market n. We take a technological view of the boundaries of the firm, in which a firm is defined by its horizontally-differentiated brand for varieties, its intangible knowledge capital for variety design, and its production knowledge for variety production. In particular, each firm f in country i faces a constant marginal cost of production of supplying its variety in each sector j ($c_{fjt}\left(\theta_{ft}, \varphi_{jft}, w_{it}^D, w_{it}^P\right)$), which depends on the firm's intangible knowledge capital that is common across sectors (θ_{ft}), the firm's production knowledge in each sector (φ_{jft}), and the price of the two primary factors of production (w_{it}^D, w_{it}^P). Additionally, firm f in country i faces a fixed cost of supplying each sector j in each market n ($\mathbb{F}_{jnt}\left(w_{it}^D, w_{it}^P\right)$), which also depends on the price of the two primary factors of production (w_{it}^D, w_{it}^P), as well as an iceberg variable cost of trade, such that $\tau_{jnit} \geq 1$ must be shipped from country i to market n in sector j at time t in order for one unit to arrive. Profit maximization under CES demand and monopolistic competition implies that the variety price for each firm is a mark-up over marginal cost:

$$p_{fjnt} = \frac{\sigma_j}{\sigma_j - 1} \tau_{jnit} c_{fjt}\left(\theta_{ft}, \varphi_{jft}, w_{it}^D, w_{it}^P\right), \tag{4}$$

where the markup depends on the constant elasticity of substitution (σ_j); and marginal costs include both the marginal production cost ($c_{fjt}\left(\theta_{ft}, \varphi_{jft}, w_{it}^D, w_{it}^P\right)$) and the iceberg variable trade cost (τ_{jnt}). Using this equilibrium pricing rule, firm variable profits in each sector and market are proportional to revenue:

$$\pi_{fjnt} = \frac{1}{\sigma_j} X_{fjnt}. \tag{5}$$

A firm chooses to serve a given sector j and market n if its variable profits exceed fixed costs:

$$j \in J_{nf} \qquad \Leftrightarrow \qquad \frac{1}{\sigma_j} X_{fjnt} \geq \mathbb{F}_{jnt}\left(w_{it}^D, w_{it}^P\right). \tag{6}$$

Total firm profits are the sum of variable profits across all sectors and markets that the firm finds it profitable to serve:

$$\pi_{ft} = \sum_{n \in N_f} \sum_{j \in J_{nf}} \frac{1}{\sigma_j} X_{fjnt} - \mathbb{F}_{jnt}\left(w_{it}^D, w_{it}^P\right). \tag{7}$$

In response to shocks to technology and trade costs, the firm may find it profitable to drop some sectors and markets in which variable profits fall below fixed costs, and add other sectors and markets in which variable profits rise above fixed costs. Therefore, the model features structural transformation across sectors in response to shocks to technology and trade costs. Key to this process of reallocation is the fact that the firm's intangible knowledge capital (θ_{ft}) can be used across different sectors. In this specification, whether structural transformation occurs within or beyond the boundaries of a firm matters, because different firms have different levels of intangible knowledge (θ_{ft}) and production knoweldge (φ_{jft}). While we focus on this heterogeneity in intangible knowledge (θ_{ft}) and production knowledge (φ_{jft}), one could also in principle allow for switching costs between sectors that differ depending on whether this reallocation across sectors occurs within and beyond the boundaries of the firm.

3.3 Production Costs

We assume that supplying a variety involves complementary activities of design and production. In particular, we assume that the marginal costs of supplying a variety for firm f in sector j and country i to market n is a constant elasticity function of design costs and production costs. Design costs are decreasing in intangible knowledge capital (θ_{ft}) and increasing in the wage of design workers (w_{it}^D). Production costs are decreasing in production knowledge (φ_{jft}) and increasing in a Cobb-Douglas function of the wage of production workers (w_{it}^P) and the price of intermediate inputs (Q_{jit}):

$$c_{fjt}\left(\theta_{ft}, \varphi_{jft}, w_{it}^D, w_{it}^P\right) = \left[\left(\frac{w_{it}^D}{\theta_{ft}}\right)^{1-\mu_j} + \left(\frac{\left(w_{it}^P\right)^{\beta_j}\left(Q_{jit}\right)^{1-\beta_j}}{\varphi_{jft}}\right)^{1-\mu_j}\right]^{\frac{1}{1-\mu_j}}, \tag{8}$$

where we assume $0 < \mu_j < 1$ such that design and production are complements and we allow the price of intermediate inputs (Q_{jit}) to vary across both countries i and sectors j. Using cost minimization, the share

of design costs in overall production costs (ξ^D_{fjt}) is given by:

$$\xi^D_{fjt} = \frac{\left(\frac{w^D_{it}}{\theta_{ft}}\right)^{1-\mu_j}}{\left(\frac{w^D_{it}}{\theta_{ft}}\right)^{1-\mu_j} + \left(\frac{\left(w^P_{it}\right)^{\beta_j}\left(Q_{jit}\right)^{1-\beta_j}}{\varphi_{jft}}\right)^{1-\mu_j}}. \tag{9}$$

