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

Xiang Ding[*] Teresa C. Fort[†] Stephen J. Redding[‡] Peter K. Schott[§]

March 30, 2022[¶]

Comments Welcome!

Abstract

We investigate the role of intangible knowledge in continuing manufacturing firms' substantial contribution to US non-manufacturing employment growth between 1977 and 2019. Empirically, we use new information on auxiliary establishments that primarily serve the other plants of their firm to develop a new measure of in-house knowledge creation and show that it is associated with faster growth and greater pivoting to different industries. Theoretically, we rationalize this relationship in a model in which a firm's investments in intangible knowledge raise its productivity in all sectors, facilitating within-firm structural change. Consistent with the model, we find that shocks to firms' input prices induce a shift from physical production to services among firms with greater in-house knowledge.

JEL CLASSIFICATION: D24, L16, O47

KEYWORDS: structural transformation, professional services, intangible knowledge, economic growth

[*]Georgetown University; xiang.ding@georgetown.edu

[†]Tuck School of Business, CEPR and NBER; teresa.fort@dartmouth.edu

[‡]Princeton University, CEPR, and NBER; reddings@princeton.edu

[§]Yale School of Management, CEPR, and NBER; peter.schott@yale.edu

[¶]We thank Marcela Eslava and Enghin Atalay for helpful discussion. We also thank Laura Alfaro, Pol Antràs, Dave Bryne, Erin Mansur, Raffaela Sadun, Thomas Sampson and participants at seminars and conferences for helpful comments, and Jim Davis for help with the disclosure process. The empirical research in this paper was conducted at the Boston and Yale Federal Statistical Research Data Centers. Any views expressed are those of the authors and not those of the U.S. Census Bureau, the National Bureau of Economic Research, or the Centre for Economic Policy Research. The Census Bureau's Disclosure Review Board and Disclosure Avoidance Officers have reviewed this information product for unauthorized disclosure of confidential information and have approved the disclosure avoidance practices applied to this release. This research was performed at a Federal Statistical Research Data Center under FSRDC Project Number 1975. (CBDRB-FY22-P1975-R9364, CBDRB-FY22-P1975-R9379)

1 Introduction

One the most striking features of the US economy over the last five decades is its transition away from manufacturing and towards services. Between 1977 and 2016, the share of US employment in manufacturing dropped by 18 percentage points, from 27 to 9 percent. While the manufacturing employment share has declined steadily since the 1940s, the level of manufacturing workers trended upwards until 1979, after which it has declined steeply without full recovery in every recession. A large literature in macro on structural change ascribes the disproportionate growth of services to rising incomes and non-homothetic demand (Comin, Lashkari, and Mestieri, 2018), unbalanced productivity growth (Baumol, 1967; Ngai and Pissarides, 2007), or both (Matsuyama, 2019). An international trade literature focuses on declining manufacturing levels and attributes them to rising import competition, particularly with low-wage countries like China (Bernard, Jensen, and Schott, 2006; Autor, Dorn, and Hanson, 2013; Pierce and Schott, 2016). The macro literature does not explain the decline in manufacturing employment, whereas work in trade is largely silent on the concurrent rise in services, and the fact that manufacturing's real-value added share has been relatively flat (Fort, Pierce, and Schott, 2018). In both literatures, the role of proprietary knowledge capital created and deployed within the boundaries of the firm remains unexplored.

In this paper, we take a firm-level view of structural change that reconciles the mechanisms proposed in the macro and trade literatures by documenting a new link between the US decline in manufacturing and concurrent rise in services. Using comprehensive data on the universe of US firms and establishments, we show that a substantial share of US growth in services is driven by a small set of continuing manufacturing firms that simultaneously increase their non-manufacturing ("NM") employment and shrink their manufacturing ("M") employment. NM employment growth among these firms, as for the United States as a whole, is concentrated in Business Services, particularly high-skill, technologically advanced management and professional services that are used as inputs across a wide range of final-goods sectors. We provide theoretical and empirical evidence that these service inputs are a complement to physical inputs in manufacturing, implying that reductions in the price of physical inputs – due to productivity or policy shocks – induce *increases* in both the levels and shares of professional services employment among manufacturing firms. Motivated by anecdotal discussions of firms' competitive advantage, we posit that in-house provision versus arm's-length purchases of these services develops proprietary knowledge capital among firms large enough to absorb the associated fixed costs. Consistent with this premise, we find that manufacturers with in-house professional services establishments exhibit greater NM employment and sales growth in response to a plausibly exogenous reduction in input costs, even after controlling for firm size. These results suggest that the firm boundary may play an important role in developing and preserving knowledge and organizational capital that cannot readily be sold in the marketplace.

In the first part of our paper, we provide a comprehensive, firm-level summary of the US transition towards services by constructing a 40-year panel of the universe of US firms and the detailed industries in which their establishments operate. In line with our interest in studying the persistence of firm knowledge, we provide this summary for two different concepts of a firm. The first, constructed by the US Census Bureau, assigns establishments to firms based on common ownership in each year. Under this definition, change in control generally defines entry and exit. Our second conceptualization of a firm, inspired by Haltiwanger, Jarmin, and Miranda (2013) and referred to as "HJM", identifies "continuing" firms as those with at least one establishment that existed in the beginning and end of the period. Using either definition, we find that continuing manufacturing firms comprise only one percent of total US firms in 2019. Despite their small number, these continuing manufactures account for 20 (Census firmid) to 62 (HJM) percent of the total decline in US M employment, and 16 to 32 percent of the rise in aggregate US NM employment between 1977 and 2019.

Detailed comparison of manufacturing versus non-manufacturing firms' NM employment growth reveals only partial overlap, indicating that manufacturing firms' service growth does not merely reflect changes in the overall economy. Manufacturers dominate Wholesale and Retail growth, while non-manufacturers' growth is concentrated in Health services. Furthermore, while Business Services represents the most substantial employment and payroll growth for both types of firms, manufacturers' growth is large in just three subsectors – Computer Systems Design, Research and Development (R&D), and Architectural and Engineering Services – that are strongly related to manufacturing, both because they constitute key inputs (e.g., R&D), and because they are complements with the output (e.g., Computer Systems Design services rely on computers). Indeed, we show that manufacturing firms' increasingly reallocate towards these services over our sample period. For example, continuing firms with Computer Systems Design establishments at the end of our sample period exhibit an average decline in their manufacturing employment share from 40 to 15 percent from 1977 to 2016. These transitions suggest a mix of *functional* and *sectoral* structural change within firms, i.e., greater provision of input services to produce the same final goods (*functional*), and transition from goods to services production (*sectoral*). They also raise a crucial question: how and why does a small set of manufacturers successfully transition to services, while most exit?

In the second part of the paper, we use novel data on firms "auxiliary" establishments to explore whether proprietary knowledge provides firms with a competitive advantage that relates to their successful transition to services. Auxiliaries, such as R&D labs and warehouses, are establishments producing service inputs that primarily serve the other plants of a firm, and are therefore plausible creators and receptacles of organization capital.[1] In particular, auxiliaries are observed in all professional service industries. We find that auxiliaries, while smaller than other establishments in the same industry, pay higher wages, suggesting they employ relatively high-skill workers. Consistent with our hypothesis that these plants can facilitate functional and sectoral structural change, we find that firm growth and reallocation across sectors increase with auxiliary employment shares, even after controlling for differences in firm size, age, and industry composition.

In third part of the paper, we rationalize US manufacturing firms' increasing use of professional services and the relationship between in-house provision of these services and firms' structural transformation in a model of heterogeneous, multi-product firms similar in spirit to Melitz (2003) and

[1] For example, Target's CIO describes shifting away from outsourced services towards in-house provision to avoid "...a third-party provider sending [an advantage through shorter lead times] to Retailer B down the road." Target had been outsourcing significant parts of its application development and backend systems to India and domestic companies including Infosys and IBM. As he told the Wall Street Journal, "We got to a stage where almost half the team is in third parties. It's unhealthy. By keeping the intellectual property generated by the inhouse software engineers, the company can preserve competitive advantage."

Bernard, Redding, and Schott (2010). In our setup, firms pay an upfront entry cost to obtain a differentiated brand and observe their productivity for each sector. Given fixed overhead costs, firms choose to participate in the subset of sectors in which they are sufficiently productive. Firms also decide whether to incur an additional fixed cost (paid in knowledge workers) to produce knowledge services in-house, or to procure them via outsourcing to a third party. When produced in-house, the knowledge generated is proprietary and gives firms a competitive advantage by lowering costs in all sectors. By contrast, when this knowledge is acquired at arm's length, it diffuses freely to all firms. In equilibrium, firms with better sector-specific productivity draws choose to produce knowledge services in-house, boosting productivity in all industries.

Our framework features two key distinctions from past work. First, firms combine manufacturing and knowledge inputs to produce goods, and we assume that these are complementary. As a result, firms will increase the level and share of knowledge inputs in response to reductions in the cost of their manufactured inputs. Second, firms that produce this knowledge within the firm gain a sector-neutral productivity advantage. Although the model is static, one interpretation of in-house knowledge investment is that it represents an accumulated stock that does not fully depreciate in response to sector-specific shocks to demand and supply, and that is non-rival within the firm.

The model shows how shocks to firms' outputs and inputs can induce within-firm structural change. A negative demand shock for firms' manufactured output, for example, decreases their manufacturing sales and their use of both manufactured and knowledge inputs, with firms with in-house knowledge being better-positioned in terms of higher, sector-neutral productivity so long as this knowledge is not fully depreciated by the shock. Reactions are similar for a positive input shock. In this case, firms increase the level and share of professional-service inputs, though only the subset of sufficiently productive firms do this in-house. Since these firms also have a relatively higher sector-neutral productivity, firms with in-house knowledge workers prior to the shock are also more likely to expand into new sectors, particularly in sectors in which professional service inputs are complementary given the non-rivalry of the initial fixed integration cost.

In the final part of the paper, we assess the empirical support for our framework by examining US manufacturers' responses to plausibly exogenous variation in output and input prices driven by China's increased integration into world markets from 1997 to 2007. On the one hand, greater import competition in firms' output markets represents a conventional, negative demand shock for the firm's manufactured goods. On the other hand, greater import competition in firms' physical inputs reduces their manufacturing costs. We construct measures of firms' output and input exposure using changes in China's market shares in Europe in firms' initial output products and material inputs. We focus on reduced-form specifications in which we regress changes in firm sales and employment by sector directly on these instruments, and on interactions of the instruments with dummy variables indicating possession of auxiliaries.

Our results confirm prior findings of large, negative effects of Chinese import competition on US manufacturers' employment and sales that are strongly increasing in firm size.[2] A 10 percentage

[2]Holmes and Stevens (2014) provide theory and evidence that smaller, customized manufacturers were relatively insulated by the China shock.

point increase in Chinese competition in a firm's outputs decreases total employment at a 500-worker firm by 8.2 percent if the firm has auxiliaries at the start of the period, versus only 3.9 percent if it does not. This gap is driven by the response of NM employment. Firms without auxiliaries exhibit no change in their NM employment, while those with auxiliaries exhibit an NM employment decline of 5.6 percent. Neither firm type exhibits statistically significant changes in their NM sales. The concomitant decline of M and NM employment among firms with auxiliaries suggests firms with in-house knowledge creation use NM workers to support M output.

Results for the input shock are quite different. We see no statistically significant impact on firms' total or M employment. However, in line with our assumed complementarity between manufactured and knowledge inputs, we find a strong, positive relationship between the input shock and NM employment: a 10 percentage point increase in China's market share in the EU in a 500 employee firm's inputs raises its NM employment by 19 percent. Examining employment and sales growth across specific industries within NM, we find that these responses are driven by professional services, suggesting that functional structural change may induce sectoral structural change as firms that produce services in-house to support their M products begin selling these services to other firms.

Our paper is related to several different strands of research. A large macro literature attributes structural change to changes in final-good expenditure shares across sectors as a result of rising incomes and non-homothetic preferences (Boppart, 2014; Comin, Lashkari, and Mestieri, 2018; Matsuyama, 2000), or unbalanced productivity growth (Baumol, 1967; Ngai and Pissarides, 2007; Herrendorf, Rogerson, and Valentinyi, 2013).[3] The research most closely related to ours focuses on the rise of skilled services (Buera and Kaboski, 2012; Buera, Kaboski, and Rogerson, 2015). Relative to those papers, we show that these services are primarily inputs that are complementary with manufacturing. While this shift may still reflect non-homothetic demand and rising incomes if richer consumers increasingly value (service) attributes within a set of physical goods (e.g., digital functions), it carries an important aggregate implication. Since professional services are used across a wide range of final goods, unbalanced growth need not result in aggregate stagnation (Baumol, 1967). Instead, aggregate productivity will grow as long as these service inputs experience positive productivity growth (Oulton, 2001). In addition, the United States will tilt towards the services, not only for internal reasons, but also in concert with increased low-wage production opportunities abroad. Prior work documents the distinct effects that an open versus closed economy can have in promoting these changes (Matsuyama, 2009, 2019; Cravino and Sotelo, 2019).[4] Our contribution is to exploit detailed firm-level transitions to show that the aggregate shift into these high-skill, technology intensive sectors is consistent with firms exploiting past knowledge and expertise to pivot towards their comparative advantage tasks within a sector.[5]

We also contribute to a large literature on the boundary of the firm. That work has largely focused on how firms can use integration to reduce transaction costs (Williamson, 1981) or change

[3]See Herrendorf, Rogerson, and Valentinyi (2014) for an extensive review.

[4]See Alessandria, Johnson, and Yi (2021) for a recent review of these papers.

[5]While these transitions most observable within firms, the emergence of factoryless-goods producers and their contribution towards US innovation Bernard and Fort (2015); Kamal (2020) suggests that the same movement towards these complementary, US comparative-advantage activities also occurs across firms.

ex-ante investment decisions when contracts are incomplete (Grossman and Hart, 1986; Hart and Moore, 1990). Antràs and Helpman (2004) develop a heterogeneous firms model with incomplete contracts in which firms produce by combining headquarter and manufactured inputs, but assume that headquarter services are necessarily integrated and focus on the decision to integrate or outsource manufactured inputs. Our focus on firms' decision to integrate versus outsource knowledge creation is closest in spirit to Teece (1982), who posits that multi-product firms can be rationalized by "organizational knowledge" that is both "fungible" and "tacit". Recent work on manufacturing firms provides compelling evidence that firms develop 'input-based comparative advantage', which allows them to expand into manufacturing industries that use similar inputs (Boehm, Dhingra, and Morrow, 2021). Our results suggest that firms can develop and use intangible knowledge to manufacture that also enables them to expand into related service sectors. Atalay, Hortacsu, and Syverson (2014) argue that the transfer of intangibles across plants is an important motive for integration decisions, Ding (2020) provides empirical evidence that knowledge inputs are shared within multi-industry firms, and Mengus and Michalski (2022) argue that certain service workers contribute to in-house knowledge. Our contribution is to construct a new measure of firms' in-house knowledge production, and to show that firms with in-house knowledge both grow and pivot more in response to shocks. This evidence supports the premise that the boundary of the firm may play an important role in both developing knowledge and excluding rivals from it.

Our work also connects with the international trade literature that studies the effects of low-wage imports. Increased competition from low-wage countries prompts firms to shut down their most-exposed plants (Bernard, Jensen, and Schott, 2006), focus on their core products (Bernard, Jensen, Redding, and Schott, 2011), and upgrade their quality and technology (Khandelwal, 2010; Bloom, Draca, and Van Reenen, 2016). Recent work focused on import competition from China documents large manufacturing employment declines in industries in which Chinese imports surged (Pierce and Schott, 2016) and the local labor markets that specialized in those industries (Autor, Dorn, and Hanson, 2013). There is some evidence that integration with low-wage countries provides offshoring opportunities that lead firms to increase employment in technology related occupations (Bernard, Fort, Smeets, and Warzynski, 2021), and UK firms in industries with tariff larger reductions shifted into services (Breinlich, Soderbery, and Wright, 2018). While there is some evidence that US plants in high-skill labor markets shifted into professional services activities in response to increased Chinese import competition, these result seem at odds with evidence of declining employment, sales, and R&D by US firms (Hombert and Matray, 2018; Autor, Dorn, Hanson, Pisano, and Shu, 2020).[6] Our contribution is to show that the same import shock represents not only a negative demand shock for some firms, but also a positive input shock for others. Our findings support prior results on large, negative manufacturing employment and sales declines for firms in response to increased competition in a firm's output products. Most notably, however, we show that increased Chinese competition in a

[6]Existing work on the effects of offshoring by US firms find differing results. While Antràs, Fort, and Tintelnot (2017) provide structural and reduced-form evidence that US firms' offshoring to China led to significant productivity gains that increased the use of domestic manufactured inputs, Boehm, Flaaen, and Pandalai-Nayar (2017) show that US MNEs decrease their manufacturing employment considerably from 1993 to 2011, and provide structural estimates that suggest offshoring displaces US manufacturing employment. A possible explanation for these differences is that the latter focus exclusively on firms' manufacturing establishments.

firm's inputs has no discernible effect on its manufacturing sales and employment, but leads to sizable increases in complementary services employment and sales for firms with in-house knowledge plants.

Finally, our focus on the disproportionate contribution of a small set of manufacturers to aggregate US growth in business services relates to a growing literature on rising concentration, markups, and new fixed-cost technologies. Recent work credits rapidly declining prices in Information and Communication Technologies (ICT) with increased spatial concentration of high-wage business services (Eckert, 2019; Eckert, Ganapati, and Walsh, 2019), disproportionate expansion by large firms across space (Hsieh and Rossi-Hansberg, 2019), increased production fragmentation Fort (2017), and rising industry concentration (Bessen, 2017; Ganapati, 2016; Lashkari, Bauer, and Boussard, 2021). Argente, Moreira, Oberfield, and Venkateswaran (2021) argue that "scalable expertise" constitutes a fixed-cost investment that provides firm-specific returns to scale, making large firms more responsive to shocks. Relative to these studies, we show that in-house knowledge, measured explicitly using firms' auxiliary establishments, is a specific fixed-cost investment in intangible capital that not only facilitates their growth relative to other firms, but also enables them to pivot away from declining sectors. Since this knowledge capital is complementary with manufacturing but housed in separate establishments, standard productivity estimation approaches based on industry-by-establishment level data will lead to over-estimates of firm productivity and markups for these large firms. Prior work on multi-product manufacturers finds that co-production is not random (Bernard, Redding, and Schott, 2010) and (Hottman, Redding, and Weinstein, 2016) show that their strategic choices bias productivity estimation for large firms. The new evidence we present on auxiliaries show that in-house knowledge is another source of bias, which may explain some of the patterns of dramatic, rising markups documented in only the largest firms (De Loecker and Eeckhout, 2017).

The remainder of the paper proceeds as follows. Section 2 discusses the construction of our data. Section 3 presents our stylized facts about structural transformation within and between firms, and Section 4 describes auxiliaries and studies their role as inhouse knowledge plants. Section 5 develops our theoretical framework that we use to rationalize these stylized facts. Section 6 uses the China shock as an exogenous source of variation to provide empirical evidence in support of the key mechanism in our theoretical framework. Section 7 concludes.