We now examine the role of changes in technology and trade in inducing structural transformation between the functions of design and production within sectors. We demonstrate this structural transformation for the shares of design in (i) overall production costs; (ii) labor costs; and (iii) employment. We start with the share of design in overall production costs, and totally differentiate equation (9) to obtain:

$$\mathrm{d}\ln \xi^D_{fjt} = \left(1-\mu_j\right)\left(1-\xi^D_{fjt}\right)\left[\begin{array}{c} \mathrm{d}\ln w^D_{it} - \beta_j \mathrm{d}\ln w^P_{it} - \left(1-\beta_j\right)\mathrm{d}\ln Q_{jit} \\ -\mathrm{d}\ln\theta_{ft} + \mathrm{d}\ln\varphi_{jft} \end{array}\right]. \tag{10}$$

Therefore, if design and production are complements ($0 < \mu_j < 1$) and holding constant factor prices ($\mathrm{d}\ln w^D_{it} = 0$ and $\mathrm{d}\ln w^P_{it} = 0$), more rapid productivity growth in production than design ($\mathrm{d}\ln\varphi_{jft} > \mathrm{d}\ln\theta_{ft}$) raises the share of design in overall production costs ($\mathrm{d}\ln\xi^D_{fjt} > 0$). Similarly, reductions in trade barriers that lower the price of intermediate inputs ($\mathrm{d}\ln Q_{jit} < 0$) raise the share of design in overall production costs ($\mathrm{d}\ln\xi^D_{fjt} > 0$).

We next examine the share of design in labor costs, which can be written as:

$$\vartheta^D_{fjt} = \frac{w^D_{it}L^D_{jit}}{w^D_{it}L^D_{jit} + w^P_{it}L^P_{jit}}. \tag{11}$$

Totally differentiating this relationship, we have:

$$\mathrm{d}\log\vartheta^D_{fjt} = \left(1-\lambda^D_{fj}\right)\left[\mathrm{d}\ln w^D_{it} - \mathrm{d}\log w^P + \mathrm{d}\log L^D_{fj} - \mathrm{d}\log L^M_{fj}\right]. \tag{12}$$

Therefore, holding constant factor prices ($\mathrm{d}\ln w^D_{it} = 0$ and $\mathrm{d}\ln w^P_{it} = 0$), a rise in the share of design in labor costs ($\mathrm{d}\log\vartheta^D_{fjt} > 0$) implies a rise in design employment relative to production employment ($\mathrm{d}\log L^D_{fj} > \mathrm{d}\log L^M_{fj}$), which in turn implies an increase in the share of design in employment.

Finally, we combine these results for the share of design in overall production costs in equation (10) with our result for the share of design in labor costs in (12) to determine the impact of technology and trade shocks on the share of design in employment. From our assumption of Cobb-Douglas production costs, expenditures on intermediate inputs are a constant multiple of the wagebill for production workers:

$$Q_{jit}M_{jit} = \frac{1-\beta_j}{\beta_j} w^P_{it}L^P_{jit}. \tag{13}$$

Using this result (13), we can re-write the share of design in overall production costs in equation (9) as:

$$\xi^D_{fjt} = \frac{w^D_{it}L^D_{jit}}{w^D_{it}L^D_{jit} + \left[1+\frac{1-\beta_j}{\beta_j}\right] w^P_{it}L^P_{jit}}. \tag{14}$$

Totally differentiating this relationship and using equations (10) and (12), we find that the share of design in labor costs moves with the share of design in overall production costs:

$$d \ln \vartheta_{fjt}^D = \left(\frac{1 - \vartheta_{fjt}^D}{1 - \xi_{fjt}^D} \right) \mathrm{d} \ln \xi_{fjt}^D, \tag{15}$$

where $0 < \vartheta_{fjt}^D < 1$ and $0 < \xi_{fjt}^D < 1$.

From equations (10) and (15), if design and production are complements ($0 < \mu_j < 1$) and holding constant factor prices ($\mathrm{d} \ln w_{it}^D = 0$ and $\mathrm{d} \ln w_{it}^P = 0$), more rapid productivity growth in production than design ($\mathrm{d} \ln \varphi_{jft} > \mathrm{d} \ln \theta_{ft}$) not only raises the share of design in overall production costs ($\mathrm{d} \ln \xi_{fjt}^D > 0$) but also raises the share of design in labor costs ($d \ln \vartheta_{fjt}^D > 0$). Similarly, reductions in trade barriers that lower the price of intermediate inputs ($\mathrm{d} \ln Q_{jit} < 0$) not only raise the share of design in overall production costs ($\mathrm{d} \ln \xi_{fjt}^D > 0$) but also raise the share of design in labor costs ($d \ln \vartheta_{fjt}^D > 0$). From equation (12), this rise in the share of design in labor costs ($d \ln \vartheta_{fjt}^D > 0$) also translates into a rise in the share of design in employment ($\mathrm{d} \log L_{fj}^D > \mathrm{d} \log L_{fj}^M$), holding constant factor prices ($\mathrm{d} \ln w_{it}^D = 0$ and $\mathrm{d} \ln w_{it}^P = 0$).