2 Data

We construct a new dataset that tracks establishments over a forty-year period from 1977 to 2016. We make three contributions in the data construction. First, we improve upon the Census firmid definitions both by fixing clearly spurious breaks and by developing a method to account for merger and acquisition activity in decomposing employment changes across continuers versus net births. Second, we employ the longitudinally consistent industry codes from Fort and Klimek (2018) to address significant changes in the US industry classification schemes over the period. Finally, we exploit four different data sources to identify auxiliary establishments consistently throughout the period and analyze their behavior. To our knowledge, ours is the first study of auxiliaries over such a long period. Together these three data contributions allow us to offer the first quantification of structural transformation within and across firms, and to provide evidence on the role of intangible knowledge in shaping this process of structural transformation.

2.1 Main Dataset Construction

The frame for our analysis is the US Census Bureau's Longitudinal Business Database (LBD), initially assembled by Jarmin and Miranda (2002) and recently updated by Chow, Fort, Goetz, Goldschlag, Lawrence, Perlman, Stinson, and White (2021) to track the employment, pay, and industry of all private, non-farm US establishments from 1977 to 2016 annually. An establishment is a single physical location where business transactions take place and for which payroll and employment are recorded. The LBD contains a longitudinally consistent establishment identifier (*lbdnum*), a firm identifier ($firmid$) that captures all of the establishments under common ownership or control in a given year, and an LBD-specific firm identifier that corrects for recycled $firmid$s in this long time series ($lbdfid$).

We augment the LBD data with additional information from Economic Censuses (ECs) of Auxiliaries (AUX), Construction (CCN), Finance, Insurance, and Real Estate (CFI), Manufactures (CMF), Mining (CMI), Retail Trade (CRT), Services (CSR), Transportation, Communications, and Utilities (CUT), and Wholesale Trade (CWH). The EC data are collected in years ending in "2" and "7", henceforth referred to as "Census" years, and provide establishment-level measures of sales for all sectors.

We also use CMF data on manufactures' input purchases and product-level sales by industry to construct shares of manufacturing firms' sales and input purchases by industry, which enable us to identify their differential exposure to changes in Chinese import competition for their outputs and inputs. These 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.[7]

2.2 New Firm Definitions

A primary goal of this paper is to assess the extent to which firms develop knowledge that may facilitate growth and pivoting across industries. This goal is complicated by the fact that Census' $lbdfid$'s are not longitudinally consistent. By Census convention, $lbdfid$s break whenever firms transition between single-unit (SU) and multi-unit (MU) status. The Census firm identifier may also change spuriously during reorganizations and mergers and acquisitions (M&A) activity. In this section we provide a brief summary of how we address these limitations, deferring a more complete discussion to Appendix Section A.1.

We correct spurious SU-to-MU breaks by developing a 'fixed' Census firm identifier based on a simple algorithm that links firms' establishments across transitions between SU and MU status.[8] We

[7]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.

[8]We use Census' $lbdfid$ in these corrections so that recycled $firmid$'s are not present in our analysis.

use this corrected firm identifier, referred to here as a "Census firm" or as *lbdfid_lc* to denote its extended longitudinal consistency, to assign establishments to firms each year. We then use these "Census firms" to compute lower bounds on firms' contribution to US structural change in Sections 3.1 and 3.2, to measure firms' reallocation to other sectors (referred to as "pivoting") in Section 3.4, and in all of our regressions.

We also develop a broader definition of the firm that accounts for merger and acquisition activity. Inspired by Haltiwanger, Jarmin, and Miranda (2013) and referred to as "HJM", this approach captures the idea that (at least some) knowledge may be preserved when plants move across firms, even if these transitions lead to firm entry or exit. Specifically, we classify a HJM firm as a continuer from year t to t' if at least one of its establishments exists in t' and t, respectively. Likewise, it is a death if all of its establishments perish before t', and it is a birth if all of its establishments are born after t. This definition thus addresses spurious breaks in firmids over time, and also allows treats a continuation of some part of the firm as a continuation of the firm. As HJM firms are broader than Census firms, they assign greater activity to continuers.[9] We use this definition to provide an upper bound on the amount of non-manufacturing employment growth accounted for continuing manufacturing firms in Section 3.4.

2.3 Consistent Industry Classification

We measure the evolution of the US economy across industries by assigning each establishment to a single, 6-digit North American Industry Classification System (NAICS) code. The governing principle under NAICS is to classify establishments based on the activities performed at the establishment, so it is particularly well-suited for studying changes in what firms and their employees actually do. As in all establishment-based Census data, all workers in an establishment are classified under the same industry.

To track activity as consistently as possible over time, we employ the new LBD's *bds_vcnaics* variable, which contains the most recent vintage NAICS code for all establishments over the entire time period, along with additional information in accompanying industry files, as detailed in Fort and Klimek (2018).[10] An establishment may change its industry code over time, as its primary activity changes. We allow for these changes, but rely most heavily on codes assigned in EC years, since these contain the most accurate information.

We use the establishment-level codes to identify the mix of industries in which multiple-establishment firms operate, and to assign each firm principal 6-, 3-, and 2-digit NAICS codes according to its largest shares of employment and pay, respectively, at those levels of aggregation.[11]

[9] To sum the employment (or count) of HJM firms in a given year, we sum the employment (or count) of "Census firms" in that year that contain the antecedent or remnant of the continuing HJM firm. Thus, while the number of continuing "Census firms" in t and t' must be the same in both years, the number of continuing HJM firms can differ in the two years.

[10] NAICS replaced the former Standard Industrial Classification System (SIC) codes in 1997. Even within SIC and NAICS years, there are multiple vintages of these codes that change over time. We follow the suggestions in Fort and Klimek (2018) to avoid using codes that have too much noise to provide meaningful information. See Online Appendix Section A.2 for details.

[11] In the cases where there is no variation in n-digit NAICS sectors within $(n-1)$-digit roots, we replace the n-digit codes with $(n+1)$-digit codes. For example, NAICS sector professional services (54) contains no variation at the 3-digit

2.4 Auxiliary Panel

A significant contribution of this paper is to construct and analyze a long time series of auxiliary establishments. Auxiliaries are establishments that primarily serve other establishments of their firm, rather than selling goods or services to other firms, e.g., an R&D lab or a warehouse. Analyzing auxiliaries over our 1977 to 2016 sample period is particularly challenging because, under the Standard Industry Classification (SIC) system used until 1997, they were classified under the industry they served rather than the activities they performed. For example, if an R&D lab conducted research for a manufacturing plant, it was assigned the manufacturing industry SIC code of that manufacturing plant.

To identify auxiliary establishments and their activities consistently across our sample period, we combine information from three sources: (1) the FK_NAICS "aux files" included in the LBD; (2) Census' AUX, Business Register (BR) and CBPBR files; and (3) the Censuses of Services (CSR) and Utilities (CUT). We find that there are 92 6-digit NAICS industries that may contain auxiliary establishments. These industries are in Trucking and Warehousing (NAICS 48-9), Information (NAICS 51), Professional, Technical, and Scientific Services (NAICS 54), Administration Services (NAICS 56), and Repair Services (NAICS 81). We provide further details on auxiliary data construction in Online Appendix Section A.3, as well as technical documentation available within the Census RDC network.

2.5 Additional Data Sources

We employ publicly available Comtrade data on Chinese exports by industry to Europe to construct plausibly exogenous measures of Chinese comparative advantage growth in other markets. These measures are discussed in Section 6.

3 An Anatomy of US Structural Change from 1977 to 2016

In this section, we characterize the US transition from manufacturing to services along a number of novel dimensions. First, we report upper and lower bounds for the amount of non-manufacturing (NM) employment and payroll growth that occurs within manufacturing firms. Second, we show that while Business Services dominates NM growth among both M and NM firms, manufacturing firms' NM growth is concentrated in a different set of Business Service subsectors that the broader economy. Third, we demonstrate that continuing manufacturing firms' reallocation towards business service inputs suggests redeployment of their manufacturing knowledge to related service activities.

3.1 Manufacturing Firms Growth in Non-Manufacturing

We assess manufacturing firms' contribution to US structural change via their share of NM employment and payroll growth from 1977 to 2016. Table 1 provides upper and lower bounds for employment

level – they are all 541. In that case, we use the $541x$ codes in place of 3-digit codes.

growth based on the two firm definitions introduced in Section 2.2. For each type of firm, we distinguish between intensive and extensive margins, i.e., continuers versus net births and deaths.

Panel A of Table 1 reports the lower bounds using the conservative "Census firm" definition, i.e., our *lbdfid_lc* modification of Census' *lbdfid* firm identifier to correct for spurious breaks. Census firms are continuers from the begin to end year if their *lbdfid_lc*'s are present in both years. The bottom panel of Table 1 presents upper bounds using HJM firms. In this case, continuers are *lbdfid_lc*'s in each year that contain at least one plant present in both years, whether or not they are part of continuing *lbdfid_lc*'s. This more liberal definition of a continuer accounts for potential survival of firm knowledge through establishments as they move across firms over time.

In both panels, we distinguish between M and NM firms. We use each firm definition to generate two time-invariant classifications of firms as M versus NM. In the top panel, a Census firm is M if it ever owns an M establishment between the begin and end years. In the bottom panel, an HJM firm is M if it contains an establishment that was ever part of a M Census firm between the begin and end years. Here, as well, this broader manufacturing classification for HJM firms is designed to capture potential transfers of knowledge across plants as they wind their way through firms that may enter and leave manufacturing.[12]

The first row in each panel of Table 1 shows M firms' contribution to M and NM employment growth over the period. The left columns in each panel show that M employment falls by 5.7 million workers, and M firms account for the total decline by definition. We decompose M firms' total contribution by continuing firms versus net birth and deaths. While the Census definition (upper panel) indicates that continuing M firms only account for 20 percent of the total decline, the HJM definition (bottom panel) attributes 62 percent of the decline to continuers. This discrepancy highlights the fact that some portion of exiting firms persists, presumably contributing positively to surviving and new firms.

Focusing on NM employment changes in the right columns of Table 1, we find that M firms account for substantial shares – 16 to 32 percent – of overall NM employment growth. Under the Census firm definition (Panel A), M firms approximately double their NM employment from 12.6 to 23.9 million workers. Perhaps unsurprisingly, NM firms exhibit even larger level growth, from 35.4 to 95.9 million workers. Nevertheless, the increase in NM employment at M firms accounts for almost one-fifth (16 percent) of the aggregate increase in NM employment. Among HJM firms (Panel B), M firms increase their NM employment from 17.4 to 40.2 million, while NM firms increase from 30.6 to 79.6 million workers. Despite this considerable growth at NM firms, M firms account for 32 percent of the aggregate increase in NM employment under the HJM definition.

Both panels of Table 1 reveal a striking difference in the margins by which M and NM firms contribute to US structural change. M firms' growth in NM employment is overwhelmingly driven by continuing firms. These continuers comprise less than one percent of total firms in 2019 under either

[12] As an example, if an R&D lab is part of a manufacturing firm *lbdfid_lc* at some point in its lifetime, we label that establishment as having belonged to an M firm. If that R&D lab is later acquired by different *lbdfid_lc*, our HJM firm definition would classify the acquiring *lbdfid_lc* firm as an M firm even if it does not have an M plant, whereas the Census definition would not unless it also had an M plant. In this way, under the HJM definition, the R&D lab's manufacturing knowledge could be carried to a service firm.

definition, yet account for 15 to 26 percent of aggregate NM growth. By contrast, continuing NM firms contribute only 18 to 16 percent of the aggregate increase in NM across the two firm types.[13] Since continuing M firms account for only one percent (or less) of all firms using either definition, their contribution to NM employment is disproportionate not only relative to NM firms, but also on a per-firm basis.

M firms' contribution to US structural change is even larger in payroll terms. Analogous decompositions for payroll reported in Appendix Table A1 reveal that M firms contribute 25 to 40 percent of NM payroll growth over the same period, with continuing M firms accounting for 17 to 31 percent. By contrast, NM continuers account for just 16 percent of payroll growth under *both* firm definitions. Taken together, these results yield our first structural change fact:

> *Fact 1: Continuing manufacturing firms account for a substantial and disproportionate share (16 to 32 percent) of aggregate non-manufacturing employment growth, and 26 to 40 percent of non-manufacturing payroll growth.*

[13] The fact that continuing NM firms under the HJM definition account for a smaller share of aggregate growth than under the Census firm definition indicates that there is employment growth at *lbdfid* firms that continue, even when all their establishments exit.

Table 1: Employment Growth in M and NM from 1977 to 2019, by Firm Type and Margin

Panel A:	**"Census Firms" (Lower Bound)**							
	Manufacturing Emp				Non-Manufacturing Emp			
	1977	2019	Change	Share	1977	2019	Change	Share
M Firms	17.7	12.1	-5.7	1.00	12.6	23.9	11.3	0.16
Continuers	5.6	4.5	-1.1	0.20	5.3	15.9	10.6	0.15
Net Birth/Death	12.1	7.5	-4.6	0.80	7.3	7.9	0.7	0.01
NM Firms					35.4	95.9	60.5	0.84
Continuers					5.6	18.2	12.6	0.18
Net Birth/Death					29.8	77.7	47.9	0.67
Total	17.7	12.1	-5.7	1.00	48.0	119.8	71.7	1.00
Panel B:	**"HJM Firms" (Upper Bound)**							
	Manufacturing Emp				Non-Manufacturing Emp			
	1977	2019	Change	Share	1977	2019	Change	Share
M Firms	17.7	12.1	-5.7	1.00	17.4	40.2	22.8	0.32
Continuers	10.8	7.2	-3.5	0.62	13.8	32.5	18.7	0.26
Net Birth/Death	7.0	4.8	-2.1	0.38	3.7	7.7	4.0	0.06
NM Firms					30.6	79.6	48.9	0.68
Continuers					7.1	18.5	11.4	0.16
Net Birth/Death					23.5	61.1	37.5	0.52
Total	17.7	12.1	-5.7	1.00	48.0	119.8	71.7	1.00

Source: Longitudinal Business Database (LBD) and authors' calculations. Table presents manufacturing (M) and non-manufacturing (NM) employment levels in 1977 and 2019, the change in these levels, and the share of the change accounted for by M firms, NM firms, and continuers versus net birth/deaths within these firm types. M employment is the sum of employment at all US establishments in the LBD classified in manufacturing. NM employment is the sum of employment at all US establishments in the LBD classified outside manufacturing. Census M firms are those that ever have an M plant between 1977 and 2019. HJM M firms are those that ever have an establishment that was ever in a firm with an M plant in the same year. Continuing Census firms are those for which the Census $lbdfid$ exists in both years. HJM continuing firms are those with an establishment in 2019 that was active in 1977. Employment is in millions. There are 27.5 thousand continuing Census M firms, 46 thousand continuing HJM firms, and 5.42 million firms in 2019.

3.2 Structural Transformation Towards Services

In this section we examine the NM sectors and industries that drive US structural change, show that they are primarily inputs into other sectors, and compare M versus NM firms' growth across these categories.

Business Services (NAICS 5) Figure 1 reports US employment (top panel) and payroll (bottom panel) by broad NAICS sectors and firm type from 1977 to 2019. The first figure in each panel depicts total employment and payroll, while the second and third and figures differentiate between growth in M versus NM firms, respectively. We focus on Census (rather than HJM) firms and, as in Section 3.1, classify a Census firm as M if it possess at least one manufacturing plant in at least one year of the sample period.

The starkest trend in Figure 1, depicted in blue, is the dramatic rise in Business Services (NAICS 5). This sector grows from 20 to 28 percent of total employment, and 22 to 40 percent of total payroll. In level terms, it dominates all other sectors in employment, and especially in payroll terms. This sector drives aggregate growth in US NM activities.

The next two figures in each panel of Figure 1 decompose the contributions of M and NM firms to aggregate growth. By definition, M firms' account for all of the decline in M employment, which falls 32 percent between 1977 and 2016, from 17.72 to 12.05 million. By contrast, M firms increase their NM employment over the period, but their NM growth is strongly concentrated in Business Services and Wholesale/Retail. By contrast, NM firms' growth is distributed more evenly across sectors, with Health (NAICS 62), Mining, Utilities and Construction (NAICS 21-23), and Accommodation and Food Services (NAICS 72) also growing strongly.

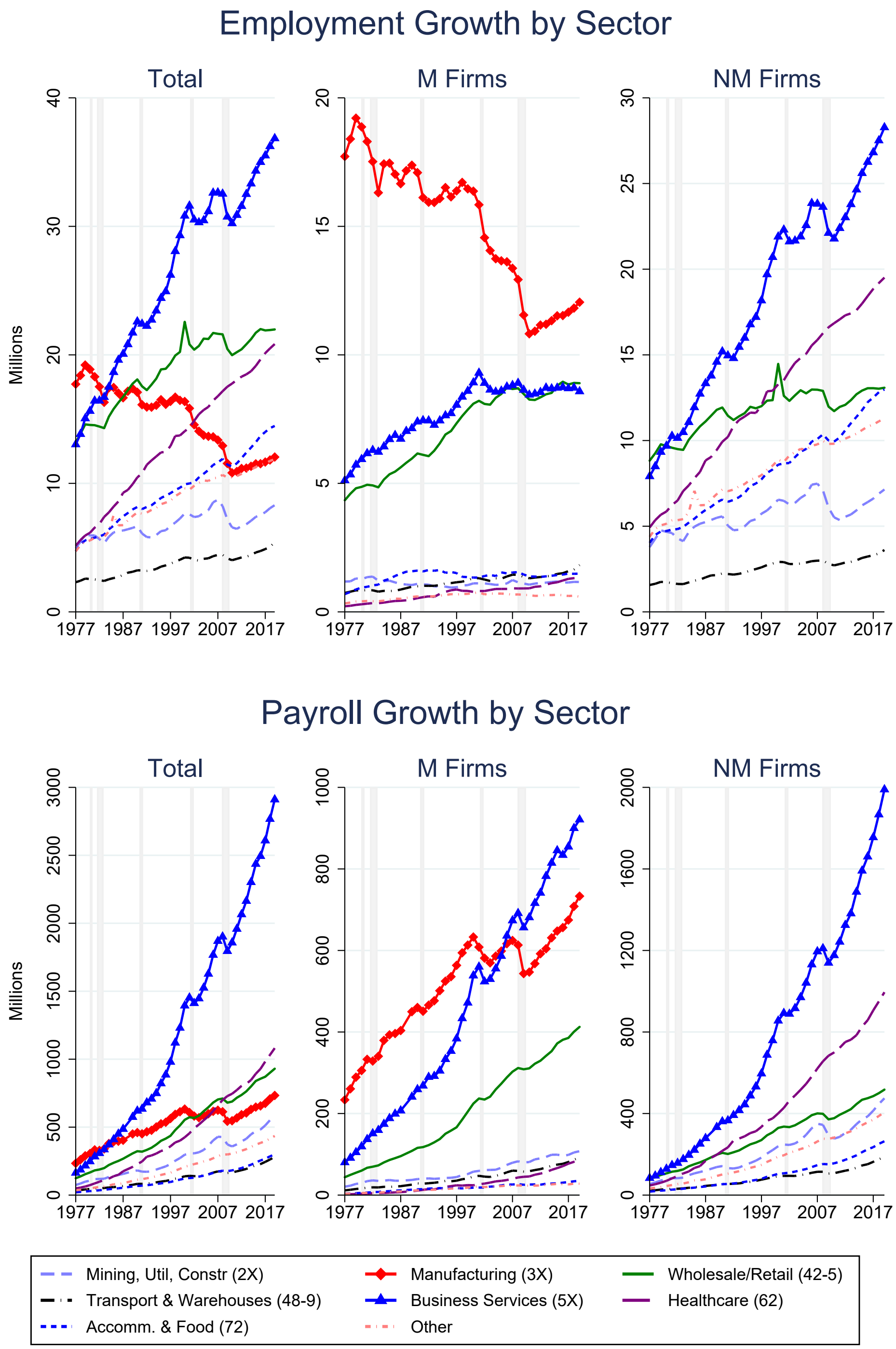
Professional, Scientific and Technical Services (NAICS 54) To understand what drives the aggregate growth in Business Services, Figure 2 plots employment and payroll changes, in total and by firm type, across the six two-digit categories that comprise the sector: Information (NAICS 51), Finance, Insurance (NAICS 52), Real Estate (NAICS 53), Professional, Scientific, and Technical Services (NAICS 54, hereafter 'Professional Services'), Management Services (NAICS 55) and Administrative and Support Services (NAICS 56). Focusing on total employment and payroll growth, Administrative Services (NAICS 56) in purple and Professional Services (NAICS 54) in green account for most of the employment growth.[14] In payroll terms, Professional Services dominate all other sectors, including Finance. Professional Services grow from 3 to 7 percent of total employment and 4 to 11 percent of total payroll over the period.

We also examine M versus NM growth across 2-digit sectors within Business Services. Most notably, the flattening in M firms' Business Services employment growth after 2000 is driven by declines in Information and FIRE (51 and 52), while employment in Professional Services and Management (54 and 55) both increase after the Great Recession. These sectors also demonstrate strong payroll growth, with Management growing disproportionately more for M versus NM firms.

Computer Systems Design (NAICS 5415) Finally, we highlight the growth of industries within Professional Services that provide knowledge services used as inputs in production. Figure 3 decom-

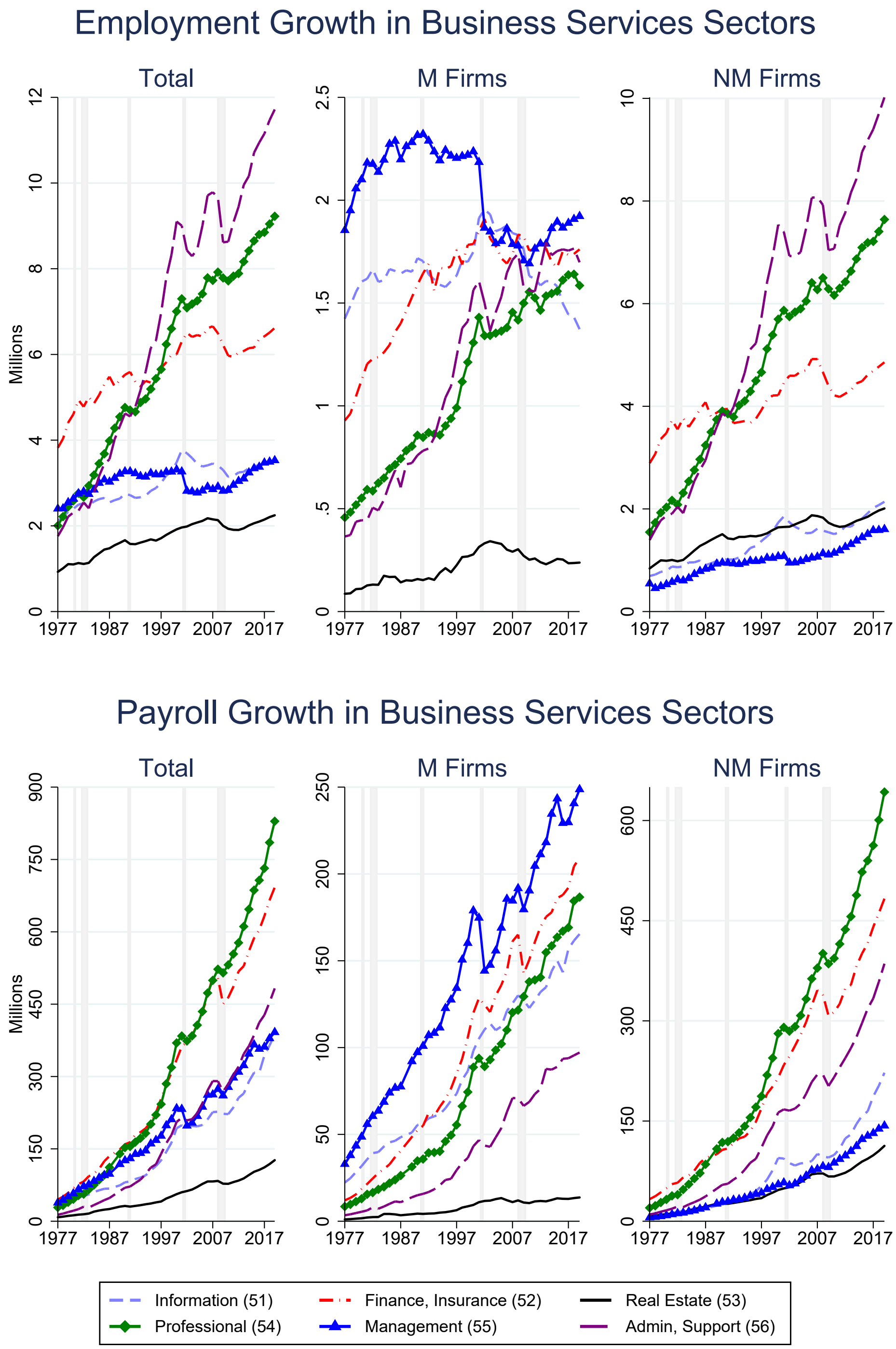
[14]See Dey, Houseman, and Polivka (2012) for evidence on the growing use of staffing services by manufacturers. Those authors estimate that US manufacturers' staffing service workers decreased measured manufacturing employment by 2.3 percent in 1989 and 9 percent in 2006.

Figure 1: US Employment and Payroll Growth by Sector and Firm Type



Source: Longitudinal Business Database and authors' calculations. Figure displays US employment (left panel) and wagebill (right panel) by broad NAICS sector from 1977 to 2019. Sector descriptions are as follows: Mining, Utilities and Construction (2), Manufacturing (3), Wholesale and Retail Trade (42-45), Transportation and Warehousing (48-49), Business Services (5), Health Care (62), Accommodation and Food Services (72), and Other, which includes Educational Services, the Arts and Public Administration. Payroll data for 1988 are missing.

Figure 2: US Business Services Employment and Payroll Growth by Sector



Source: Longitudinal Business Database and authors' calculations. Figure displays US Business Services (NAICS 5X) employment (left panel) and wagebill (right panel) by two-digit NAICS sectors from 1977 to 2019. Sector descriptions are as follows: Information (51), Finance and Insurance (52), Real Estate (53), Professional Services (54), Headquarters Services (55) and Administration Services (56). Payroll data for 1988 are missing.

poses Professional Services growth into its four-digit NAICS components: Legal Services (5411), Accounting (5412), Architectural and Engineering (5413), Specialized Design (5414), Computer Systems Design (5415), Management, Scientific, and Technical Consulting (5416), Research and Development (5417), and Other, within Advertising (5418) and Other (5419) services.

As indicated in the figure, Computer Systems Design (5415), in green, exhibits the largest growth over the sample period, in both employment and payroll terms. Its employment increases to 1.93 million in 2019, or from 0.02 to 1.5 percent of overall US employment, while its share of overall US payroll increases from 0.03 to 2.8 percent.[15]

The right two figures in each panel of Figure 3 decompose Professional Services growth by firm type. While NM firms' exhibit significant employment growth in all sub-sectors except for Specialized Design Services (5414), M firms' growth is concentrated in just three of them: Architectural and Engineering Services (5413), Computer Systems Design (NAICS 5415), R&D (5417). This differential growth is even starker in payroll terms, where M firms' growth is notably different from NM firms. These sectors are most relevant for manufacturing both because they constitute an important input (e.g., R&D), and because they are complementary with the physical good (e.g., computers and Computer Systems Design).

We summarize the empirical results from this subsection as our second structural change fact:

> *Fact 2: US aggregate employment is moving towards services and especially technology and skill-intensive Professional, Scientific, and Technical Services.*

3.3 Professional Services as Intermediate Inputs

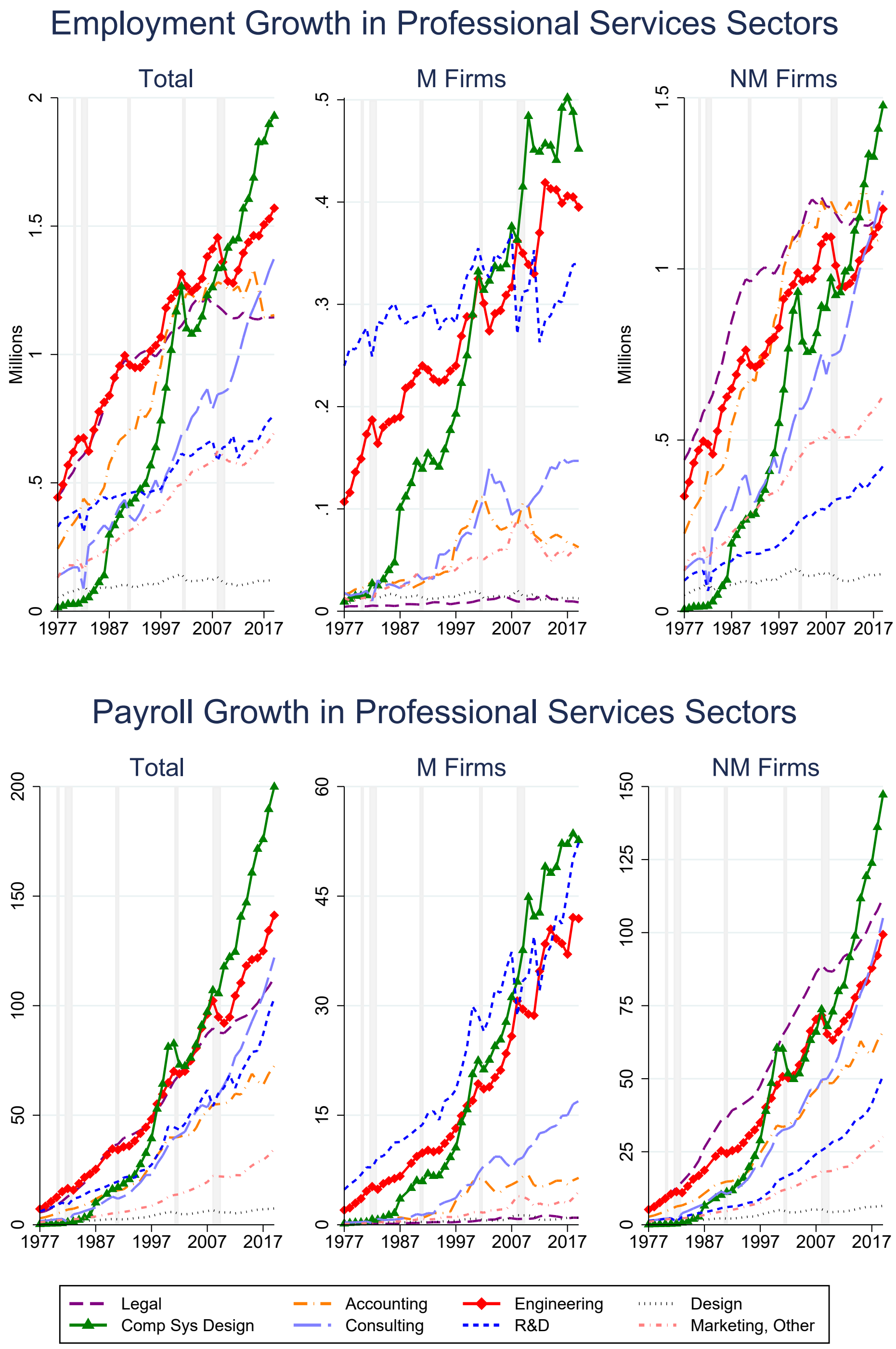
A distinctive feature of Professional Services is that they are disproportionately used as intermediate inputs rather than for final consumption. In Figure 4, we use data from the 1997 US supply-use input-output table to report the share of the value of output *not* sold to final consumers (i.e. used for intermediate inputs) across 2-digit NAICS sectors.[16] We use 1997 because it is halfway through our sample period, and the earliest input-output table using NAICS industries, but we find similar results for subsequent years. We find that Wholesale (NAICS 42), Management Services (NAICS 55) and Professional Services (NAICS 54) have the highest intermediate input shares, while Healthcare (NAICS 62), Education (NAICS 61) and Retail (NAICS 44-45) have the lowest. Therefore, the growth of professional services documented above is largely driven by intermediate input demand rather that changing shares across final consumption goods, our third fact about US structural change:

> *Fact 3: A substantial component of US structural change is reallocation towards service inputs rather than final goods, particularly Professional Services (NAICS 54).*

[15] Establishments providing these services are far more difficult to measure and analyze using SIC codes because under that industry classification system, vertically integrated establishments that primarily served other establishments of their firm were classified in the industry that they served. For example, an automobile manufacturing firm's R&D lab would be classified in automobile manufacturing. We are able to track these establishment during both the SIC and NAICS eras here using the Fort and Klimek (2018) NAICS codes discussed above.

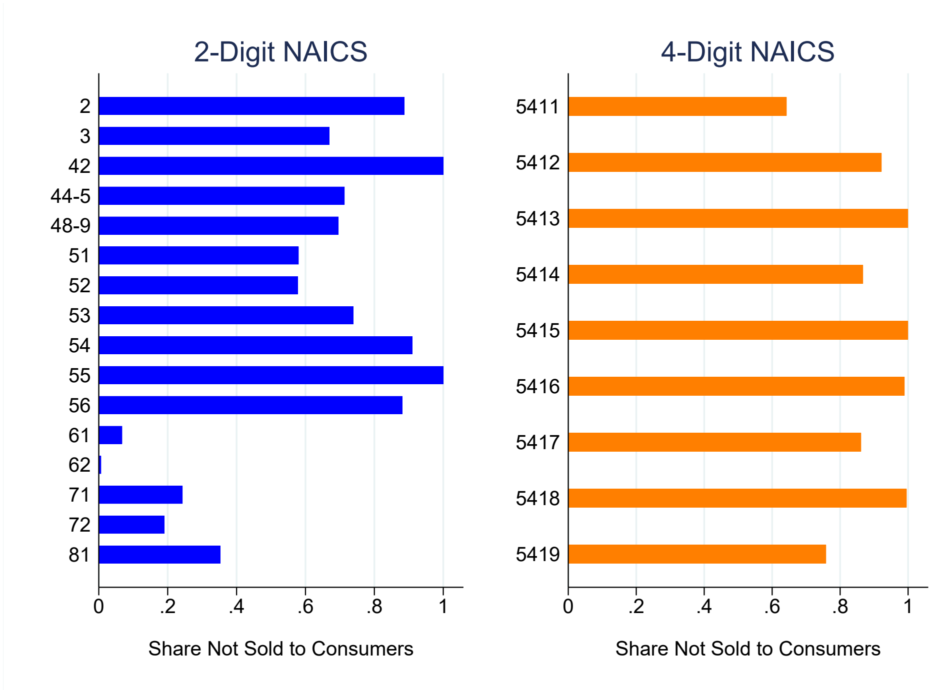
[16] Output sold to final consumers is identified via BEA output sector F01000.

Figure 3: Professional Services Employment and Payroll Growth by Sector and Firm Type



Source: Longitudinal Business Database and authors' calculations. Figure displays US Professional, Scientific, and Technical Services (NAICS 54X) employment (left panel) and wage bill (right panel) by four-digit NAICS sectors from 1977 to 2016. Sector descriptions are as follows: Legal (5411), Accounting (5412), Engineering (5413), Computer Systems Design (5415), Consulting (5416), R&D (5417) and Other (Specialized Design, Advertising, and Other) (5414, 5418, 5419). Payroll data for 1988 are missing.

Figure 4: Share of the Value of Output Used for Intermediate Inputs in 1997



Source: Bureau of Economic Analysis and authors' calculations. Figure displays the share of each sector's value sold as intermediates to firms or the government. Data are from the detailed 1997 US Supply-Use Table. The NAICS 2-digit sectors in the left panel are Mining, Utilities and Construction (2), Manufacturing (3), Wholesale Trade (42), Retail Trade (44-45), Transportation and Warehousing (48-49), Information Services (51), Finance, Insurance, Real Estate Services (52-3), Professional, Scientific and Technical Services (54), Management Services (55), and Administrative Services (5), Education (61), Health Care (62), Arts and Entertainment (61), Accommodation and Food Services (72), and Other (81). The NAICS 4-digit sectors in the right panel are: Legal (5411), Accounting (5412), Engineering (5413), Computer Systems Design (5415), Consulting (5416), R&D (5417) and Design, Marketing and Other (5419).

3.4 Within-Firm Reallocation Towards Services

In this subsection, we provide two views of US manufacturing firms that suggest the NM employment and payroll growth of M firms displayed in the section 3.2 captures reallocation from M to NM *within* manufacturing firms.