In the previous section, we established that shocks to technology and trade costs induce structural transformation across *sectors* within firms, because firm intangible knowledge capital can be applied across different sectors. In this section, we find that shocks to technology and trade costs also induce structural transformation across the *functions* of design and production within firms and within sectors.

3.4 Intermediate Input Costs

We now explore further the determination of intermediate input costs for firm f in sector j and country i. We assume a version of roundabout production, in which input costs in country i depend on the price index for each sector in that country:

$$Q_{jit} = \left[\sum_{k \in J} \left(\frac{P_{kit}}{\psi_{kit}} \right)^{1-\nu} \right]^{\frac{1}{1-\nu}}, \tag{16}$$

where ψ_{kit} controls the relative tastes of sector k in sector j's costs; and ν is the elasticity of substitution across sectors. Using Shephard's Lemma, the share of industry k in industry j's costs in country i is depends on its price relative to its tastes (P_{jit}/ψ_{jit}) compared to the price relative to tastes for all other sectors k (P_{kit}/ψ_{kit}):

$$\xi_{jit}^Q = \frac{\left(\frac{P_{jit}}{\psi_{jit}} \right)^{1-\nu}}{\sum_{k \in J} \left(\frac{P_{kit}}{\psi_{kit}} \right)^{1-\nu}}. \tag{17}$$

3.5 Exact Hat Algebra

We now show that that the system of equations for general equilibrium in the model can be written in terms of relative changes or "exact hat algebra" following Dekle, Eaton and Kortum (2007). We define the relative change in a variable between a pair of time periods t and τ as $\hat{X}_{ft} = X_{f\tau}/X_{ft}$. We use these results in the next section to show how the model can be quantified to back out the unobserved changes in technology and trade that rationalize the observed changes in the endogenous variables in the data. We illustrate these results here for a constant set of markets for each firm (N_f) and a constant set of industries for each firm and market (J_{nf}). But the analysis can be extended to allow for changes in the set of markets for each firm and the set of industries for each firm and market.

Using equation (3), we can write the relative change in total firm sales using exact-hat algebra as:

$$X_{ft}\hat{X}_{ft} = \sum_{n\in N_f}\sum_{j\in J_{nf}} X_{jnt}P_{jnt}^{\sigma_j-1}p_{fjnt}^{1-\sigma_j}\hat{X}_{jnt}\hat{P}_{jnt}^{\sigma_j-1}\hat{p}_{fjnt}^{1-\sigma_j}. \tag{18}$$

Re-writing this equation, we obtain:

$$\hat{X}_{ft} = \sum_{n\in N_f}\sum_{j\in J_{nf}} \xi_{fjnt}^{X}\hat{X}_{jnt}\hat{P}_{jnt}^{\sigma_j-1}\hat{p}_{fjnt}^{1-\sigma_j}, \qquad \xi_{fjnt}^{X} \equiv \frac{X_{fjnt}}{X_{ft}}, \tag{19}$$

where ξ_{fjnt}^{X} is the share of a market-sector pair in total firm sales. Intuitively, the relative change in firm sales is the expenditure-share-weighted average of the relative change in firm sales in each market and industry, which in turn depends on the relative change in market demand ($\hat{X}_{jnt}\hat{P}_{jnt}^{\sigma_j-1}$) and the relative change in own firm prices ($\hat{p}_{fjnt}^{1-\sigma_j}$). In our reduced-form regressions, we interpret the output tariff measure as capturing the relative change in product market competition in US firms domestic market.

Using equation (4), the relative change in own firm prices can be written as:

$$\hat{p}_{fjnt} = \hat{\tau}_{jnt}\hat{c}_{fjnt}. \tag{20}$$

Intuitively, relative changes in own firm prices depend on relative changes in trade costs and changes in marginal costs. Using equation (7), we can express the relative change in firm variable profits as:

$$\pi_{ft}\hat{\pi}_{ft} = \sum_{n\in N_f}\sum_{j\in J_{nf}} \frac{1}{\sigma_j}X_{fjnt}\hat{X}_{fjnt}, \tag{21}$$

and hence:

$$\hat{\pi}_{ft} = \sum_{m\in N_f}\sum_{j\in J_{nf}} \xi_{fjmt}^{\pi}\hat{X}_{fjmt}, \qquad \xi_{fjmt}^{\pi} \equiv \frac{\frac{1}{\sigma_j}X_{fjmt}}{\sum_{n\in N_f}\sum_{k\in J_{nf}}\frac{1}{\sigma_k}X_{fknt}}. \tag{22}$$

Intuitively, relative changes in firm profits are the profit-share-weighted average of relative changes in firm profits in each industry and market.