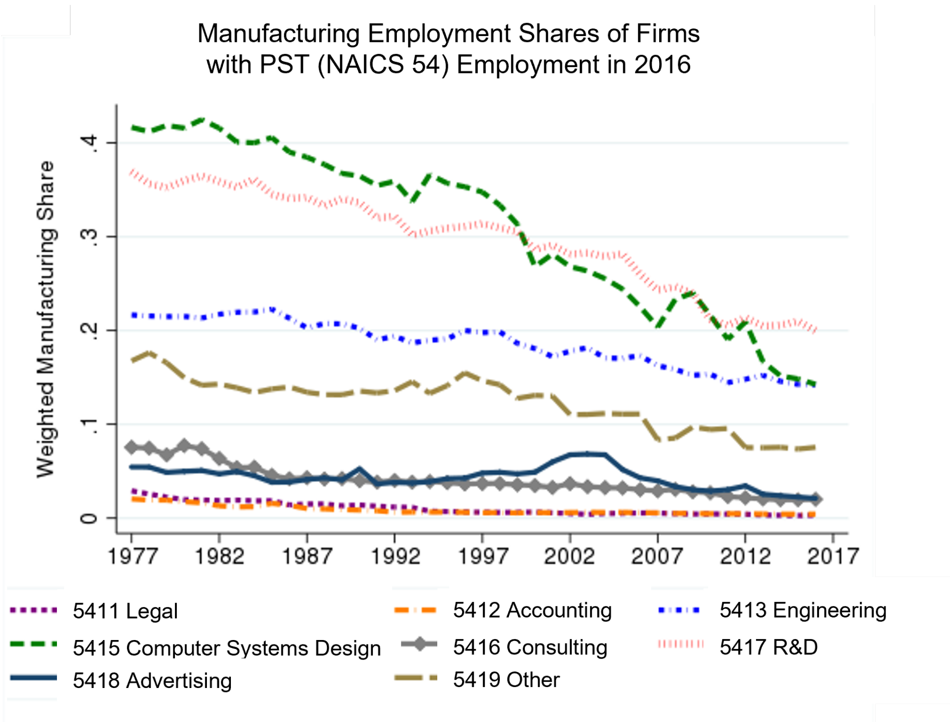
Continuing M Firms' Declining M Shares To assess whether M firms' growth in Professional Services sectors depicted in Figure 3 reflects pivoting *within* the same firm, we analyze the extent to which firms with Professional Services employment at the end of our period previously engaged in manufacturing. Focusing on the subset of firms with Professional Services employment at the end of the period that also existed in 1977 (i.e., continuers) we calculate their manufacturing employment shares in each year. Figure 5 displays the weighted average of these firms' manufacturing employment shares, using their end period Professional Services employment as weights.[17]

Figure 5 depicts two clear trends. First, manufacturing employment shares in 2016 are notably higher in the same three Professional Services industries (highlighted in Figure 3), in which M firms

[17] As in Section 3.2, we focus on Census firms. A given Census firm may contribute to the average in more than one line in Figure 5 if it has end-year employment in more than one Professional Services sector.

grew their NM employment and payroll over the period: Architectural and Engineering (NAICS 5413), Computer Systems Design (NAICS 5415), and R&D (NAICS 5417). On average, firms with employment in these three industries have 15 to 20 percent of their total employment in manufacturing. Second, these firms' manufacturing employment shares fall significantly over time. Firms with Computer Systems Design employment in 2016 saw their average manufacturing employment share more that halve over the period, falling from 40 percent in 1977 to about 15 percent in 2016. By contrast, firms in Legal and Accounting Services have almost no manufacturing employment throughout the period.

Figure 5: Firm Pivoting from Manufacturing into Professional and Technical Services from 1977-2016



Source: Longitudinal Business Database and authors' calculations. Sample is continuing firms with Professional and Technical Services (NAICS 54) employment in 2016. Figure displays the share of manufacturing in the employment of these firms in each year.

These patterns indicate that surviving manufacturing firms "pivot" into related professional services industries over time, either to embed higher levels of service inputs into their own physical products (*functional* structural change) or to produce these services for others (*sectoral* structural change).

Specific M-to-NM-Firm Transitions Census disclosure limitations preclude us from offering specific examples of firms that transition from M to NM over the sample period. To compensate, we exploit publicly available data from Compustat, with the caveat that these data include a relatively small number of large, publicly traded firms. Table 2 presents a transition matrix for continuing Compustat firms from 1987 to 2018, where the rows and columns correspond to firms' reported major

NAICS sector in the begin and end years.[18] Each cell in the table reports the 1987 global employment (in thousands) across all continuing firms inhabiting that cell. Blank cells indicate zero employment.

Unsurprisingly, there is substantial persistence in major NAICS sectors over time, with the diagonals accounting for approximately 88 percent of all employment. More strikingly, however, we find that off-diagonal cells are generally unpopulated except for initial manufacturing firms, which are relatively likely to transition to Business Services (NAICS 5), specifically Information (NAICS 51), Finance and Insurance (NAICS 52), and Professional services (NAICS 54), with Information and Professional services containing the largest off-diagonal employment. Examining the last two transitions in more detail, we find that they capture firms that formerly were in Computer and Electronics manufacturing that transitioned into Data Processing (518) and Computer Systems Design (5415).[19]

These examples suggest M firms may pivot into NM sectors related to their past production activities. Together with Figure 5, they provide our fourth fact on US structural change:

> *Fact 4: Manufacturing firms' pivot towards a subset of growing NM input sectors that relate to their past manufacturing activities.*

Table 2: Firms' Major NAICS Transition Matrix, 1985 to 2018

								Major NAICS Sector in 2018						
Major NAICS Sector in 1985	20	30	42	44	48	51	52	53	54	56	60	70	81	Total
20	982	8	1		2		0.02	1				0.2		994
30	47	7,659	29			410	70	0.1	165	0.04	0.2	21		8,401
42		9	63	0.02	6			2			5			85
44	7	2		231			27	11				1		279
48	1	0			780			5		13				800
51		1				388			11	14	6			421
52	3	418				5	703	0.4						1,129
53								30						30
54		24						0.02	22		0.1			46
56		0							1	547				548
60										12	122			135
70						37	0.04	157				211		405
81		3						1					15	18
Total	1,040	8,124	92	231	788	840	800	207	199	587	134	233	15	13,291

Source: Computstat data and authors' calculations. Sample is the 839 continuing firms for which major 2-digit NAICS sector is available in COMPUSTAT in 1987 and 2018. Rows are firms' major NAICS sector in 1987. Columns are firms' major NAICS sector in 2018. Each cell reports continuing firms' global employment (in thousands) in 1987. NAICS industries are Mining (20); Manufacturing (30); Wholesale Trade (42); Retail Trade (44); Transportation and Warehousing (48); Professional Services (50); Education (60); Accommodation and Food (70); Other Services (80).

The four facts about US structural change emerging from this section indicate a transition towards high-skill Business Services primarily used by firms as inputs. Continuing manufacturing firms, which comprise only one percent of firms in 2019, account for 16 to 32 percent of aggregate NM growth. These 'ever' manufacturing firms do not simply grow their NM employment along with the aggregate

[18] Data on firms' major sector in Compustat is not available until 1987.

[19] The firm transitioning into Data Processing is IBM. The two firms switching to Professional Services are National Cash Register Company and Unisys.

economy, and instead transition into a subset of related service sectors. A key question that arises from this evidence on within-firm structural change is why these manufacturers transition successfully, while most manufactures simply exit?

4 Auxiliary Establishments as Knowledge Plants

Manufacturing firms' shift towards services suggests the presence of general capabilities or intangible knowledge that firms can redeploy as they move between these two sectors. In this section, we propose auxiliaries as establishments in which this knowledge is created and maintained within the firm, such that the knowledge remains proprietary and excludable. We begin by describing auxiliaries and analyzing how they differ from other establishments in the same detailed industries. We then examine how firms with auxiliaries differ from other firms, and how their auxiliary employment is distributed within the firm. Finally, we investigate associations between the presence of auxiliaries and firm growth and pivoting.

4.1 Characteristics of Auxiliary Establishments

Auxiliaries are plants that primarily serve other establishments of their firm, such as an R&D lab or a warehouse. They are present in 92 6-digit NAICS, which belong to the following seven 2-digit NAICS sectors: Transportation (48), Warehousing (49), Information (51), Professional (54), Management of Companies and Enterprises (55), Administrative and Support Services (56), and Repair Services (81). Within these broad sectors, there is considerable variation in terms of the number of 4- and 6-digit NAICS sub-sectors in which they appear. Of note, auxiliaries are present in all 4-digit subsectors of Professional (NAICS 54), though their importance varies considerably across them and over time.

We begin by examining differences in performance between auxiliaries and other establishments within the same 6-digit industry. To do so, we estimate the following regression specification:

$$y_{ift} = \beta_0 AUX_{ift} + \sum_j \beta_j (AUX_{ift} \times NAICS2(j)_{ift}) + X_{ift} + \beta_y Year_t + \epsilon_{ift}, \tag{1}$$

where AUX_{ift} is an indicator equal to one if establishment i at firm f in year t is an auxiliary, and the second term on the right-hand side is the 2-digit NAICS of the establishment interacted with its auxiliary indicator. Baseline controls include a set of plant age fixed effects (indicators for birth, 1 to 4 years, 5 to 9 years, 10 to 20 years and 20+ years), 6-digit NAICS industry fixed effects, and year fixed-effects. For outcomes y_{ift} we consider the log of establishment employment, sales, and wage (payroll/employment). We limit the sample for this regression to 6-digit NAICS sectors that have auxiliary establishments, and to Census years ending in "2" and "7" from 1977 to 2012. Since all establishments classified in NAICS 551114 are auxiliaries, we exclude NAICS 55 from this analysis.[20]

Results from estimating equation (1) via OLS are presented in Table 3. Columns 1 and 4 indicate that auxiliary establishments are 76 and 97 log points larger than non-auxiliaries in terms of employ-

[20] It is unclear whether establishments in 551111 or 551112 are auxiliaries, and in any case these sectors are too small to analyze and disclose.

ment and sales, respectively. Column 7 shows that auxiliaries' wages are on average 38 log points higher even when compared to their peers within the same detailed industry (e.g., an in-house R&D plant compared to a stand-alone R&D plant).

Table 3: Auxiliary Establishment Premia

	$ln(emp_{ijt})$			$ln(sales_{ijt})$			$ln(wage_{ijt})$		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$Auxiliary_{ijt}$	0.764***	-0.078***		0.970***	-0.158***		0.383***	0.064***	
	(0.027)	(0.021)		(0.025)	(0.021)		(0.016)	(0.011)	
$Auxiliary_{ijt}$ in:									
Transportation			-0.231**			-0.862***			-0.262
(NAICS 48)			(0.102)			(0.304)			(0.255)
Warehousing			-0.331***			-0.198***			0.059***
(NAICS 49)			(0.061)			(0.062)			(0.016)
Information			0.002			-0.2			0.034
(NAICS 51)			(0.119)			(0.138)			(0.030)
Professional			-0.054***			-0.172***			0.075***
(NAICS 54)			(0.020)			(0.018)			(0.010)
Administrative			-0.110***			-0.112***			0.093***
(NAICS 56)			(0.032)			(0.031)			(0.012)
Repair			0.097			-0.033			0.036**
(NAICS 81)			(0.068)			(0.030)			(0.015)
Adj. R^2	0.22	0.84	0.84	0.24	0.86	0.86	0.35	0.95	0.95
Plant Age FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm Age FEs	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Firm Dep Var	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
$ln(estabs_{ft})$	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes

Source: Table presents results from estimating equation (1) via OLS. Dependent variable is the log of employment, sales, or wage for establishment i, in industry j, and year t, as indicated in columns. $Auxiliary_{ijt}$ is an indicator for whether the establishment primarily serves other establishments in its firm. "$Auxiliary_{ijt}$ in:" denotes the 2-digit NAICS sector of an auxiliary: 48 - Transportation, 49 - Warehousing, 51 - Information, 54 - Professional, 56 - Administrative, 81 - Repair. Sample limited to 6-digit NAICS industries with auxiliary establishments and covers each Economic Census year (years ending in 2 or 7) from 1977 to 2012. All regressions include 6-digit NAICS, FIPs, and Year fixed effects. "Firm Dep Var" is the firm-level measure of the dependent variable. $ln(estabs_{ft})$ is the log number of establishments at the establishment's firm in year t. Age categories are: births, 1-4, 5-9, 10-19, and 20+. Standard errors clustered by firm.

Columns 2, 5, and 8 add additional controls for the corresponding outcome variable of the firm as a whole as well for firm age (by category) and for the firm's log number of establishments ($ln(estabs_{ft})$). After controlling for these firm characteristics, we find that auxiliary establishments are *smaller* than non-auxiliaries, particularly in terms of sales. Since the sales measure at auxiliaries captures sales to *other* firms, this outcome is consistent with the premise that these establishments are generally focused on providing inputs within their own firm. In contrast to the negative size premia, Column 8 indicates that auxiliary establishments pay higher wages, even when controlling for the average firm wage. This finding is consistent with our premise that auxiliaries contain higher-skill workers relative to the rest of the firm.

We next investigate whether these average differences associated with auxiliaries differ by their industry classification. Columns 3, 6, and 9 break out the auxiliary indicator by the establishments' 2-digit NAICS sector, e.g., an R&D auxiliary would be interacted with a professional services (NAICS 54) dummy. These estimates indicate that auxiliary wage differentials are particularly high in Warehousing (NAICS 49) and professional services.[21] They are absent from Transportation (NAICS 48), in which trucking is the predominant auxiliary activity.[22] The premia documented in this section are consistent with auxiliary establishments using relatively high-skill workers to create knowledge.

4.2 Characteristics of Firms with Auxiliaries

In this subsection, we examine how *firms* with auxiliary establishments differ from other firms. We focus on all firms alive in one or more of the EC years from 1977 to 2012. Firms with auxiliaries are rare, comprising less than one percent of all firms over this period. We first analyze the types of auxiliaries firms have by calculating the share of their employment in all of their auxiliaries, as well as by the auxiliaries' two-digit NAICS. Table 4 presents the mean and standard deviation of these employment shares, and shows that these firms have on average 17 percent of their employment in auxiliaries. Table 4 also indicates that headquarters (NAICS 55) is the most prominent auxiliary type, with 14 percent of these firms' employment. An important note about headquarters (NAICS 551114) is that establishments that perform two or more professional services (e.g., an R&D lab and an Engineering center) primarily for their firm are classified in 551114. These establishments are thus more than just a firm 'headquarter', and in fact one firm many own multiple 551114 establishments.

Table 4: Average Auxiliary Employment Among Firms with Auxiliaries, by Sector

	All	By 2-digit NAICS						
	Auxes	48	49	51	54	55	56	81
Mean	0.173	0.001	0.012	0.001	0.012	0.138	0.007	0.002
Standard Deviation	0.191	0.022	0.063	0.025	0.072	0.173	0.058	0.034

Source: Table presents the mean and standard deviation of firms' employment shares in auxiliary establishments for 14.2 million observations of continuing firms in each decade from 1977 to 2007. Statistics calculated for firm-year observations in which the firm has at least one auxiliary.

[21] The only six-digit NAICS industry with auxiliary establishments in Warehousing is General Warehousing and Storage (493110), for which the EC forms inquire about supply chain management, a potentially high-skill activity. We are investigating those data to see if we can provide additional evidence on how those types of activities may occur in these establishments.

[22] In additional results not reported here, we investigate the robustness of these results in two ways. First, we confirm that the results in Table 3 are insensitive to controlling for firm employment (rather than the analogous firm-level measure of the dependent variable), to limiting the sample to multi-unit firms, and to examining the wage premia by 4-digit in NAICS 51 and 54. We do not find a statistically significant estimate for wage premia in Legal Services (NAICS 5411). By contrast, Telecommunications (517) and Data Processing (518) both exhibit positive and significant wage premia. Second, we assess whether in-house manufacturing establishments display similar characteristics as these in-house "knowledge" plants. In contrast to the results we document here, manufacturing plants that provide inputs to other establishments of their firm are larger, but do not pay higher wages relative to non-in-house plants in the same detailed industries.

We gauge how firms with auxiliaries differ from other firms by estimating

$$y_{ft} = \beta_0 AUX_{ft} + \beta_1 EmpSh_{ft}(AUX) + \sum_{j \in N2} \gamma_j EmpSh_{ft}(j) + X_{ft} + \beta_y Year_t + \epsilon_{ft}, \tag{2}$$

where AUX_{ft} is an indicator equal to one if firm f in year t has one or more auxiliary establishments, $EmpSh_{ft}(AUX)$ is the share of the firm's employment in auxiliaries. We also control for $EmpSh_{ft}(j)$, which capture the firm's employment shares across all 2-digit NAICS sectors, to ensure that our auxiliary measure does not capture activity across potential auxiliary sectors more generally. X_{ft} includes fixed effects for the main 4-digit NAICS of the firm (based on employment), and year. We estimate equation (2) using the log of firm employment, the log of firm sales, the log number of establishments, and firm age as dependent variables. We use the Economic Census data in each decade from 1977 through 2007 for these regressions.

Table 5 presents the results from estimating equation (2) via OLS. We find that firms with auxiliaries are substantially larger, older, and have more establishments. All of these premia are decreasing in a firm's share of auxiliary employment. Since the average firm with an auxiliary has 17 percent of its employment in auxiliaries (Table 4), the average firm is still about 348 log points larger in employment terms and 369 log points larger in sales.[23]

Table 5: Auxiliary Firm Premia

	$ln(emp_{ft})$		$ln(sales_{ft})$		$ln(estabs_{ft})$		Age_{ft}	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$Auxiliary_{ft}$	3.481***	3.840***	3.690***	4.023***	2.186***	2.431***	5.310***	5.557***
	(0.008)	(0.011)	(0.009)	(0.012)	(0.006)	(0.008)	(0.029)	(0.040)
$EmpShare_{ft}(Auxiliary)$		-2.377***		-2.469***		-1.965***		-2.294***
		(0.056)		(0.063)		(0.033)		(0.217)
Adj. R-Squared	0.20	0.20	0.30	0.30	0.35	0.36	0.24	0.24
N2 Non-Aux Emp Shares	No	Yes	No	Yes	No	Yes	No	Yes

Source: Table presents results from estimating equation (2) via OLS. Dependent variable is the log of employment, sales, number of establishments or age for firm f, in year t, as indicated in columns. $Auxiliary_{ft}$ is an indicator for whether the firm has an auxiliary establishment. $AuxEmpShare_{ft}$ is the firm's share of employment in auxiliary establishments. For firms with an auxiliary, the mean and standard deviation of their auxiliary employment share are 0.17 and 0.19, respectively. All regressions include fixed effects for the firm's main 4-digit NAICS (by employment) and year. Standard errors clustered by firm. N2 Non-Aux Emp Shares are the share of non-auxiliary employment by 2-digit NAICS. Sample consists of 14.2 million observations of firms in each decade from 1977 to 2007.

[23] For employment, a firm with an auxiliary and the average auxiliary employment share is 3.840+(-2.377*0.173)=343 log points larger.

4.3 Auxiliaries, Firm Growth and Pivoting

In this section we examine how firm growth and pivoting are associated with the presence of auxiliaries. We estimate the following regression:

$$\begin{aligned}\Delta y_{ft,t+10} =& \beta_0 AUX_{ft} + \beta_1 EmpSh_{ft}(AUX) + \sum_{j \in N2} \gamma_j EmpSh_{ft}(j) + \\ & Controls_{ft}(X_{ft}, \text{Age, NAICS}) + \epsilon_{ft},\end{aligned} \tag{3}$$

where $\Delta y_{ft,t+10}$ is the change in a firm outcome over decades defined by Census years from 1977 to 2007, and the other variables are defined as in equation (1). In light of the significant size and age premia of firms with auxiliaries documented in Table 5, we include a vector of firm-by-year controls (X_{ft}) that contains the log of firm employment, firm age category dummies, and the log of the number establishments at the firm. As before, we include industry and year fixed effects.

We examine how the presence of auxiliaries in a firm relates to its log change in employment and sales, as well as a measure of "pivoting" that captures the extent to which firms' industry mix overlaps each decade. Specifically, we calculate

$$Pivot_{ft} = 1 - \sum_{j \in NAICS6} \min\{EmpSh_{ft}(j), EmpSh_{f,t+10}(j)\}, \tag{4}$$

a number bounded between 0 and 1, with 1 indicating no overlap (more change) in industries across begin and end years t and $t+10$, and 0 corresponding to identical proportionate employment (less change) across the two years.