Using equation (8), we can write the relative change in firm costs as:

$$c_{fjt}\hat{c}_{fjt} = \left[\left(\frac{w_{it}^{D}\hat{w}_{it}^{D}}{\theta_{ft}\hat{\theta}_{ft}}\right)^{1-\mu_j} + \left(\frac{\left(w_{it}^{P}\right)^{\beta}\left(\hat{w}_{it}^{P}\right)^{\beta}\left(Q_{jit}\right)^{1-\beta}\left(\hat{Q}_{jit}\right)^{1-\beta}}{\varphi_{jft}\hat{\varphi}_{jft}}\right)^{1-\mu_j}\right]^{\frac{1}{1-\mu_j}}, \tag{23}$$

which can be further re-written as:

$$\hat{c}_{fjt} = \left[\xi^D_{fjt} \left(\frac{\hat{w}^D_{it}}{\hat{\theta}_{ft}} \right)^{1-\mu_j} + \left(1 - \xi^D_{fjt}\right) \left(\frac{\left(\hat{w}^P_{it}\right)^{\beta} \left(\hat{Q}_{jit}\right)^{1-\beta}}{\hat{\varphi}_{jft}} \right)^{1-\mu_j} \right]^{\frac{1}{1-\mu_j}}, \tag{24}$$

Using equation (9), the relative change in the share of design in costs can be written as:

$$\xi^D_{fjt}\hat{\xi}^D_{fjt} = \frac{\left(\frac{w^D_{it}}{\theta_{ft}}\right)^{1-\mu_j} \left(\frac{\hat{w}^D_{it}}{\hat{\theta}_{ft}}\right)^{1-\mu_j}}{\left(\frac{w^D_{it}}{\theta_{ft}}\right)^{1-\mu_j} \left(\frac{\hat{w}^D_{it}}{\hat{\theta}_{ft}}\right)^{1-\mu_j} + \left(\frac{\left(w^P_{it}\right)^{\beta}\left(\hat{w}^P_{it}\right)^{\beta}\left(Q_{jit}\right)^{1-\beta}\left(\hat{Q}_{jit}\right)^{1-\beta}}{\varphi_{jft}\hat{\varphi}_{jft}} \right)^{1-\mu_j}}, \tag{25}$$

which can be rewritten as:

$$\xi^D_{fjt}\hat{\xi}^D_{fjt} = \frac{\xi^D_{fjt} \left(\frac{\hat{w}^D_{it}}{\hat{\theta}_{ft}}\right)^{1-\mu_j}}{\xi^D_{fjt} \left(\frac{\hat{w}^D_{it}}{\hat{\theta}_{ft}}\right)^{1-\mu_j} + \left(1 - \xi^D_{fjt}\right) \left(\frac{\left(\hat{w}^P_{it}\right)^{\beta}\left(\hat{Q}_{jit}\right)^{1-\beta}}{\hat{\varphi}_{jft}} \right)^{1-\mu_j}}. \tag{26}$$

Intuitively, the relative change in the share of design in costs depends on the relative change in design costs and the relative change in production costs.

Using equation (16), the relative change in input costs can be expressed as:

$$Q_{jit}\hat{Q}_{jit} = \left[\sum_{k \in J} \left(\frac{P_{kit}\hat{P}_{kit}}{\psi_{kit}\hat{\psi}_{kit}} \right)^{1-\nu} \right]^{\frac{1}{1-\nu}}, \tag{27}$$

which can be further re-written as:

$$\hat{Q}_{jit} = \left[\sum_{k \in J} \xi^Q_{kit} \left(\frac{\hat{P}_{kit}}{\hat{\psi}_{kit}} \right)^{1-\nu} \right]^{\frac{1}{1-\nu}}. \tag{28}$$

Using equation (17), the relative change in firm input cost shares can be written as:

$$\xi^Q_{jit}\hat{\xi}^Q_{jit} = \frac{\left(\frac{P_{jit}\hat{P}_{jit}}{\psi_{jit}\hat{\psi}_{jit}} \right)^{1-\nu}}{\sum_{k \in J} \left(\frac{P_{kit}\hat{P}_{kit}}{\psi_{kit}\hat{\psi}_{kit}} \right)^{1-\nu}}, \tag{29}$$

which can be re-written as:

$$\xi^Q_{jit}\hat{\xi}^Q_{jit} = \frac{\xi^Q_{jit} \left(\frac{\hat{P}_{jit}}{\hat{\psi}_{jit}} \right)^{1-\nu}}{\sum_{k \in J} \xi^Q_{kit} \left(\frac{\hat{P}_{kit}}{\hat{\psi}_{kit}} \right)^{1-\nu}}. \tag{30}$$

Intuitively, relative changes in the share of inputs in costs depend on the relative change in the price of each input and the relative change in its importance in input costs.

3.6 Quantitative Analysis

We now show that we can use these results from the previous section to solve for the unobserved changes in productivities or structural residuals that exactly rationalize the observed data as an equilibrium. Using these solutions for the unobserved changes in productivities, we can quantify the contribution of different mechanisms for structural transformation within firms. We can examine the importance of these changes in productivities relative to the importance of changes in output prices and input costs and the impact of trade on these output prices and input costs.

We undertake this quantitative analysis using firm sales in the domestic market. In particular, suppose that we observe firm sales $\{X_{ft}, \hat{X}_{ft}, X_{jit}, \hat{X}_{jit}, \xi^X_{fjit}, \hat{\xi}^X_{fjit}\}$, input cost shares $\{\xi^Q_{fjit}, \hat{\xi}^Q_{fjit}\}$, design cost shares $\{\xi^D_{fjt}, \hat{\xi}^D_{fjt}\}$, wages $\{w^D_{it}, \hat{w}^D_{it}, w^P_{it}, \hat{w}^P_{it}\}$ and price indexes $\{P_{jit}, \hat{P}_{jit}\}$ and know the parameters $\{\beta, \mu_j, \sigma_j, \nu\}$. Using the observed shares of inputs in input costs $\{\xi^Q_{fjit}, \hat{\xi}^Q_{fjit}\}$ and the observed price indexes $\{P_{jit}, \hat{P}_{jit}\}$, we can solve for the unobserved relative changes in the importance of each input $\{\hat{\psi}_{kit}\}$:

$$\xi^Q_{jit}\hat{\xi}^Q_{jit} = \frac{\xi^Q_{jit}\left(\frac{\hat{P}_{jit}}{\hat{\psi}_{jit}}\right)^{1-\nu}}{\sum_{k\in J}\xi^Q_{kit}\left(\frac{\hat{P}_{kit}}{\hat{\psi}_{kit}}\right)^{1-\nu}}. \tag{31}$$

Using these solutions for the relative importance of each input $\{\hat{\psi}_{kit}\}$ and the observed input cost shares $\{\xi^Q_{kit}\}$ and price indexes $\{\hat{P}_{jit}\}$, we can solve for the unobserved relative change in input costs $\{\hat{Q}_{jit}\}$:

$$\hat{Q}_{jit} = \left[\sum_{k\in J}\xi^Q_{kit}\left(\frac{\hat{P}_{kit}}{\hat{\psi}_{kit}}\right)^{1-\nu}\right]^{\frac{1}{1-\nu}}. \tag{32}$$

Using these solutions for input costs $\{\hat{Q}_{jit}\}$, the observed shares of design in costs $\{\xi^D_{fjt}, \hat{\xi}^D_{fjt}\}$, and the observed wages $\{\hat{w}^D_{it}, \hat{w}^P_{it}\}$, we can solve for the unobserved relative changes in firm relative productivity in each sector $\{\hat{\varphi}_{jft}/\hat{\theta}_{ft}\}$:

$$\xi^D_{fjt}\hat{\xi}^D_{fjt} = \frac{\xi^D_{fjt}\left(\hat{w}^D_{it}\right)^{1-\mu_j}}{\xi^D_{fjt}\left(\hat{w}^D_{it}\right)^{1-\mu_j} + \left(1-\xi^D_{fjt}\right)\left(\frac{\left(\hat{w}^P_{it}\right)^{\beta}\left(\hat{Q}_{jit}\right)^{1-\beta}}{\hat{\varphi}_{jft}/\hat{\theta}_{ft}}\right)^{1-\mu_j}}. \tag{33}$$

Finally, using equations (19), (20), (24), $\hat{\tau}_{jit} = 1$, observed domestic firm sales $\{\hat{X}_{fit}, \xi^X_{fjit}, \hat{X}_{jit}\}$, observed price indexes $\{\hat{P}^{\sigma_j-1}_{jit}\}$, observed wages $\{\hat{w}^D_{it}, \hat{w}^P_{it}\}$, observed shares of design in firm costs $\{\xi^D_{fjt}\}$ and our solutions for input costs $\{\hat{Q}_{jit}\}$ and firm relative productivities $\{\hat{\varphi}_{jft}/\hat{\theta}_{ft}\}$, we can solve for the unobserved relative change in firm intangible knowledge capital $\{\hat{\theta}_{ft}\}$:

$$\hat{X}_{fit} = \sum_j \xi^X_{fjit}\hat{X}_{jit}\hat{P}^{\sigma_j-1}_{jit}\hat{\theta}^{\sigma_j-1}_{ft}\left[\xi^D_{fjt}\left(\hat{w}^D_{it}\right)^{1-\mu_j} + \left(1-\xi^D_{fjt}\right)\left(\frac{\left(\hat{w}^P_{it}\right)^{\beta}\left(\hat{Q}_{jit}\right)^{1-\beta}}{\hat{\varphi}_{jft}/\hat{\theta}_{ft}}\right)^{1-\mu_j}\right]^{\frac{1-\sigma_j}{1-\mu_j}}. \tag{34}$$

We have thus recovered the unobserved changes in productivities or structural residuals $\{\hat{\psi}_{kit}, \hat{\varphi}_{jft}, \hat{\theta}_{ft}\}$ that ensure that the model exactly rationalizes the observed data as an equilibrium. We can thus quantify the contribution of these unobserved changes in productivities $\{\hat{\psi}_{kit}, \hat{\varphi}_{jft}, \hat{\theta}_{ft}\}$ relative to changes in output and input prices $\{\hat{P}_{kit}, \hat{Q}_{jit}\}$ in explaining the observed structural transformation in the data.