The top panel of Table 6 presents the results from estimating equation (3) via OLS. As indicated in the table, while firms with auxiliaries do not seem to grow differentially on average, their growth rate is strongly increasing in their share of auxiliary employment. Firms with the average share of auxiliary employment (0.173) grow approximately 3.4 percentage points more relative to firms without auxiliaries ($-0.048 + (0.472 \times 0.173)$). This differential growth rate is even more pronounced for sales, where firms with the average auxiliary employment share grow about 4.2 percentage points more than firms without auxiliaries.

Columns 5 and 6 in the top panel of Table 6 document the relationship between auxiliary employment and pivoting. Firms with the average share of auxiliary employment pivot relatively more than firms without an auxiliary. A firm with the average auxiliary employment share pivots by 1.28 ($-.013 + (0.149 \times 0.173)$) points more. Concentration of auxiliary employment within the firm appears to confer a growth advantage and is associated with increased pivoting. These differential effect of auxiliary employment exists even after controlling for firm size along multiple dimensions, and for the firm's non-auxiliary employment shares across sectors.

Table 6: Auxiliaries and Firm Outcomes

	$\Delta ln(emp_{ft})$		$\Delta ln(sales_{ft})$		$Pivot_{ft}$	
Panel A: Any Auxiliary	(1)	(2)	(3)	(4)	(5)	(6)
$Auxiliary_{ft}$	0.00	-0.048***	-0.011	-0.086***	0.002	-0.013***
	(0.007)	(0.009)	(0.009)	(0.010)	(0.003)	(0.003)
$EmpShare_{ft}(Auxiliary)$		0.472***		0.738***		0.149***
		(0.045)		(0.059)		(0.016)
Adj. R-Squared	0.09	0.09	0.06	0.06	0.11	0.11
Panel B: Auxiliary Employment Shares by N2						
$Auxiliary_{ft}$		-0.049***		-0.096***		-0.017***
		(0.009)		(0.011)		(0.003)
$EmpShare_{ft}(Auxiliary \times N2)$:						
Transportation		0.315*		0.002		-0.156***
(NAICS 48)		(0.167)		(0.251)		(0.057)
Warehousing		0.458***		0.693***		0.227***
(NAICS 49)		(0.107)		(0.131)		(0.038)
Information		0.478		1.227**		0.048
(NAICS 51)		(0.382)		(0.580)		(0.112)
Professional		0.446***		0.566***		0.156***
(NAICS 54)		(0.086)		(0.102)		(0.036)
Management		0.475***		0.926***		0.218***
(NAICS 55)		(0.059)		(0.076)		(0.019)
Administrative		0.666***		0.627***		0.047
(NAICS 56)		(0.106)		(0.110)		(0.043)
Repair		0.338***		0.503***		0.002
(NAICS 81)		(0.107)		(0.120)		(0.047)
Adj. R-Squared		0.09		0.06		0.11
Observations (M)	3.9	3.9	3.9	3.9	3.9	3.9

Source: Table presents results from estimating equation (3) via OLS. Dependent variables in columns (1) to (4) are the log change of firm employment or sales by decade. $Pivot_{ft}$ measures the share of employment in $t+1$ in the same industries as the firm's employment in t. $Auxiliary_{ft}$ is an indicator for whether the firm has an auxiliary establishment. $AuxEmpShare_{ft}$ is the firm's share of employment in auxiliary establishments. For firms with an auxiliary, the mean and standard deviation of their auxiliary employment share are 0.17 and 0.19, respectively. All regressions include fixed effects for the firm's main 4-digit NAICS (by employment) and year, and control for the log of firm employment, firm age categories, and the log number of establishments, and the firm's share of non-auxiliary employment across 2-digit NAICS sectors. Standard errors clustered by firm. Sample consists of 3.9 million observations of continuing firms in each decade from 1977 to 2007.

In the bottom panel of Table 6, we interact the auxiliary dummy variable with the firms' auxiliary employment shares in each of the six sectors in which these establishments appear. As indicated in the table, the increased pivoting associated with auxiliary employment is driven by auxiliary employment in professional services, Management Services and Warehousing. The industry descriptions for these sectors, and our results with respect to wages above, suggest that these are particularly high-skill or technology-intensive sectors.[24] In sum, firms with auxiliaries in these relatively technology-intensive sectors grow relatively faster and pivot across industries relatively more than other firms in the same industry, even after controlling for differences in firm size and age.

We summarize the empirical findings in this section as our fifth fact about US structural change:

> *FACT 5: Auxiliary establishments have relatively high wages, and firms with auxiliaries are older, employ more workers, have more establishments and exhibit greater growth and pivoting as their share of auxiliary employment increases.*

5 Theoretical Framework

We rationalize the empirical patterns of US structural change presented above in a model in which firm operations require both production activities and management and professional (MPRO) services, which are complementary to one another. MPRO services involve investments in intangible knowledge that are specific to the firm but general across sectors. If structural transformation occurs within firms, this intangible knowledge can be redeployed from one sector to another. In contrast, if reallocation occurs through the entry and exit of firms, this firm-specific intangible knowledge is destroyed. Firms that undertake MPRO services within firm boundaries have greater incentives to invest in intangible knowledge, because it is easier to exclude other firms from these investments when they are undertaken in-house. Therefore, firms that vertically integrate MPRO services make greater investments in intangible knowledge, and hence have greater ability to pivot across sectors.

This theoretical framework features structural transformation within and between firms. We distinguish between "sectoral" structural change, in which the reallocation of economic activity towards services occurs across final consumption expenditure categories (e.g. from manufacturing to health-care services) and "functional" structural change, in which this reallocation towards services occurs through intermediate input expenditure categories (e.g. from production to MPRO services). This functional structural change can occur within firms, if MPRO services and production are vertically integrated within the boundaries of the same firm, and otherwise occurs between firms.

5.1 Preferences

We consider a world of N countries indexed by $n, i \in N$.[25] Consumer's preferences in country n are defined over consumption indexes (C_{nj}) of a set of final demand sectors indexed by $j \in J$:

$$U_n = \left[\sum_{j \in J} \left(\frac{C_{nj}}{\eta^U_{nj}} \right)^{\frac{\nu-1}{\nu}} \right]^{\frac{\nu}{\nu-1}}, \tag{5}$$

[24] As discussed in Footnote 21, Warehousing includes supply-chain management.

[25] Unless otherwise noted, we use n to indicate countries of consumption (destinations) and i to denote countries of production (origins).

where ν is the elasticity of substitution across sectors; η_{nj}^U captures the representative consumer's relative preferences across sectors; to streamline notation, we suppress the implicit dependence on time, but take it as understood that we allow all variables to vary over time.

The consumption index for each sector j in destination country n (C_{nj}) is defined over consumption (c_{njf}) of horizontally-differentiated varieties supplied by firms $f \in F_{ij}$ from each origin country i:

$$C_{nj} = \left[\sum_{i \in N} \sum_{f \in F_{ij}} c_{nijf}^{\frac{\sigma_j - 1}{\sigma_j}} \right]^{\frac{\sigma_j}{\sigma_j - 1}}, \tag{6}$$

where σ_j is the elasticity of substitution across varieties within sectors. Given this nested constant elasticity of substitution (CES) demand structure, sales for firm f from origin country i in destination country n and in sector j (x_{nijf}) are:

$$x_{nijf} = p_{nijf}^{1-\sigma_j} X_{nj} P_{nj}^{\sigma_j - 1}, \tag{7}$$

where X_{nj} is expenditure on sector j in destination country n and P_{nj} is the price index for sector j in destination country n (dual to equation (6)). Total firm sales (x_{if}) are the sum of sales across all sectors within each destination country and across all destination countries served by the firm:

$$x_{if} = \sum_{n \in N_{if}} \sum_{j \in J_{nif}} x_{nijf} = \sum_{n \in N_{if}} \sum_{j \in J_{nif}} p_{nijf}^{1-\sigma_j} X_{nj} P_{nj}^{\sigma_j - 1}, \tag{8}$$

where N_{if} is the set of destination countries served by firm f from origin country i and J_{nif} denotes the set of sectors in which firm f from origin country i serves destination country n.

5.2 Final Goods Production

Each country i is endowed with inelastic supplies of production workers ($\bar{L}_i^P$), who undertake production tasks (as indicated by the superscript P), and knowledge workers ($\bar{L}_i^S$), who perform MPRO services (as indicated by the superscript S). Our specification of production and entry builds on Melitz (2003) to incorporate multiple sectors and factors of production, with a complementary between MPRO services and production activities. In order to enter, a final goods firm must incur an upfront entry cost of f_e units of knowledge workers. Incurring this sunk entry cost creates a horizontally-differentiated brand, which can be used to supply one variety in each sector j, and reveals the firm's productivities in each sector (φ_{fj}). If the firm chooses to serve a country n in sector j, it must incur an additional fixed market entry cost of F_{nj}^N units of knowledge workers for that country and sector. After incurring this market entry cost, the firm can supply its variety in sector j to country n at a constant unit cost that depends on its productivity in that sector (φ_{fj}). Additionally, the firm faces iceberg variable trade costs, such that $\tau_{nij} \geq 1$ units of a variety must be shipped from origin country i in sector j in order for one unit to arrive in destination country n, where $\tau_{nij} > 1$ for $n \neq i$ and $\tau_{nnj} = 1$. Finally, if a firm decides to enter, it faces a constant probability of death (δ), which induces ongoing entry and exit of firms in the steady-state equilibrium of the model.

Unit costs for firm f in sector j in origin country i depend on the cost of performing MPRO services (e.g. managing, marketing, advertising, accounting) and production activities (e.g. assembling, machining, stamping). We assume that MPRO services and production activities are combined according to the following CES unit cost function:

$$\frac{1}{\theta_f}\gamma_{ifj} = \frac{1}{\theta_f}\left[\left(q_{if}^S\right)^{1-\mu_j} + \left(\frac{\left(w_i^P\right)^{\beta_j}\left(Q_{ij}\right)^{1-\beta_j}}{\varphi_{fj}}\right)^{1-\mu_j}\right]^{\frac{1}{1-\mu_j}}, \qquad \begin{array}{l} 0<\mu_j<1 \\ 0<\beta_j<1 \end{array}, \tag{9}$$

where $\theta_f \geq 1$ is a Hicks-neutral productivity shifter that depends on firm investments in intangible knowledge; q_{if}^S is the cost of MPRO services; w_i^P is the wage of production workers, which can differ from the wage of knowledge workers (w_i^S) used for MPRO services; Q_{ij} is the cost of intermediate inputs in sector j in country i; μ_j is the elasticity of substitution between MPRO services and production activities in sector j; and β_j controls the intensity with which production in sector j involves the use of production workers and intermediate inputs.

We model intermediate inputs using roundabout production, in which each sector uses all sectors as intermediate inputs with the same elasticity of substitution between sectors as for final demand. The cost of intermediate inputs for each sector (Q_{ij}) takes the same form as the price index dual to the utility function (5):

$$Q_{ij} = \left[\sum_{k\in J}\left(\frac{P_{ik}}{\eta_{ijk}^P}\right)^{1-\nu}\right]^{\frac{1}{1-\nu}}, \tag{10}$$

where η_{ijk}^P controls the relative intensity with which each sector k is used as an input for sector j, which can differ from the relative preferences for each sector k in consumption ($\eta_{nk}^U \neq \eta_{ijk}^P$).

Two aspects of this production technology are noteworthy. First, we assume that MPRO services and production activities are complements ($0 < \mu_j < 1$), which is in line with the assumption in the macroeconomics literature of that services and goods are complements, although here we make the assumption about the production technology rather than final demand. Second, we assume that the same MPRO services are used across sectors within firms, which implies that the cost of MPRO services is the same across all sectors within firms ($q_{ifj}^S = q_{if}^S$ for all j), although we show below that the relative shares of MPRO services and production activities in unit costs vary across sectors with the firm's productivity in each sector (φ_{fj}). We now turn to examine the determination of this cost of MPRO services (q_{if}^S).

5.3 Management and Professional (MPRO) Services

Each final goods firm faces the choice between outsourcing MPRO services to a standalone supplier or incurring a fixed cost of F^S units of knowledge workers to undertake them in-house. Each firm also chooses how much to invest in intangible knowledge to reduce unit costs. We assume that a firm can obtain a stock of $\theta_f > 1$ of intangible knowledge by employing $\psi\left(\theta_f^{\zeta} - 1\right)$ knowledge workers in research.[26] The parameter ψ governs the productivity of these investments, while the parameter ζ controls the convexity of research costs with respect to these investments. We assume that investments in intangible knowledge are only excludable if MPRO services are undertaken within the boundaries of the firm.[27] Therefore, if a final goods firm incurs the fixed cost of vertically integrating MPRO services, only it retains access to its intangible knowledge. In contrast, if the final goods firm outsources MPRO services, its intangible knowledge diffuses freely to all firms in the economy.

Under these assumptions, the vertical integration and intangible investment decisions become closely connected. If a firm incurs the fixed cost of vertically integrating MPRO services and invests in intangible knowledge, its exclusive access to this intangible knowledge raises its share of revenue within each sector. In contrast, if a firm outsources MPRO services, any investment in intangible knowledge diffuses freely to all firms, and leaves the firm's share of revenue within each sector unchanged. Assuming that each firm is sufficiently small that its investments in intangible knowledge have a negligible effect on the sector price index and total sector expenditure, it follows that no firm that outsources MPRO services has any incentive to undertake costly investments in intangible knowledge ($\theta_f = 1$). In contrast, firms that vertically integrate MPRO services in general undertake positive investments in intangible knowledge ($\theta_f > 1$), as determined further below.

We assume that MPRO services are produced using knowledge workers according to the following unit cost function:

$$q_{if}^S = w_i^S, \tag{11}$$

where q_{if}^S denotes the unit cost of MPRO services for firm f in origin country i.

We assume that this production technology for MPRO services is freely available to all firms. If MPRO services are outsourced, they are produced by a standalone supplier using this technology under conditions of perfect competition. Therefore, zero profits implies that the price of MPRO services equals unit cost, which is equal to the wage of knowledge workers (w_i^S). If MPRO services are vertically integrated in-house, they are produced by the final goods firm using this same technology, which implies that unit cost is again equal to the wage of knowledge workers (w_i^S). Therefore, in either case, the final goods firm's unit cost function (9) can be re-written as follows:

$$\frac{1}{\theta_f}\gamma_{ifj} = \frac{1}{\theta_f}\left[\left(w_i^S\right)^{1-\mu_j} + \left(\frac{\left(w_i^P\right)^{\beta_j}\left(Q_{ij}\right)^{1-\beta_j}}{\varphi_{fj}}\right)^{1-\mu_j}\right]^{\frac{1}{1-\mu_j}}. \tag{12}$$

Under our assumptions, there are only two differences between vertical integration and outsourcing. First, vertical integration requires an additional fixed cost (F^S) to be incurred. Second, only final goods firms that vertically integrate MPRO services have an incentive to invest in intangible knowledge ($\theta_f > 1$). In contrast, final goods firms that outsource MPRO services make zero investments in intangible knowledge ($\theta_f = 1$).

[26] This formulation of research costs ensures that a firm that makes no investment in intangible knowledge ($\theta_f = 1$) incurs zero costs, since $\psi\left(1^\zeta - 1\right) = 0$.

[27] For a broader discussion of knowledge-based approaches to the boundaries of the firm, see Demsetz (1988).

5.4 Firm Problem

We assume that final goods firms compete under conditions of monopolistic competition within each sector. Each firm chooses the number of countries to serve, the number of sectors in which to serve each country, whether to outsource MPRO services or undertake them in-house, its investment in intangible knowledge, the price to charge for each variety, and inputs of MPRO services, production and knowledge workers, and intermediate inputs to maximize its profits. Using the unit cost function (12), the firm problem can be written as follows:

$$\max_{\{\{p_{nifj}\},N_{if},J_{nif},\mathbb{I}^S_{if},\theta_f\}} \left\{ \begin{array}{c} \sum_{n\in N_{if}} \sum_{j\in J_{nif}} p_{nifj} y_{nifj}\left(p_{nifj}\right) - \frac{1}{\theta_f} \gamma_{ifj} y_{nifj}\left(p_{nijf}\right) \\ - \sum_{n\in N_{if}} \sum_{j\in J_{nif}} w^S_i F^N_{nj} - \mathbb{I}^S_{if} w^S_i F^S - w^S_i \psi \left(\theta^{\zeta}_f - 1\right) \end{array} \right\}, \tag{13}$$

where $y_{nifj}\left(p_{nijf}\right)$ is output of firm f from origin country i in each sector j and destination country n, which is a function of the price chosen for its variety (p_{nijf}; and $\mathbb{I}^S_{if}$ is an indicator variable that equals one if firm f in origin country i chooses to undertake MPRO services in-house and zero otherwise.

We characterize the solution to the firm's problem as follows. First, we solve for the equilibrium price for the firm's variety in each country and sector conditional on its choice of the sets of countries and sectors to serve, its decision whether to organize MPRO services in-house, and its investment in intangible knowledge. Second, we determine a firm's usage of factor inputs conditional on its market entry, vertical integration and intangible investment decisions. Third, we characterize the firm's choice of the set of countries and sectors to serve conditional on its vertical integration and intangible investment decisions. Fourth, we analyze the firm's vertical integration and intangible investment decisions.

5.5 Equilibrium Prices

Beginning with the equilibrium pricing rule, profit maximization under CES demand and monopolistic competition implies that the equilibrium price for each firm variety is a markup over marginal cost:

$$p_{nifj} = \frac{\sigma_j}{\sigma_j - 1} \tau_{nij} \frac{1}{\theta_f} \gamma_{ifj}, \tag{14}$$

where the markup depends on the constant elasticity of substitution (σ_j); and marginal costs include both the unit production cost (γ_{ifj}/θ_f) and the iceberg variable trade cost (τ_{nij}).

Using this equilibrium pricing rule in the revenue function (7), firm revenue in a given sector and market is a power function of firm unit costs:

$$x_{nifj} = \left(\frac{\sigma_j}{\sigma_j - 1} \tau_{nij} \frac{1}{\theta_f} \gamma_{ifj} \right)^{1-\sigma_j} X_{nj} P^{\sigma_j - 1}_{nj}. \tag{15}$$

Therefore, the relative revenues of any two firms within the same sector and destination market depend solely on their relative unit costs:

$$\frac{x_{nifj}}{x_{ni\ell j}} = \left(\frac{\gamma_{ifj}/\theta_f}{\gamma_{i\ell j}/\theta_\ell} \right)^{1-\sigma_j}. \tag{16}$$

From equilibrium revenue in equation (15), although we have interpreted intangible knowledge investments as reducing unit costs, an isomorphic interpretation for equilibrium firm revenue is that they increase product quality.