4 Reduced-form Evidence on Complementarities

In this section, we assess the extent to which the broad patterns of structural transformation documented in section 2 occur within firms in response to demand and input cost shocks. A key feature of the model presented in section 3 is the potential existence of complementarities between a firm's design and manufacturing activities, as governed by μ. Whenever $\mu < 1$, design and manufacturing are complements, i.e., a reduction in firm's manufacturing input costs induce an increase in its share of design inputs over total inputs.

We examine whether US manufacturing firms exhibit evidence of such a complementarity by exploiting a plausibly exogenous shock to US firms' input costs: China's 2001 re-entry into the WTO and rapid rise as a low-cost location for manufacturing. We also assess the extent of within-firm structural transformation in response to demand shocks by studying how firms reallocate employment in response to increased Chinese imports in a firm's output industries.

We focus on the period 1997 to 2007 because these two Census years span China's WTO entry and are far enough apart to allow for the types of organizational changes predicted by the model to manifest. We begin by defining firms' potential exposure to China in 1997, and then relate this exposure to changes in a wide range of firm outcomes over the sample period.

A number of recent papers highlight the increase in US import competition associated with China's export growth (Autor, Dorn, and Hanson (2013), Pierce and Schott (2016)), while others focus on China's as a source of low-cost inputs (Antràs, Fort, and Tintelnot (2017) Amiti, Dai, Feenstra, and Romalis (2017)). An important contribution of our analysis is to distinguish between two forms of exposure to China–greater import competition with respect firms' output, and potentially beneficial shocks to the prices of their inputs–within the same analysis. We find that increased import penetrationin the latter, which likely depresses the price of firms' inputs, decreases manufacturing employment shares and increases headquarter and professional and technical services employment, in terms of both shares and levels.

4.1 Estimating the impact of the China shock on within-firm structural change

To assess the impact of new production cost savings on firm employment across sectors, our baseline specification estimates

$$\Delta Outcome_{f}^{1997-2007} = +\gamma_1 \Delta Expoure_{f,1997}^{Ouput} + \gamma_2 \Delta Exposure_{f,1997}^{Input} + \epsilon_f, \tag{35}$$

where the first two terms on the right-hand side are firm-specific measures of exposure to Chinese imports based on firms' outputs and inputs in 1997. We consider a wide range of firm outcomes, including firms' total employment, manufacturing employment levels and shares, management and professional and technical services employment levels and shares, and various measures of export activity.[9] We focus on management, professional and technical employment since workers in these establishments are engaged in the type of activities – such as R&D and computer systems design – which seem most likely to be complementary with production, and to contribute to the accumulation of intangible capital within the firm.

4.2 Measuring US Firms' Exposure to Trade Liberalization with China

China's exports grew dramatically from $183 billion in 1997 to $1,120 billion in 2007, with its share of world exports rising from 3.5 percent to 9.0 percent over the period. A number of factors contributed to these changes. First, China implemented various reforms in the 1990s, such as allowing for private ownership and reducing internal migration restrictions, that led to productivity gains within China. Second, China re-entered the WTO in 2001, which required that it implement a number of reforms, including lowering tariffs on many imports and reducing production subsidies. As part of its re-entry into the WTO, China also received permanent normal trade relations (PNTR) status from the United States, eliminating the need for annual renewal of its access to the relatively low NTR tariff rates the US extends to is favored trading partners. This reduction in tariff uncertainty, discussed in Pierce and Schott (2016) and Handley and Limão (2017), increased Chinese exports relatively more in those goods that would have faced large tariff increases if annual renewal had failed.

In this paper, our goal is to capture the impact of all of these channels of Chinese export growth. As a result, we follow Bernard, Jensen, and Schott (2006) in exploiting variation in the growth of US import penetration from China across sectors to measure firms' differential exposure to both output competition and input cost savings. Using data from the US Census of Manufactures, we calculate

$$\Delta Exposure_f^{Output} = \sum_{k \in Output_{1997}} \frac{Sales_{k1997}}{Sales_{1997}} \Delta ImpPen_k \tag{36}$$

$$\Delta Exposure_f^{Input} = \sum_{k \in Input_{1997}} \frac{Inputs_{k1997}}{Inputs_{1997}} \Delta ImpPen_k, \tag{37}$$

where $Sales_{k1997}$ is the firm's sales in the six-digit NAICS industry k, and $Inputs_{k1997}$ is the firm's purchases of material inputs in the six-digit NAICS industry k. The change in output exposure for firm f between 1997 and 2007 is the change in the weighted average of US import penetration across the industries in which the firm is active in 1997, using its sales shares as weights. Likewise, firm f's change in

[9] Specifically, we measure firm employment in management and professional and technical services as employment in the firm's establishments classified in NAICS 54 and 55.

input exposure is the change in the weighted average of US import penetration across all material inputs the firm used to produce these outputs, using input value shares as weights.

We measure firm sales across industries based on the NAICS industry of each of the firm's establishments. This measure is thus firm-specific for firms with establishments in more than one sector, but identical for firms with establishments in only one six-digit NAICS manufacturing industry. Our input measure shock is more novel, since we exploit the material trailer files of the CM to construct a firm-specific measure based on the mix of six-digit NAICS inputs that the firms' manufacturing establishments use to produce their goods. The material trailer data are only available for a subset of manufacturing establishments that includes all large, multi-unit firms with industry-specific thresholds for the number of employees, as well as a random sample of smaller firms.[10] For those firms without material trailer data, we impute input usage across industries based on the establishment's output industry and the 1997 US input-output tables produced by the US Bureau of Economic Analysis (BEA).

Given the likely endogeneity of US import growth across sectors, we follow Antràs, Fort, and Tintelnot (2017) in instrumenting for the growth of US import penetration in industry k with the growth in Chinese market share in Europe in industry k. This approach, similar in spirit to Autor, Dorn, and Hanson (2013), identifies the portion of Chinese import growth in the United States that is attributable to Chinese gains in comparative advantage, due either to changes in trade policy or productivity gains in China.

4.3 Results

Results from estimating Equation (35) via ordinary least squares (OLS) are reported in Table 3. In line with a well-established literature on the negative effects of Chinese import competition, we find that an increase in exposure to Chinese import competition in a firm's output industries is associated with a decline in the firm's total employment and in its manufacturing employment. In contrast, increased Chinese import penetration in a firm's inputs has a positive, though not significant, relationship with changes in the firm's employment. Consistent with the idea that manufacturing and design are complementary, we also find that increased import penetration in a firm's inputs is associated with a decrease in its share of manufacturing employment and an increase its share of professional and technical services employment.

Table 4 presents first-stage results. The estimated coefficients on input and output industry market share changes are positive and statistically significant at conventional levels in both cases. The Kleibergen-Paap F-statistic of 17.33 indicates that the input and output shock measures are sufficiently uncorrelated to identify input exposure separately from output exposure.

The results from the estimating Equation (35) via 2SLSs are presented in Table 5. In line with prior work, we find that increased output exposure decreases a firm's total as well as its manufacturing employ-

[10] The Census of Manufactures includes all manufacturing establishments in the United States. For very small establishments, data are based only on administrative records. All establishments that belong to multi-unit firms with at least 250 employees are sent the long census form, which includes questions about input purchases and sales by detailed product categories. A random sample of smaller establishments are also sent the long form. Remaining establishments are sent the short form, which does not include the questions on detailed inputs.

Table 3: Estimates of Chinese exposure and firm-level employment changes

Dependent variable is the change from 1997 to 2007 in a firm's				
	Share Manuf Emp	Share Prof Emp	log Emp	log Manuf Emp
$\Delta Exposure_f^{Output}$	-0.033***	-0.005	-1.413***	-1.503***
	0.011	0.006	0.204	0.214
$\Delta Exposure_f^{Input}$	-0.312***	0.136***	0.709	-0.155
	0.084	0.039	1.020	1.082
Constant	0.001**	-0.000	0.037**	0.040**
	0.00	0.00	0.02	0.02
Observations	72,500	72,500	72,500	72,500

Notes: * p<0.10, ** p<0.05, *** p<0.01.
Standard errors clustered at the industry level.

ment. In contrast, there is a positive, though still insignificant relationship between input exposure and overall employment. Consistent with the presence of complementarities between manufacturing inputs and design within the firm, an increase in Chinese import penetration in a firm's inputs, which we interpret as lowering the costs of inputs, results in a positive and statistically significant increase in the firm's share of professional and technical workers.

The OLS and IV estimates all point towards a reallocation of employment from manufacturing towards professional and technical services in response to a reduction in a firm's manufacturing input costs. To assess whether this reallocation also entails a change in the level of a firm's employment in R&D and design-related workers, we estimate Equation (35) with log changes in the levels of employment in professional and technical services employment as the dependent variable. To do so, we focus only on the balanced panel of firms with professional and technical services employment in both periods. As shown in section 2, the majority of non-manufacturing employment is added via new establishments (which is captured in our share measure), so this subset of firms is thus much smaller.

Table 6 presents the results. Columns 1-3 show qualitatively similar patterns for these firms in terms of employment responses to both the input and output shocks as found when using the entire sample. The final column presents results for log changes in the firm's professional and technical employment and shows a negative and significant impact of increased product-market exposure, but a large, positive, and significant effect from increased input exposure. These results suggest that firms increase both their share and level of professional workers in response to cheaper manufacturing inputs.