5.6 Final Goods Costs

Turning now to the firm's optimal choice of factor inputs, we establish a number of predictions that we provide empirical evidence on below. Using cost minimization, the share of MPRO services in the unit costs of final goods firm f in origin country i in sector j (ξ^S_{ifj}) depends on the prices of knowledge and production workers in that country (w^S_i, w^P_i), the cost of intermediate inputs in that sector and country (Q_{ij}), and firm productivity (φ_{fj}):

$$\xi^S_{ifj} = \frac{\left(w^S_i\right)^{1-\mu_j}}{\left(w^S_i\right)^{1-\mu_j} + \left(\frac{\left(w^P_i\right)^{\beta_j} \left(Q_{ij}\right)^{1-\beta_j}}{\varphi_{fj}} \right)^{1-\mu_j}}. \tag{17}$$

We now establish some properties of this final goods cost share with respect to shocks to technology and international trade. Totally differentiating this cost share (17), the log change in the share of MPRO services in firm costs can be linearly decomposed into log changes in factor prices and log changes in productivity:

$$\mathrm{d}\ln \xi^S_{ifj} = \left(1-\mu_j\right)\left(1-\xi^S_{ifj}\right) \left[\ \mathrm{d}\ln w^S_i - \beta_j \mathrm{d}\ln w^P_i - \left(1-\beta_j\right) \mathrm{d}\ln Q_{ij} + \mathrm{d}\ln \varphi_{fj} \ \right]. \tag{18}$$

Using our assumption that MPRO services and production activities are complements ($0 < \mu_j < 1$), and holding constant factor prices ($\mathrm{d}\ln w^S_i = 0$ and $\mathrm{d}\ln w^P_i = 0$), equation (18) implies that both productivity growth ($\mathrm{d}\ln \varphi_{fj} > 0$) and lower prices of intermediate inputs as a result of lower trade costs ($\mathrm{d}\ln Q_{ij} < 0$) induce structural transformation in the form of a higher share of MPRO services in unit costs ($\mathrm{d}\ln \xi^S_{ifj} > 0$).[28] The mechanism underlying this structural transformation is the same as that in the macroeconomics literature on unbalanced productivity growth following Baumol (1967). Whereas this macroeconomics literature focuses on structural transformation between final goods sectors, our framework features both this sectoral structural transformation and functional structural transformation between intermediate activities (MPRO services versus production activities), consistent with our stylized facts above.

We now connect this result for the share of MPRO services in overall firm unit costs to the share of MPRO services in labor costs and employment, which are directly observable in the data. We start

[28] Although we hold factor prices constant here, wages of knowledge workers rise faster than those of production workers during our sample period, which raises the share of MPRO services in unit costs under our assumption that MPRO services and production activities are complements.

with the share of MPRO services in labor costs:

$$\vartheta^S_{ifj} = \frac{w^S_i L^S_{ifj}}{w^S_i L^S_{ifj} + w^P_i L^P_{ifj}}. \tag{19}$$

Totally differentiating this share of MPRO services in labor costs, we have:

$$\mathrm{d}\ln\vartheta^S_{ifj} = \left(1 - \vartheta^S_{ifj}\right)\left[\mathrm{d}\ln w^S_i - \mathrm{d}\ln w^P_i + \mathrm{d}\ln L^S_{ifj} - \mathrm{d}\ln L^P_{ifj}\right]. \tag{20}$$

Therefore, holding constant factor prices ($\mathrm{d}\ln w^S_i = 0$ and $\mathrm{d}\ln w^P_i = 0$), and noting $0 < \vartheta^S_{ifj} < 1$, a rise in the share of MPRO services in labor costs ($\mathrm{d}\log\vartheta^S_{ifj} > 0$) implies a rise in MPRO services employment relative to production employment ($\mathrm{d}\log L^S_{ifj} > \mathrm{d}\log L^P_{ifj}$), and hence an increase in the share of MPRO services in total employment.

To link these changes in labor cost and employment shares to the changes in unit cost shares examined above, we use the implication of the Cobb-Douglas production technology that expenditures on intermediate inputs are a constant multiple of the wage bill for production workers:

$$Q_{ij}M_{ifj} = \frac{1-\beta_j}{\beta_j} w^P_i L^P_{ifj}, \tag{21}$$

where M_{ifj} is the quantity of intermediate inputs used by firm f from origin country i in sector j.

Using this linear relationship between intermediate input costs and production worker costs, we can rewrite the share of MPRO services in overall unit costs in equation (17) as:

$$\xi^S_{ifj} = \frac{w^S_i L^S_{ifj}}{w^S_i L^S_{ifj} + w^P_i L^P_{ifj} + Q_{ij}M_{ifj}} = \frac{w^S_i L^S_{ifj}}{w^S_i L^S_{ifj} + \left[1 + \frac{1-\beta_j}{\beta_j}\right] w^P_i L^P_{ifj}}. \tag{22}$$

Totally differentiating this relationship and using our earlier expressions for the total derivatives of unit costs (18) and labor costs (20), we find that the change in the share of MPRO services in labor costs is linearly related to the change in the share of MPRO services in unit costs as follows:

$$d\ln\vartheta^S_{ifj} = \left(\frac{1-\vartheta^S_{ifj}}{1-\xi^S_{ifj}}\right)\mathrm{d}\ln\xi^S_{ifj}, \tag{23}$$

where the shares of unit costs (ξ^S_{ifj}) and labor costs (ϑ^S_{ifj}) both lie strictly in between zero and one for $0 < \mu_j < 1$, thereby ensuring that the term in parentheses in equation (23) is strictly positive.

Combining the total derivative of the share of professional services in unit costs (18) with this linear relationship between unit cost and labor cost shares in equation (23), we can now characterize the effects of technology and trade shocks on the shares of MPRO services in labor costs and employment. Under our assumption that MPRO services and production activities are complements ($0 < \mu_j < 1$) and holding constant factor prices ($\mathrm{d}\ln w^S_i = 0$ and $\mathrm{d}\ln w^P_i = 0$), equations (18) and (23) imply that productivity growth ($\mathrm{d}\ln\varphi_{fj} > 0$) and lower prices of intermediate inputs due to lower trade costs ($\mathrm{d}\ln Q_{ij} < 0$) raise the share of MPRO services in unit costs ($\mathrm{d}\ln\xi^S_{ifj} > 0$) and hence the share of MPRO services in labor costs ($d\ln\vartheta^S_{ifj} > 0$). From the relationship between the share of MPRO services in labor costs and employment levels in equation (20), and holding constant factor prices ($\mathrm{d}\ln w_i^S = 0$ and $\mathrm{d}\ln w_i^P = 0$), this higher share of MPRO services in labor costs also translates into a higher share of MPRO services in employment.

Therefore, using only properties of the firm cost minimization problem, we obtain sharp empirical predictions for the effect of technology and input price shocks on structural transformation towards MPRO services. In contrast to the macroeconomic literature on sectoral structural transformation, these predictions are for functional structural transformation between intermediate activities (MPRO services versus production activities). For firms that vertically-integrate MPRO services in-house, these reallocations occur within firms. For firms that outsource MPRO services, these reallocations occur between firms, namely between each final goods firm and its standalone supplier.

5.7 Market Entry

We have thus completed our characterization of the final goods firm's equilibrium price and factor input choices. We now turn its choice of the sets of the countries and sectors to serve conditional on its vertical integration and intangible investment decisions. Using the firm's equilibrium pricing rule (14) in the definition of firm variable profits for a given sector and market, we obtain the standard result under CES demand and monopolistic competition that variable profits are a constant multiple of revenue in that sector and market:

$$\pi_{nifj} = \frac{1}{\sigma_j} x_{nifj}. \tag{24}$$

Given this solution for equilibrium variable profits, firm f from origin country i chooses to serve a given sector j and destination country n if these variable profits exceed the fixed market entry costs for that sector and country (F_{nj}^N). Therefore, the set of sectors J_{nif} served by the firm within a given destination country is simply the set of sectors for which these variable profits exceed the fixed market entry costs:

$$J_{nif} = \left\{ j : \frac{1}{\sigma_j} x_{nifj} - w_i^S F_{nj}^N \geq 0 \right\}. \tag{25}$$

Similarly, the set of countries N_{if} served by the firm is simply the set of countries for which there is at least one sector for which these variable profits exceed the fixed market entry costs:

$$N_{if} = \left\{ n : \max_j \left\{ \frac{1}{\sigma_j} x_{nifj} - w_i^S F_{nj}^N \right\} \geq 0 \right\}. \tag{26}$$

Conditional on the firm's vertical integration and intangible investment decisions, its choice whether to enter a given sector and country is independent of its choice whether to enter any other sector and country, because of the property of equation (12) that variable costs are constant. Substituting the equilibrium revenue function (15) into equation (25), the zero-profit condition to enter a given country and sector can be re-written as:

$$J_{nif} = \left\{ j : \frac{1}{\sigma_j} \left(\frac{\sigma_j}{\sigma_j - 1} \tau_{nij} \frac{1}{\theta_f} \gamma_{ifj} \right)^{1-\sigma_j} X_{nj} P_{nj}^{\sigma_j - 1} - w_i^S F_{nj}^N \geq 0 \right\}. \tag{27}$$

This zero-profit condition highlights that the model also features conventional structural transformation between sectors in response to shocks to technology and trade costs that affect final demand within each sector (through sectoral expenditure (X_{nj}) or the sectoral price index (P_{nj})). While the conventional macroeconomics literature is typically silent as to whether these reallocations occur through the entry and exit of firms or through reallocations of resources within firms, our model features both of these margins of adjustment. As shocks to technology and trade costs increase variable profits in some sectors and reduce them in others, the set of sectors chosen by entering firms will change (between-firm reallocations) and incumbent firms will choose to drop some sectors and add other sectors (within-firm reallocations).

From this zero-profit condition (27), a lower unit cost ($\frac{1}{\theta_f}\gamma_{ifj}$) increases a firm's variable profits and expands the set of countries and sectors that it finds it profitable to enter. As discussed in the previous section, firms that vertically integrate and invest in intangibles have lower unit costs ($\theta_f > 1$) than firms that outsource professional services and make no investment in intangibles ($\theta_f = 1$). Therefore, by reducing unit costs and increasing variable profits, these investments in intangibles increase the set of countries and sectors in which a firm operates.

5.8 Investments in Intangible Knowledge Capital

Finally, we turn to the final goods firm's vertical integration and intangible investment decisions. We already established that firms that outsource MPRO services make no investments in intangibles. Therefore, we first solve for a firm's optimal investment in intangibles conditional on vertically integrating MPRO services. Taking into account this optimal investment decision, we next determine whether the firm outsources or vertically integrates MPRO services by comparing the firm's total profits under these two alternatives.

Using the equilibrium revenue function (15), the total profits of a firm across all countries and sectors can be written as follows:

$$\Pi_{if}\left(\boldsymbol{\varphi}\right) = \begin{array}{r} \sum_{n\in N_{if}} \sum_{j\in J_{nif}} \frac{1}{\sigma_j}\left(\frac{\sigma_j}{\sigma_j-1}\tau_{nij}\frac{1}{\theta_f}\gamma_{ifj}\right)^{1-\sigma_j} X_{nj}P_{nj}^{\sigma_j-1} - \sum_{n\in N_{if}} \sum_{j\in J_{nif}} w_i^S F_{nj}^N \\ -\mathbb{I}_{if}^S w_i^S F^S - w_i^S \psi\left(\theta_f^{\zeta}-1\right) \end{array}, \tag{28}$$

which depends on the firm's vector of productivity draws across sectors $\{\varphi_{fj}\}$ through its vector of unit costs across sectors $\{\gamma_{ifj}\}$.

Conditional on incurring the fixed cost of vertically integrating professional services inhouse, the first-order condition for the firm's investment in intangibles yields the following optimal investment:

$$\sum_{n\in N_{if}} \sum_{j\in J_{nif}} \frac{\sigma_j-1}{\sigma_j}\left(\frac{\sigma_j}{\sigma_j-1}\tau_{nij}\gamma_{ifj}\right)^{1-\sigma_j} X_{nj}P_{nj}^{\sigma_j-1}\left(\theta_{if}^*\right)^{(\sigma_j-1)-\zeta} = \zeta\psi w_i^S, \tag{29}$$

which depends on the firm's vector of productivity draws across sectors $\{\varphi_{fj}\}$ through its vector of unit costs across sectors $\{\gamma_{ifj}\}$. As a firm that makes no investment in intangibles has a unit productivity ($\theta_f = 1$), only firms for which there is an interior solution in which $\theta_f^* > 1$ make positive investments in intangibles. For sufficiently convex research costs ($\zeta > (\sigma_j - 1)$), this optimal positive investment in intangibles is finite ($1 < \theta_f^* < \infty$).

From this solution for equilibrium investment in intangibles and the unit cost function (12), higher firm productivity across all sectors $\{\varphi_{fj}\}$ lowers unit costs (through lower $\{\gamma_{ifj}\}$), which increases total firm profits in equation (28) on both the intensive margin (higher profits within each sector and country) and the extensive margin (entry into more sectors and countries). These higher total profits in turn raise the return to intangible investments and increase the equilibrium level of these intangible investments. This role for the extensive margin of the range of sectors and countries served in influencing equilibrium intangible investment implies that there is an interdependence between a firm's decisions to serve each sector and country and its level of intangible investment. On the one hand, serving an additional sector and country raises the return to intangible investment. On the other hand, an increased investment in intangibles raises the variable profits from entering each sector and country.

Given the solution for the firm's optimal investment in intangibles (θ_{if}^*) implicitly defined by equation (29), we have determined a firm's total profits from vertically integrating MPRO services. A firm chooses to vertically integrate MPRO services if the total profits from doing so exceed those from outsourcing MPRO services to a standalone supplier. As vertical integration involves incurring an additional fixed cost F^S, only the most productive firms find it profitable to perform MPRO services in-house. Through this selection mechanism, the model rationalizes our empirical findings above that firms that vertically integrate MPRO services (as measured by auxiliary establishments in the data) are more productive than those that do not. Furthermore, as these firms that vertically integrate MPRO services make greater investments in intangible knowledge in equilibrium, they have lower unit costs across all sectors, and hence are more likely to be able to pivot to other sectors.

5.9 General Equilibrium

All of the empirical predictions that we examine in the next section were derived above from the properties of the firm optimization problem for given sectoral expenditures (X_{nj}), sectoral price indexes (P_{nj}), knowledge wages (w_i^S) and production wages (w_i^P). In this section, we briefly discuss closing the model to determine these variables in general equilibrium.

The general equilibrium of the model is referenced by the following variables: (i) the set of sectors served for each country ($J_{ni}(\boldsymbol{\varphi})$) and the set of countries served ($N_i(\boldsymbol{\varphi})$) as a function of a firm's productivity vector across sectors ($\boldsymbol{\varphi}$); (ii) an indicator variable for whether a firm vertically integrates MPRO services ($\mathbb{I}_i^S(\boldsymbol{\varphi})$) as a function of its productivity vector; (iii) investment in intangibles as a function of a firm's productivity vector ($\theta(\boldsymbol{\varphi})$); (iv) the wage for knowledge workers (w_i^S), (v) the wage for production workers (w_i^P); (vi) the price index for each sector and country (P_{nj}); and (vii) aggregate expenditure for each country (X_n). All other endogenous variables can be determined as functions of these elements of the equilibrium vector.

General equilibrium is determined by the following equilibrium conditions: (i) a firm with each productivity vector makes non-negative profits from all sectors and countries that it enters; (ii) a firm with each productivity vector incurs the fixed cost to vertically integrate MPRO services if this yields higher total profits than outsourcing MPRO services and vice versa; (iii) investment in intangibles equals zero for productivities for which firm's outsource MPRO services and is chosen to maximize profits for productivities for which firms vertically integrate; (iv) the labor market for knowledge workers clears; (v) the labor market for production workers clears; (vi) revenue in each sector and country equals expenditure on goods produced in that sector and country; (vii) free entry ensures that the expected value of entry is equal to the sunk entry cost.

5.10 Sectoral and Functional Structural Transformation Within and Between Firms

Our theoretical framework thus rationalizes both sectoral and functional structural transformation and allows these two forms of structural transformation to occur either within or between firms. "Sectoral" structural change occurs through changes in tastes or average firm productivity across final goods sectors. As these parameters change across final goods sectors, some previously profitable sectors become unprofitable, and some previously unprofitable sectors become profitable. Therefore, continuing firms drop some existing sectors and add other new sectors, thereby inducing sectoral structural change within firms. Additionally, entering firms choose to participate in a different set of sectors from exiting firms, which generates sectoral structural change between firms.

"Functional" structural change occurs through changes in the relative productivity of MPRO services and production activities. As MPRO services and production are complements, reductions in production costs lead to increases in the share of MPRO services in total firm costs. For firms that have chosen to vertically integrate MPRO services, this reallocation occurs within firms. In contrast, for firms that have chosen to outsource MPRO services, this reallocation occurs between firms. Additionally, entering firms choose different shares of MPRO services in total firm costs from exiting firms, again inducing reallocation from production to MPRO services.

Our theoretical framework also highlights the role of firm productivity in shaping sectoral and functional structural change. More productive firms can profitably produce in a wider range of sectors, which increases their ability to pivot away from declining to expanding sectors. More productive firms are also more likely to vertically integrate MPRO services, such that functional structural change occurs within firms. Additionally, more productive firms make greater investments in intangible knowledge, which further expands the range of sectors in which they can profitably produce, and hence further enhances their ability to pivot away from declining to expanding sectors.

6 Firm Structural Transformation and Intangible Knowledge

In this section we provide empirical evidence in support of four novel predictions generated by the model introduced in the last section. The first prediction is that firms respond differently to shocks affecting the relative profitability of final-goods sector ("output shocks") than shocks altering the relative cost of physical versus service inputs ("input shocks"). The second implication is that input shocks induce within-firm structural transformation towards services due to the complementarity between physical production and knowledge services. The third prediction is that firms with auxiliaries non-manufacturing employment is more sensitive to output and input shocks because they produce knowledge in-house. The final implication, assuming firms' knowledge stocks do not fully depreciate in response to input and output shocks, is that firms with proprietary knowledge capital are less responsive to a negative output shock, and more responsive to a positive input shock, as this capital lowers their production costs in all sectors thereby granting them an advantage in terms of moving into other industries.

In examining these predictions, we follow a large empirical literature in using the "China shock" as a source of quasi-experimental variation in firm outcomes, but differ from the typical approach in this literature in three ways. First, we construct separate output and input shocks. Second, we compute exposure to these shocks at the firm level using detailed information about firms' product and input mixes. Third, we investigate the role of firm knowledge capital in mediating these shocks by interacting them with firms' auxiliary status at the *beginning* of the sample period to mitigate the endogeneity associated with firms' decision to operate auxiliaries.

6.1 Measuring Shocks to Input and Output Prices

We exploit the substantial growth of Chinese exports during the middle of our 1977 to 2016 sample period to identify plausibly exogenous variation in competition in firms' outputs and inputs. In terms of our model, we interpret increased output competition as a reduction in P_{nj}, which lowers residual demand for the firm's products, and increased input competition as a reduction in Q_{ij}, which lowers the firm's unit costs. Using data from Comtrade, we compute the 1997 to 2007 change in China's EU import market shares across industries as our measure of increased competition.[29]

A novel feature of our approach is to utilize detailed data from the Product and Material Trailers of the Census of Manufacturers on the products firms produce and the material inputs they purchase. This variation within industry but across firms allows us to distinguish the impact of increased output competition from reduced input prices.[30] We define firm f's output exposure as the sales-weighted average change in China's EU market share across the six-digit NAICS manufacturing industries it sells in 1997, using the concordance from Pierce and Schott (2012) to aggregate the Harmonized System trade data to the NAICS level,

$$\Delta Output_f = \sum_{j \in \text{Manuf}} \frac{Sales_{fj}^{1997}}{Sales_f^{1997}} \Delta EUImpShChina_j. \tag{30}$$

$Sales_{fj}^{1997}$ is the firm's sales in the six-digit manufacturing NAICS industry j in 1997 and $\Delta EUImpShChina_j$ is the 1997 to 2007 change in China's market share in the EU (relative to other non-US producers) in that 6-digit NAICS industry. The denominator used to construct these weights, $Sales_f^{1997}$, is the

[29] As in Antràs, Fort, and Tintelnot (2017), we focus on market-shares rather than levels (Autor, Dorn, and Hanson, 2013), which differences out common shocks from the numerator and denominator of these market shares.

[30] Pierce and Schott (2016) exploit industry-level input-output tables to distinguish US manufacturing establishments' own, upstream, and downstream exposure to Chinese import competition. Mion and Zhu (2013) estimate a firm's offshoring of inputs using the firm's imports of any goods it imports outside its main three-digit industry. Greenland, Ion, Lopresti, and Schott (2020) measure firms' overall exposure to trade liberalization with China using equity market reactions.

firm's total sales in both manufacturing and non-manufacturing, which allows for predominantly non-manufacturing firms to be naturally less affected by import competition shocks in its manufacturing output markets.

Similarly, we define firm f's input shock as the expenditure-weighted average change in China's EU market share across the six-digit goods it purchases as inputs in 1997:

$$\Delta Input_f = \sum_{j \in \text{Manuf}} \frac{Expenditures_{fj}^{1997}}{Expenditures_f^{1997}} \Delta EUImpShChina_j, \tag{31}$$

where $Expenditures_{fj}^{1997}$ is the firm's purchases of inputs in the 6-digit NAICS manufacturing industry j, and the denominator $Expenditures_f^{1997}$ is a proxy for the total variable costs of the firm, which allows firms that are either predominantly non-manufacturing or manufacturing but more labor intensive to be naturally less affected by import competition shocks in manufacturing input markets. By using detailed information on input-usage from the Material Trailers, our input shock measure can vary even across firms producing in the same industry.[31]

6.2 Empirical Specification

We implement variants of the following reduced-form specification, in which we regress changes in firm outcomes directly on our instruments:

$$\begin{aligned} \Delta Outcome_f =& \beta_O \Delta Output_f + \beta_{OA} \Delta Output_f \times AUX_f^{1997} + \beta_{OE} \Delta Output_f \times ln(Emp_f^{1997}) \\ &+ \beta_I \Delta Input_f + \beta_{IA} \Delta Input_f \times AUX_f^{1997} + \beta_{IE} \Delta Input_f \times ln(Emp_f^{1997}) \\ &+ \beta_A AUX_f^{1997} + \beta_E ln(Emp_f^{1997}) + \beta_X X_f^{1997} + \epsilon_{fj}, \end{aligned} \tag{32}$$

where $\Delta Outcome_f$ denotes the firm's 1997 to 2007 growth rate in employment or sales. We focus on a balanced panel of firms with manufacturing establishments in 1997, but note that this panel is not balanced with respect to M or NM activity. That is, it includes firms that survive but exit manufacturing entirely, and surviving M firms that add non-manufacturing over the sample. As a result, we compute growth rates following Davis, Haltiwanger, and Schuh (1996), where entry or exit into M or NM is measured as 2 and -2, respectively:

$$\Delta Outcome_f \equiv (Outcome_f^{2007} - Outcome_f^{1997})/((Outcome_f^{2007} + Outcome_f^{1997})/2). \tag{33}$$

Shocks to firms' output and input markets, $\Delta Output_f$ and $\Delta Input_f$, are defined in equations 30 and 31 above. We interact these shocks with the firm's auxiliary status in 1997 (AUX_f^{1997}) to assess our hypothesis that these in-house knowledge plants affect firms' ability to grow in complementary service sectors in response to manufactured input-cost reductions. Since firms with auxiliaries are

[31] For a susbset of firms that do not report data in the material trailers, we follow Pierce and Schott (2016) in imputing input usage across their output products from the 1997 US input-output tables produced by the US Bureau of Economic Analysis (BEA). See Online Appendix D for more information.

considerably larger, we also interact the log of firm employment in 1997, $ln(Emp_f^{1997})$, with both shocks to ensure that our auxiliary-by-shock interactions do not simply reflect a differential impact of the shock on large versus small firms.

In all our specifications we also include a vector of controls for firm attributes in 1997, X_f^{1997}: age quintiles, the log number of establishments, and fixed effects for the firm's main 4-digit NAICS industry (by employment). We note that inclusion of the latter remove substantial across-industry variation in outcomes documented in the literature (Autor, Dorn, and Hanson, 2013; Pierce and Schott, 2016), but serve here to address potential concerns about industry-level demand and technology trends that might drive correlated changes in Chinese import penetration in Europe and US manufacturers' shift into services. We also control for the sums of shares used to construct the output and input shocks: (i) the share of manufacturing in the firm's total sales, and (ii) the share of manufacturing inputs in the firm's total variable expenditures. These "incomplete sum of shares" account for the possibility that our output and input shocks could merely capture manufacturing intensity rather than exposure to increased competition (Borusyak, Hull, and Jaravel, 2021).[32] We two-way cluster the standard errors by the firm's main output and input industries.[33]

The coefficients $\{\beta_O, \beta_I\}$ in equation 32 identify the impact of Chinese input and output exposure among comparable firms, i.e., those in the same 4-digit NAICS industry and of similar age, size, and number of establishments. The interaction coefficients $\{\beta_{OA}, \beta_{OE}, \beta_{IA}, \beta_{IE}\}$ capture the extent to which the impact of such exposure differs by firms' auxiliary status and size.

6.3 Results

We present our main estimation results for firm sales and employment growth over the period 1997-2007 in Table 7. Panel A reports the employment results, while Panel B contains the sales results. Since our focus is on how different firms respond to shocks, we report unweighted regressions, but include interactions between the shocks and firm size in the second column for each outcome variable. Columns 1 and 2 report estimates for firms' total activity (both manufacturing and non-manufacturing); Columns 3 and 4 present estimates for manufacturing activity; and Columns 5 and 6 give estimates for non-manufacturing activity.

Consistent with most prior work that documents a negative relationship between Chinese import competition and employment, Panel A displays large, negative, and statistically significant effects of

[32] Though not shown in equation (32), we also interact these sum-of-share controls with AUX_f^{1997} to ensure that any differential effects we estimate for firms with auxiliaries are not similarly biased. When we include the interaction between the shocks and firm size, we also interact firm size with these sum-of-share controls.

[33] The latest research on shift-share analyses emphasizes the importance of adjusting the standard errors to address the mismatch between the levels at which the shocks are observed versus applied, as in Adão, Morales, and Kolesár (2019) or Borusyak, Hull, and Jaravel (2021). Our application differs from the settings that these papers study, because we estimate our regressions at the firm rather than the regional level, and we construct and utilize multiple shift-share shocks with differing Bartik weights. Our results are robust across two-way clustering, one-way clustering (e.g. by the firm's main output industry), or using conventional heteroskedasticity-robust standard errors. We also perform various Monte Carlo simulations to assess the potential implications for inference that arise from serial correlation across firms through output or input mix. In our simulations, when using standard errors clustered by the firm's main input and/or output industry, one percent significant level tests reject the (true) null that $\beta = 0$ for approximately five percent of the samples simulated. Therefore, for our results with p-values < 0.01, a conservative adjustment would put their simulated p-value at 0.05. Online Appendix Section D.2.5 discusses these exercises in detail.

the output shock on firms' total, M, and NM employment. While the first columns for both total and M employment suggest that this inmpact is statistically significant only for firms with auxiliaries, the second columns for each of these variables reveal that it is strongly increasing in firm size. The estimates in Column 2 imply that a 10 percentage point increase in China's EU market share in the outputs of a firm with 500 employees decreases its total employment by 3.9 percent if it does not have auxiliaries, and 8.2 percent if it does. By contrast, the estimates in Columns 5 and 6 indicate that the same output shock would reduce a firm's non-manufacturing employment by 5.6 percent, independently of its size, but only if it had auxiliaries prior to the shock.

Results for the input shock are quite different. We see no statistically significant impact on firms' total or M employment. However, in line with our assumed complementarity between manufactured and knowledge inputs, we find a relationship between the input shock and NM employment. Indeed, a 10 percentage point increase in China's market share in the EU in a 500 employee firm's inputs raises its NM employment by 19 percent. As this effect is only present for firms with auxiliaries, it supports our hypothesis that in-house knowledge plants play a key role in firms' ability to pivot across complementary sectors.

We present comparable estimates for sales growth in Panel B of Table 7. The output shock has a large, negative, and statistically significant impact on firms' total and M sales that is strongly decreasing in firm size. The most notable distinction from the employment results in Panel A is that firms' NM sales do not decrease in response to the output shock. The fact that the output shock reduces NM employment for firms with auxiliaries but has no statistically significant impact on NM sales is consistent with firms using NM workers to produce in-house knowledge to support their manufacturing output. As with employment, the input shock has no statistically significant impact on total or M sales, but does raise their NM sales: a 10 percentage point increase in Chinese import competition in firms' inputs raises the NM sales of firms with auxiliaries by 17 percent. This result suggests that functional structural change may itself lead to sectoral structural change, as firms that produce services in-house eventually sell them to other firms.

In Table 8, we examine the impact of output and input shocks on specific service sectors within NM. We find that the input shock leads to growth in professional services (NAICS 54-5) employment and sales, CUT (NAICS 21-3), and Transportation and Warehousing (NAICS 48-9). By contrast it has no statistically significant effect in Health, Education, or other Business Services outside of NAICS 54-5. These results are in line with the aggregate patterns depicted in Figure 1. On the other hand, while M firms exhibit strong growth in Wholesale and Retail, we do not find a statistically significant impact of the input or output shocks on their employment or sales in these sectors.

Overall, the results in Table 8 suggest US M firms tilt in response to the China shock towards high-skill, technology-intensive sectors that are inputs into manufacturing. These responses are in line with functional structural change, in which cheaper foreign manufactured inputs lead firms to reorient towards complementary knowledge inputs. The fact that firm sales also grow in these sectors, however, suggests that this functional structural change may also lead to sectoral functional change, as firms begin to sell those inputs to other firms.[34]

[34]Consider as an example Amazon's creation of cloud computing services to host its website traffic. Over time, and

Table 7: Effects of Output and Input Shocks on Firm Sales and Employment

Dependent variable is the DHS growth rate from 1997 to 2007 of firm-level outcome indicated in column header

Panel A: Employment	Total Emp		Manuf Emp		Non-Manuf Emp	
	(1)	(2)	(3)	(4)	(5)	(6)
Output Shock	-0.046	0.324*	-0.064	0.465*	0.068	0.132
	(0.092)	(0.196)	(0.113)	(0.271)	(0.066)	(0.211)
Output Shock $\times Aux_f^{1997}$	-0.703***	-0.433**	-1.110***	-0.709**	-0.636**	-0.579**
	(0.208)	(0.210)	(0.262)	(0.312)	(0.248)	(0.256)
Output Shock $\times ln(emp_f^{1997})$		-0.115**		-0.164**		-0.018
		(0.049)		(0.067)		(0.059)
Input Shock	-0.024	-0.067	-0.149	-0.238	0.094	-0.224
	(0.200)	(0.450)	(0.192)	(0.440)	(0.158)	(0.543)
Input Shock $\times Aux_f^{1997}$	0.465	0.457	0.149	0.135	1.725***	1.537***
	(0.565)	(0.533)	(0.497)	(0.510)	(0.646)	(0.551)
Input Shock $\times ln(emp_f^{1997})$		0.018		0.034		0.091
		(0.130)		(0.138)		(0.140)
AUX_f^{1997}	0.176***	0.013	0.204***	0.099	0.077	0.233***
	(0.045)	(0.050)	(0.059)	(0.075)	(0.055)	(0.052)
$ln(emp_f^{1997})$	-0.116***	-0.015	-0.072***	0.002	0.005	-0.086***
	(0.009)	(0.014)	(0.008)	(0.026)	(0.007)	(0.018)
R^2	0.115	0.116	0.082	0.084	0.058	0.059

Panel B: Sales	Total Sales		Manuf Sales		Non-Manuf Sales	
	(1)	(2)	(3)	(4)	(5)	(6)
Output Shock	-0.036	0.615**	-0.046	0.875***	0.105	0.075
	(0.127)	(0.237)	(0.154)	(0.318)	(0.067)	(0.195)
Output Shock $\times Aux_f^{1997}$	-0.690***	-0.192	-1.307***	-0.591*	-0.234	-0.250
	(0.232)	(0.210)	(0.306)	(0.338)	(0.369)	(0.391)
Output Shock $\times ln(emp_f^{1997})$		-0.201***		-0.283***		0.009
		(0.060)		(0.077)		(0.054)
Input Shock	-0.127	-0.163	-0.214	-0.322	0.140	0.229
	(0.162)	(0.569)	(0.203)	(0.662)	(0.162)	(0.438)
Input Shock $\times Aux_f^{1997}$	0.014	0.031	-0.129	-0.128	1.569**	1.619***
	(0.579)	(0.481)	(0.516)	(0.502)	(0.641)	(0.598)
Input Shock $\times ln(emp_f^{1997})$		0.020		0.045		-0.026
		(0.169)		(0.194)		(0.111)
AUX_f^{1997}	0.113**	-0.011	0.211***	0.150*	-0.109*	-0.079
	(0.050)	(0.054)	(0.067)	(0.085)	(0.062)	(0.068)
$ln(emp_f^{1997})$	-0.047***	0.037**	-0.002	0.051*	-0.006	-0.025
	(0.009)	(0.017)	(0.009)	(0.028)	(0.006)	(0.023)
R^2	0.075	0.077	0.067	0.069	0.067	0.067
Observations	73,500	73,500	73,500	73,500	73,500	73,500

Notes: Table presents results from estimating equation (32) via OLS. Aux_f^{1997} is an indicator for whether the firm has one or more auxiliary establishments in 1997. Davis-Haltiwanger-Schuh (DHS) growth rate is $DHS_f = (x_f^{2007} - x_f^{1997})/((x_f^{2007} + x_f^{1997})/2)$. All regressions include firm-level controls for age, the log number of establishments, the share of sales in manufacturing and its interaction with Aux_f^{1997}, the share of materials in manufacturing costs and its interaction with Aux_f^{1997}, and 4-digit NAICS fixed effects. Columns 2, 4, and 6 include the manufacturing sales and cost shares interacted with $ln(emp_f^{1997})$ Standard errors two-way clustered by firm's primary output and input NAICS..

Table 8: Effects of Output and Input Shocks on Firm Sales and Employment

Dependent variable is the DHS growth rate from 1997 to 2007 of firm-level outcome indicated in column header

Panel A: Employment	MPro (54 & 55)	WRt (42-45)	TrWh (48-49)	MUC (21-23)	Other BS (51-53, 56)	AAF (71-72)	Other (60, 80)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Output Shock	0.244**	-0.037	0.006	0.011	0.052	-0.044	0.066
	(0.108)	(0.114)	(0.048)	(0.048)	(0.065)	(0.047)	(0.060)
Output Shock $\times Aux_f^{1997}$	-0.603**	-0.087	-0.297	-0.860***	0.270	-0.028	0.221**
	(0.257)	(0.265)	(0.221)	(0.265)	(0.207)	(0.084)	(0.110)
Output Shock $\times ln(emp_f^{1997})$	-0.081**	0.033	0.009	-0.001	-0.008	0.013	-0.013
	(0.033)	(0.032)	(0.014)	(0.016)	(0.019)	(0.014)	(0.017)
Input Shock	-0.178	-0.572*	0.000	-0.147	0.053	-0.112	-0.243
	(0.224)	(0.333)	(0.140)	(0.265)	(0.191)	(0.106)	(0.159)
Input Shock $\times Aux_f^{1997}$	1.324***	0.391	0.830***	2.545***	-0.329	0.198*	-0.389**
	(0.384)	(0.416)	(0.286)	(0.806)	(0.268)	(0.118)	(0.157)
Input Shock $\times ln(emp_f^{1997})$	0.048	0.153*	-0.013	0.059	-0.005	0.027	0.077
	(0.066)	(0.090)	(0.040)	(0.085)	(0.054)	(0.027)	(0.047)
AUX_f^{1997}	-0.609***	0.083	-0.124**	0.050	-0.022	0.060**	0.024
	(0.065)	(0.052)	(0.061)	(0.044)	(0.046)	(0.025)	(0.028)
$ln(emp_f^{1997})$	-0.007	-0.027	0.007	-0.031	0.019*	0.011	-0.007
	(0.016)	(0.018)	(0.015)	(0.019)	(0.012)	(0.011)	(0.012)
R^2	0.098	0.045	0.040	0.124	0.031	0.044	0.031
Observations	73,500	73,500	73,500	73,500	73,500	73,500	73,500

Panel B: Sales	MPro (54 & 55)	WRt (42-45)	TrWh (48-49)	MUC (21-23)	Other BS (51-53, 56)	AAF (71-72)	Other (60, 80)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Output Shock	0.064	0.050	-0.008	0.019	0.045	-0.041	0.056
	(0.095)	(0.124)	(0.039)	(0.041)	(0.064)	(0.045)	(0.052)
Output Shock $\times Aux_f^{1997}$	-0.108	-0.138	-0.167	-0.788***	0.261	-0.049	0.077
	(0.318)	(0.238)	(0.156)	(0.281)	(0.212)	(0.093)	(0.104)
Output Shock $\times ln(emp_f^{1997})$	-0.018	0.011	0.010	-0.006	-0.003	0.013	-0.008
	(0.028)	(0.033)	(0.012)	(0.012)	(0.018)	(0.013)	(0.014)
Input Shock	-0.405**	-0.251	-0.229**	0.271	-0.018	-0.109	-0.118
	(0.170)	(0.341)	(0.114)	(0.210)	(0.179)	(0.103)	(0.118)
Input Shock $\times Aux_f^{1997}$	0.780**	0.229	0.892***	2.143**	-0.100	0.155	-0.136
	(0.334)	(0.405)	(0.231)	(0.959)	(0.238)	(0.126)	(0.170)
Input Shock $\times ln(emp_f^{1997})$	0.118**	0.065	0.052	-0.050	0.010	0.028	0.042
	(0.055)	(0.091)	(0.035)	(0.064)	(0.049)	(0.027)	(0.036)
AUX_f^{1997}	-0.298***	0.030	-0.072	0.033	0.000	0.067**	0.001
	(0.060)	(0.055)	(0.046)	(0.030)	(0.046)	(0.027)	(0.029)
$ln(emp_f^{1997})$	-0.045**	-0.042**	-0.036**	-0.028	0.022	0.013	0.005
	(0.021)	(0.017)	(0.014)	(0.018)	(0.014)	(0.012)	(0.011)
R^2	0.042	0.044	0.051	0.270	0.031	0.038	0.028
Observations	73,500	73,500	73,500	73,500	73,500	73,500	73,500

Notes: Table presents results from estimating equation (32) via OLS. MPro is Management and Professional Services; WRt is Wholesale/Retail; TrWh is Transportation and Warehousing; MUC is Mining, Utilities, and Construction; Other BS is other Business Services; AAF is Arts, Accommodation and Food Services; Other is Education, Health, and Repair. Aux_f^{1997} is an indicator for whether the firm has one or more auxiliary establishments in 1997. Davis-Haltiwanger-Schuh (DHS) growth rate is $DHS_f = (x_f^{2007} - x_f^{1997})/((x_f^{2007} + x_f^{1997})/2)$. All regressions include firm-level controls for age, the log number of establishments, the share of sales in manufacturing, the share of materials in manufacturing costs, these shares interacted with Aux_f^{1997} and $ln(emp_f^{1997})$, and 4-digit NAICS fixed effects. Standard errors two-way clustered by firm's primary output and input NAICS.