Finally, we examine the effect of Chinese import penetration on firms' export behavior. Table 7 presents the results. In the first column, we estimate Equation (35) using a Davis-Haltiwanger-Schuh (DHS) growth

Table 4: First stage estimates

Dependent variable is		
	$Exposure_f^{Output}$	$Exposure_f^{Input}$
$\Delta MktShareEU_f^{Output}$	0.188***	0.011***
	0.030	0.003
$\Delta MktShareEU_f^{Input}$	0.110***	0.106***
	0.038	0.009
Constant	-0.013***	-0.000
	0.0038	0.000
Observations	72,500	72,500
R-squared	0.209	0.479
Fstat	27.69	151.9

Notes: * p<0.10, ** p<0.05, *** p<0.01.
First Stage KP F-stat 17.33
Standard errors clustered at the industry level.

rate in exports that captures both intensive and extensive margin changes in exports.[11] The estimates show that increased exposure to Chinese import competition in a firm's outputs decreases its exporting activities. In contrast, increased Chinese import penetration in a firm's inputs leads to positive growth in a firm's exports. Columns 2 and 3 present similar relationships for the log number of countries to which a firm exports and the log number of six-digit HS code products exported by the firm. Firms that face increased Chinese import penetration in their product markets decrease both the countries and products that they export, while firms that experience increased Chinese imports into the US in the set of inputs that they use in 1997 export more products and to more countries. These results are all consistent with the scale effect evident in the theoretical framework presented in section 3, but we find that the results hold even when controlling for changes in firm sales over the period. This suggests a possible role for the firm's increased use of professional workers in expanding its export market participation, which we aim to investigate in subsequent drafts.

To summarize, we find that increased Chinese import penetration in a firm's output industries leads the firm to shrink its employment across sectors, and to decrease its export activity. In contrast, increased Chinese import penetration in a firm's input industries leads to a decline in the share, but not the level of manufacturing employment and increases in both the shares and levels of professional and technical employment. In addition, this reallocation towards design and innovative activities is accompanied by a

[11]The DHS growth rate of $x$is calculated as $GrX = \frac{x_t - x_{t-1}}{(x_t + x_{t-1})/2}$. Firms that begin exporting or stop exporting over the period thus have growth rates of 2 and -2, respectively. We use the DHS growth rates to capture both intensive and extensive margin changes in exports.

Table 5: IV Estimates of Chinese exposure and firm-level employment changes

Dependent variable is the change from 1997 to 2007 in a firm's				
	Share Manuf Emp	Share Prof Emp	log Emp	log Manuf Emp
$\Delta Exposure_f^{Output}$	-0.001	-0.033**	-1.698***	-1.747***
	0.0252	0.0164	0.633	0.658
$\Delta Exposure_f^{Input}$	-0.406***	0.275***	0.922	-0.087
	0.119	0.0583	2.159	2.316
Constant	0.002**	-0.001	0.041**	0.045**
	0.00	0.00	0.02	0.02
Observations	72,500	72,500	72,500	72,500

Notes: * p<0.10, ** p<0.05, *** p<0.01.
First Stage KP F-stat 17.33
Standard errors clustered at the industry level.

growth in exports, in terms of the value of exports, the number of exported products, and the number of countries to which firms export. We interpret these results as evidence that negative demand shocks cause firms to contract, while a shock to inputs leads manufacturing firms to grow their design and engineering capabilities and penetrate more new markets.

In subsequent drafts, we aim to tie these empirical results more directly to the model, and ultimately to use the model to quantify the impact of structural change within firms on aggregate outcomes, such as the firm size distribution and growth.

5 Conclusion

To be written.

Table 6: IV estimates for subset of firms with professional and technical services employment

Dependent variable is the change from 1997 to 2007 in a firm's	Share Manuf Emp	Share Prof Emp	log Emp	log Manuf Emp	log Prof Emp
$\Delta Exposure_f^{Output}$	-0.565**	-0.175	-3.582**	-5.667***	-4.346***
	0.222	0.262	1.410	1.662	1.570
$\Delta Exposure_f^{Input}$	-2.673***	2.220***	0.343	-5.794	14.47***
	0.703	0.714	5.283	6.186	4.848
Constant	0.007	-0.007	0.036	0.045	-0.004
	0.006	0.005	0.033	0.040	0.047
Observations	2,900	2,900	2,900	2,900	2,900

Notes: * p<0.10, ** p<0.05, *** p<0.01.
First Stage KP F-stat 26.09
Standard errors clustered at the industry level.

Table 7: IV estimates of Chinese exposure and firm-level exports

Dep var is the change from 1997 to 2007 in a firm's	DHS Exports	Log No. Exp Countries	Log No. Exp HS6 Prods
$\Delta Exposure_f^{Output}$	-3.433**	-2.189**	-1.970**
	1.500	0.989	0.846
$\Delta Exposure_f^{Input}$	16.11**	11.56***	9.963***
	6.630	4.390	3.854
Constant	0.227***	0.129***	0.120***
	0.04	0.03	0.03
Observations	72,500	72,500	72,500

Notes: * p<0.10, ** p<0.05, *** p<0.01.
First Stage KP F-stat 17.33
Standard errors clustered at the industry level.

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