7 Conclusion

We provide new theory and evidence on the large-scale structural transformation that occurred in the United States over the last forty years. We use a newly-constructed dataset that allows us for the first time to track structural transformation with and across firms and to provide evidence on the role of firm intangible capital in this process of structural transformation.

We use these new data to highlight three key stylized facts about structural transformation. First, while most existing research emphasizes the reallocation of final consumption, we find that a substantial proportion of the observed reallocation occurs towards business services that are largely used as intermediate inputs rather than for final consumption. Second, we show that a major component of this reallocation. occurs within surviving manufacturing firms, as they pivot away from production and towards MPRO services and retail. Third, we develop a new measure of in-house investments in intangible knowledge, based on auxiliary establishments that primarily serve other establishments of their firm (e.g. a headquarters or a R&D lab). We show that this measure of investment in intangible knowledge is correlated with higher growth and pivoting to new industries.

To rationalize these features of the data, we develop a theoretical model, in which firm operations involve both knowledge services and production activities, which are complementary to one another. Knowledge services involve investments in intangible capital that are specific to the firm but general across sectors. If structural transformation occurs within firms, this intangible knowledge can be redeployed from one sector to another. In contrast, if reallocation occurs through the entry and exit of firms, this firm-specific intangible capital is destroyed. Firms that undertake knowledge services within firm boundaries have greater incentives to invest in intangible knowledge, because it is easier to exclude other firms from these investments when they are undertaken in-house. Therefore, firms that vertically integrate knowledge services have greater investments in intangible capital, and hence greater ability to pivot across sectors.

Our empirical findings and theoretical framework convey a number of micro and macro implications. First, in existing research on structural transformation through unbalanced productivity growth, reallocation of final consumption expenditure and employment across sectors is captured through the change in a common technology parameter across all firms. In contrast, when structural transformation occurs within firms, the magnitude of the resulting employment reallocation across sectors depends on endogenous within-industry reallocations across production establishments and within-firm reallocations between production and knowledge services. Second, the extent to which economic growth involves creative destruction depends on whether structural transformation occurs within versus between firms. To the extent that intangible knowledge is firm-specific but general across sectors, intangible knowledge can be preserved within firm boundaries, but is created and destroyed when firms enter and exit, respectively.

Third, the complementary between knowledge services and production activities shapes the response to the economy to shocks, such as increases in import competition. We provide empirical evidence in support of these theoretical predictions using the natural experiment on China's emergence

in an effort to capitalize on excess capacity it required during the Christmas shopping period, Amazon began selling those services to other firms.

into the global economy. Whereas most prior research on the China shock has exploited variation across sectors or local labor markets, we construct new measures of input and output exposure to the China shock at the level of individual firms. Consistent with the predictions of our model, we find that greater import competition in final output markets leads to the conventional contraction of firm employment, whereas greater import competition in intermediate input markets induces structural transformation within firms from production to knowledge services. We show that firms with greater intangible knowledge, as measured by auxiliary establishments, are more responsive to these output and input market shocks.

Taken together, our findings highlight the role of both sectoral structural transformation (across final demand sectors) and functional structural transformation (between economic activities within firms and sectors). Our results also emphasize the role of intangible knowledge and its heterogeneous distribution across firms in shaping these processes of structural transformation.

References

Adão, R., E. Morales, and M. Kolesár (2019): "Shift-Share Designs: Theory and Inference," *Quarterly Journal of Economics*, 134(4), 1949–2010.

Alessandria, G. A., R. C. Johnson, and K.-M. Yi (2021): "Perspectives on Trade and Structural Transformation," Working Paper 28720, NBER.

Antràs, P., T. C. Fort, and F. Tintelnot (2017): "The Margins of Global Sourcing: Theory and Evidence from U.S. Firms," *American Economic Review*, 107(9), 2514–64.

Antràs, P., and E. Helpman (2004): "Global Sourcing," *Journal of Political Economy*, 112(3), 552–80.

Argente, D., S. Moreira, S. Oberfield, and V. Venkateswaran (2021): "Scalable Expertise," Princeton University, mimeograph.

Atalay, E., A. Hortacsu, and C. Syverson (2014): "Vertical Integration and Input Flows," *American Economic Review*, 104(4), 1120–48.

Autor, D., D. Dorn, G. H. Hanson, G. Pisano, and P. Shu (2020): "Foreign Competition and Domestic Innovation: Evidence from US Patents," *American Economic Review: Insights*, 2(3), 357–374.

Autor, D. H., D. Dorn, and G. H. Hanson (2013): "The China Syndrome: Local Labor Market Effects of Import Competition in the United States," *American Economic Review*, 103(6), 2121–68.

Baumol, W. J. (1967): "Macroeconomics of Unbalanced Growth: The Anatomy of Urban Crisis," *American Economic Review*, 57, 415–26.

Bernard, A. B., and T. Fort (2015): "Factoryless Goods Producing Firms," *American Economic Review*, forthcoming.

Bernard, A. B., T. C. Fort, V. Smeets, and F. Warzynski (2021): "Heterogeneous Globalization: Offshoring and Reorganization," Working Paper 26854, NBER.

Bernard, A. B., J. B. Jensen, S. Redding, and P. Schott (2011): "Multi-Product Firms and Trade Liberalization," *Quarterly Journal of Economics*, 126(3), 1271–1318.

Bernard, A. B., J. B. Jensen, and P. K. Schott (2006): "Survival of the Best Fit: Exposure to Low-Wage Countries and the (Uneven) Growth of U.S. Manufacturing Plants," *Journal of International Economics*, 68, 219–237.

Bernard, A. B., S. J. Redding, and P. K. Schott (2010): "Multi-product Firms and Product Switching," *American Economic Review*, 100(1), 70–97.

Bessen, J. (2017): "Information technology and industry concentration," *Boston University School of Law Law & Economics Paper Series*, 17-41.

Bloom, N., M. Draca, and J. Van Reenen (2016): "Trade Induced Technical Change: The Impact of Chinese Imports on Innovation, Diffusion, and Productivity," *Review of Economic Studies*, 83, 87–117.

Boehm, C. E., A. Flaaen, and N. Pandalai-Nayar (2017): "Multinationals, Offshoring, and the Decline of US Manufacuturing," working paper, University of Texas at Austin.

Boehm, J., S. Dhingra, and J. Morrow (2021): "The Comparative Advantage of Firms," Discussion paper, LSE.

Boppart, T. (2014): "Structural Change and the Kaldor Facts in a Growth Model with Relative Price Effects and Non-Gorman Preferences," *Econometrica*, 82(6), 2167–2196.

Borusyak, K., P. Hull, and X. Jaravel (2021): "Quasi-Experimental Shift-Share Research Designs," *Review of Economic Studies*, forthcoming.

Breinlich, H., A. Soderbery, and G. C. Wright (2018): "From Selling Goods to Selling Services: Firm Responses to Trade Liberalization," *American Economic Journal: Economic Policy*, 10(4).

Buera, F. J., and J. P. Kaboski (2012): "The rise of the service economy," *American Economic Review*, 102(6), 2540–69.

Buera, F. J., J. P. Kaboski, and R. Rogerson (2015): "Skill Biased Structural Change," Working Paper 21165, National Bureau of Economic Research.

Chow, M., T. Fort, C. Goetz, N. Goldschlag, J. Lawrence, E. R. Perlman, M. Stinson, and T. K. White (2021): "Redesigning the Longitudinal Business Database," Working Paper 21-08, CES.

Comin, D., D. Lashkari, and M. Mestieri (2018): "Structural Change with Long-run Income and Price Effects," Northwestern, mimeograph.

Cravino, J., and S. Sotelo (2019): "Trade-Induced Structural Change and the Skill Premium," *AEJ: Macroeconomics*, 11(3), 289–326.

Davis, S. J., J. Haltiwanger, and S. Schuh (1996): *Job Creation and Destruction*. MIT Press, Cambridge MA.

De Loecker, J., and J. Eeckhout (2017): "The rise of market power and the macroeconomic implications," Discussion paper, National Bureau of Economic Research.

Dey, M., S. H. Houseman, and A. E. Polivka (2012): "Manufacturers' Outsourcing to Staffing Services," *ILR Review*.

Ding, X. (2020): "Industry Linkages from Joint Production," *Mimeo*.

Eckert, F. (2019): "Growing apart: Tradable services and the fragmentation of the us economy," UCSD.

Eckert, F., S. Ganapati, and C. Walsh (2019): "Skilled Tradable Services: The Transformation of U.S. High-Skill Labor Markets," UCSD.

Fort, T. C. (2017): "Technology and Production Fragmentation: Domestic versus Foreign Sourcing," *Review of Economic Studies*, 84(2), 650–687.

Fort, T. C., and S. Klimek (2018): "The Effects of Industry Classification Changes on US Employment Composition," CES Working Paper 18-28, US Census Bureau.

Fort, T. C., J. R. Pierce, and P. K. Schott (2018): "New perspectives on the decline of us manufacturing employment," *Journal of Economic Perspectives*, 32(2), 47–72.

Ganapati, S. (2016): "The Modern Wholesaler: Global Sourcing, Domestic Distribution, and Scale Economies," Discussion paper, Yale mimeo.

Greenland, A. N., M. Ion, J. W. Lopresti, and P. K. Schott (2020): "Using Equity Market Reactions to Infer Exposure to Trade Liberalization," Working Paper 27510, National Bureau of Economic Research.

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

Haltiwanger, J., R. S. Jarmin, and J. Miranda (2013): "Who creates jobs? Small versus large versus young," *Review of Economics and Statistics*, 95(2), 347–361.

Hart, O. D., and J. Moore (1990): "Property Rights and the Nature of the Firm," *Journal of Political Economy*, 98, 1119–58.

Herrendorf, B., R. Rogerson, and A. Valentinyi (2013): "Two Perspectives on Preferences and Structural Transformation," *American Economic Review*, 103(7), 2752–89.

——— (2014): "Growth and Structural Transformation," in *Handbook of Economic Growth*, ed. by P. Aghion, and S. N. Durlauf. Elsevier North Holland, Amsterdam.

Holmes, T. J., and J. J. Stevens (2014): "An Alternative Theory of the Plant Size Distribution, with Geography and Intra- and International Trade," *Journal of Political Economy*, 122(2), 369–421.

Hombert, J., and A. Matray (2018): "Can Innovation Help US Manufacturing Firms Escape Import Competition from China?," *The Journal of Finance*, 73(5), 2003–2039.

Hottman, C., S. Redding, and D. Weinstein (2016): "Quantifying the Sources of Firm Heterogeneity," *Quarterly Journal of Economics*, 131, 1291–1364.

Hsieh, C.-T., and E. Rossi-Hansberg (2019): "The Industrial Revolution in Services," University of Chicago.

Jarmin, R. S., and J. Miranda (2002): "The Longitudinal Business Database," *Center for Economic Studies Working Paper*, 02(17).

Kamal, F. (2020): *The Challenges of Globalization in the Measurement of National Accounts*chap. A Portrait of Factoryless Goods Producers. University of Chicago Press.

Khandelwal, A. (2010): "The Long and Short (of) Quality Ladders," *Review of Economic Studies*, 77(4), 1450–1476.

Lashkari, D., A. Bauer, and J. Boussard (2021): "Information Technology and Returns to Scale," mimeo, Boston College.

Matsuyama, K. (2000): "A Ricardian Model with a Continuum of Goods under Nonhomothetic Preferences: Demand Complementarities, Income Distribution and North-South Trade," *Journal of Political Economy*, 108, 1093–1120.

——— (2009): "Structural Change in an Interdependent World: A Global View of Manufacturing Decline," *Journal of the European Economic Association*.

——— (2019): "Engel's law in the global economy: Demand-induced patterns of structural change, innovation, and trade," *Econometrica*, 87(2), 497–528.

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

Mengus, E., and T. Michalski (2022): "Within-firm Services and Firm Capabilities," mimeograph, HEC Paris.

Mion, G., and L. Zhu (2013): "Import competition from and offshoring to China: A curse or blessing for firms?," *Journal of International Economics*, 89(1), 202 – 215.

Ngai, L. R., and C. A. Pissarides (2007): "Structural Change in a Multisector Model of Growth," *American Economic Review*, 97(1), 429–443.

Oulton, N. (2001): "Must the growth rate decline? Baumol's unbalanced growth revisited," *Oxford Economic Papers*, 53(4), 605–627.

Pierce, J. R., and P. K. Schott (2012): "A Concordance between Ten-Digit U.S. Harmonized System Codes and SIC/NAICS Product Classes and Industries," *Journal of Economic and Social Measurement*, 37, 61–96.

——— (2016): "Trade Liberalization and Mortality: Evidence from US Counties," Working Paper 22849, NBER.

Teece, D. J. (1982): "Towards an economic theory of the multiproduct firm," *Journal of Economic Behavior & Organization*, 3(1), 39–63.

Williamson, O. E. (1981): "The Economics of Organization: The Transaction Cost Approach," *The American Journal of Sociology*, 87(3), 548–577.

A Appendix Tables and Figures

In this appendix, we provide supporting tables and figures discussed in the text.

A.1 Headline numbers for payroll

Table A1: Payroll Growth in M and NM from 1977 to 2019, by Firm Type and Margin

Panel A:	**"Census" (Upper Bound)**							
	Manufacturing Pay				Non-Manufacturing Pay			
	1977	2019	Change	Share	1977	2019	Change	Share
M Firms	234	733	500	1.00	165	1682	1518	0.25
Continuers	87	306	219	0.44	70	1066	996	0.17
Net Birth/Death	147	427	280	0.56	94	616	522	0.09
NM Firms					335	4838	4503	0.75
Continuers					59	1048	989	0.16
Net Birth/Death					276	3790	3514	0.58
Total	234	733	500	1.00	500	6520	6021	1.00
Panel B:	**"HJM Firms" (Upper Bound)**							
	Manufacturing Pay				Non-Manufacturing Pay			
	1977	2019	Change	Share	1977	2019	Change	Share
M Firms	234	733	500	1.00	219	2620	2401	0.40
Continuers	158	474	316	0.63	175	2037	1862	0.31
Net Birth/Death	75	259	184	0.37	43	583	540	0.09
NM Firms	0	0	0	0.00	281	3901	3620	0.60
Continuers					72	1046	974	0.16
Net Birth/Death					209	2855	2646	0.44
Total	234	733	500	1.00	500	6521	6021	1.00

Source: Longitudinal Business Database (LBD) and authors' calculations. Table presents manufacturing (M) and non-manufacturing (NM) payroll levels in 1977 and 2019, the change in these levels, and the share of the change accounted for by M firms, NM firms, and continuers versus net/birth day withing these firm types. M pay is the sum of payroll at all US establishments in the LBD classified in manufacturing. NM pay is the sum of payroll at all US establishments in the LBD classified outside manufacturing. Census M firms are those that ever have an M plant between 1977 and 2019. HJM M firms are those that ever have an establishment that was ever in a firm with an M plant in the same year. Continuing Census firms are those for which the Census *lbdfid* exists in both years. HJM continuing firms are those with an establishment in 2019 that existed in 1977. Pay is in millions. There are 27.5 thousand continuing Census M firms in both years, out of 5.42 million firms in 2019. There are 46 thousand continuing HJM firms in 2019.

A.2 Reduced-form analysis

Table A2 documents the share of overall M and NM employment across 1997 and 2007 accounted for by our regression sample. Table A3 shows that Chinese market share gains in the EU in a firm's inputs and outputs predict increased import penetration in the United States in those measures.

Table A2: Regression Sample of Firms in Relation to the Overall Economy

	num firms	M emp			NM emp		
		1997	Δ 1997-2007	Share of Δ	1997	Δ 1997-2007	Share of Δ
Regression Panel	73,500	10.00	-0.77	0.26	8.75	3.90	0.20
Non-AUX firms	69,900	3.85	0.26	-0.09	0.29	0.41	0.02
AUX firms	3,600	6.15	-1.03	0.34	8.45	3.49	0.18
All other Firms		6.38	-2.24	0.74	78.04	15.59	0.80
Overall Economy		16.38	-3.01		86.79	19.49	

Notes: This table summarizes the importance of our regression sample in relation to the overall economy in terms of manufacturing and non-manufacturing employment, in both levels in 1997 and 2007 as well as changes over time. Employment is in millions.

Table A3: First Stage: Relationship between China's competitiveness in US and EU markets

	$\Delta ChineseMktSh_f^{US,Output}$			$\Delta ChineseMktSh_f^{US,Input}$		
	-	$\times Aux_{ft}$	$\times ln(emp_{ft})$	-	$\times Aux_{ft}$	$\times ln(emp_{ft})$
Output Shock	0.246***	-0.011***	-0.818***	0.038***	0.001	-0.029
	(0.061)	(0.003)	(0.214)	(0.011)	(0.001)	(0.028)
$\times Aux_{ft}$	-0.059**	0.511***	-0.075	0.022***	0.079***	0.132***
	(0.029)	(0.057)	(0.166)	(0.006)	(0.023)	(0.049)
$\times ln(emp_{ft})$	0.031***	0.002***	0.593***	-0.003*	-0.001***	0.035**
	(0.009)	(0.001)	(0.073)	(0.002)	(0.000)	(0.015)
Input Shock	0.263***	0.002	0.394	0.194***	-0.015**	-0.209**
	(0.086)	(0.007)	(0.441)	(0.061)	(0.006)	(0.095)
$\times Aux_{ft}$	0.061*	0.048	0.058	-0.054**	0.179***	-0.248*
	(0.034)	(0.050)	(0.216)	(0.022)	(0.063)	(0.134)
$\times ln(emp_{ft})$	-0.037**	0.000	0.000	0.018***	0.005***	0.325***
	(0.016)	(0.002)	(0.125)	(0.005)	(0.002)	(0.065)
R^2	0.645	0.639	0.654	0.667	0.757	0.700
F-stat	40.54	115.6	38.06	168.9	121.8	74.76

Notes: Table presents results from estimating equation (32) via OLS. Aux_f^{1997} is an indicator for whether the firm has one or more auxiliary establishments in 1997. All regressions include firm-level controls for Aux_f^{1997}, $ln(emp_f^{1997})$, firm age, the log number of establishments, the share of sales in manufacturing, the share of materials in manufacturing costs, these shares interacted with Aux_f^{1997} and $ln(emp_f^{1997})$, and 4-digit NAICS fixed effects. Standard errors two-way clustered by firm's primary output and input NAICS. Our regression sample contains 73,500 firms.