Unraveling the U.S. Supply Chain

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Abstract

We introduce a new method to account for where along the U.S. supply chain economic activity takes place. This method allows us to convert the complex input-output relationships in the U.S. economy into measures of steps taken along the supply chain.

We apply our method to a sequence of U.S. input-output tables containing data on 174 sectors and covering the period 1983-2000. Our results provide the following insights: (*i*) the aggregate U.S. supply chain seems fairly constant over time. However on a more disaggregated level, (*ii*) manufacturing activity seems to have moved upstream, and (*iii*) the contribution of business services value added to final demand has more than doubled, with personnel supply services quintupling their contribution and also moving up the supply chain.

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1. Introduction

Existing growth accounting methods, as applied by for example Jorgenson and Stiroh (2000) and Oliner and Sichel (2000), allow us to measure increases in productivity growth in individual sectors as well as the overall economy. They do not, however, allow us to consider whether, and to what extent, the interactions between firms and sectors in the U.S. economy have changed over the past decade.

Both economic theories as well as anecdotal evidence suggest that a potentially large part of productivity gains might be due to shifts in economic activity along the supply chain. On the theoretical side, classic theories of the division of labor, as in Smith (1776) and Stigler (1952), suggest an increasing number of steps along the supply chain as the size of the economy increases. Modern theories of outsourcing, like the one in Ono (2000), follow up on this and suggest that the movement of economic activity along the supply chain can potentially be an important source of economic growth and structural change.

The problem with theories that emphasize the evolution of the supply chain as a crucial part of economic progress is that, contrary to the measurement of productivity growth, there are no coherent methods to account for movements of value added along the aggregate supply chain. For this reason, these theories rely in large part on microevidence, as presented in Ono (2000), and on specific industry studies, as in Macher and Mowery (2004).

In this paper we provide such a coherent method that allows us to unravel the U.S. supply chain and consider where along the supply chain U.S. economic activity is taking place.

Our method converts input-output tables into two measures. The first measures how many steps a dollar of value added generated in an industry takes along the supply chain before it reaches consumers. We call this the *distance from final demand*. It is essentially a measure of where value added, once created, is going to. The second measures how many steps along the supply chain a dollar of consumption spending has taken. We call this measure *steps embodied in final demand*. It is essentially a measure of where along the supply chain value added is coming from.

Both of our measures can be interpreted as applications of multi-step transition probabilities in the context of discrete time Markov chains. We explain this common interpretation.

We apply our method to a sequence of input-output tables for the U.S. economy. These tables contain 174 sectors of economic activity and cover the period 1983-2000. Our application allows us to consider which stylized facts about the U.S. supply chain have been fairly constant over the past two decades as well as to pinpoint the areas where the supply chain has changed most notably. We consider the position of two dimensions of economic activity along the supply chain, namely nominal value added as well as employment.

The gist of our results is the following. On the aggregate level, the U.S. supply chain does not seem to have changed a lot over the last twenty years. However, below the surface, at a more disaggregated level, several marked changes have occurred. The compositional shift of manufactured goods towards knowledge intensive ones has shifted manufacturing activity away from final stages of assembly towards the production of more high-tech intermediate products. Finally, consistent with the perception of increased importance of outsourcing, the contribution of business services to final demand has doubled over the past two decades and shifted slightly up the supply chain. The most profound effect is observed for personnel supply services, whose contribution has gone up fivefold and who have moved up the supply chain.

The structure of the rest of this paper is as follows. In the next section we introduce the two main supply chain concepts that we consider in this paper. These are *distance from final demand* and *steps embodied in final demand*. We illustrate these concepts with a few examples and argue why they provide insight into issues related to specialization, outsourcing, and productivity growth. In Section 3 we show how these concepts can be applied to the U.S. input-output tables. In Section 4 we present the results obtained when we do so. We conclude in Section 5.

2. Two main supply chain concepts

Our aim is to consider where along the supply chain economic activity, both in terms of dollars as well as jobs, takes place. It is tempting to think of the supply chain as a linear relationship in which firm *1* supplies to firm *2*, firm *2* sells to firm *3*, and firm *3* sells to U.S. consumers. In practice, however, the U.S. supply chain is a lot more complicated than that. In this section we introduce the two major supply chain concepts that we use throughout the rest of this paper and illustrate their empirical relevance. These are *steps embodied in final demand* and *distance from final demand*.

To set the stage, let's consider a simple example of the supply chain for bread. This supply chain is depicted in figure 1. It considers the supply chain of a loaf of bread worth $1 when bought as final demand by the consumer. For simplicity we will consider this loaf as being fully made America. We will deal with imports later on. The 100 cents of U.S. value added embodied in this loaf of bread can be attributed to three firms along the supply chain. The first 20 cents are produced by the farmer. The second 30 cents are added by the miller, while the remaining 50 cents of value are added by the baker.

This simple example allows us to illustrate the two concepts that we consider, i.e. *steps embodied in final demand* and *distance from final demand*. Essentially, the former measures where a dollar of final demand comes from while the latter reflects where a dollar of value added goes. In both cases the 'where' is measured in terms of steps along the supply chain.

Steps embodied in final demand measures the distribution of the number of steps that the value added embodied in the bread takes to reach final demand. The minimum number of steps is one. In this case 50%, i.e. 50 cents out of the dollar, takes just one step from the baker to the consumer. The 30 cents produced by the miller take two steps, while the 20 cents produced by the farmer take 3. Hence, for bread we obtain a distribution of steps embodied of final demand of 50% at 1 step, 30% at two, and the remaining 20% at 3. The average number of steps that a dollar of value added takes to reach final demand of bread is 1.7 steps.

Distance from final demand measures the distribution of the number of steps that the value added produced by a firm/sector takes to reach final demand. Let us, for the moment, assume that both the farmer and the miller only sell their output for the production of bread. In that case 100% of the value added produced by the farmer is three steps away from final demand and 100% of the value added of the miller is two steps removed from the consumer. If the baker only sells its bread to consumers, then 100% of its output is one step away from final demand.

In practice, however, the farmer, miller, as well as the baker, might sell their products to each other as well as directly to final demand. That is, the actual U.S. supply chain is far from linear. Figure 2 depicts the general case of a three firm supply chain. In this example, ω_{ij} is the amount of input that firm j uses from firm i and f_i is the amount that firm *i* sells to final demand.

The bread supply chain is nested in this more general example. The general case boils down to the linear supply chain of the earlier example under the restrictions *(i)* $\omega_{13}=\omega_{21}=\omega_{31}=\omega_{32}=f_1=f_2=0$, *(ii)* $\omega_{12}=0.2$, *(iii)* $\omega_{23}=0.5$, and *(iv)* $f_3=0.5$.

We have already seen how our concepts of steps embodied in final demand and distance from final demand apply to the simple linear supply chain case. What remains to be defined is how they apply to the general supply chain. In order to show how we define our concepts in this case, we will illustrate each of them with an example.

These examples are the *steps embodied in final demand* supplied by firm *1* and the *distance from final demand* of firm *1*'s value added. On the one hand, total output/revenue of firm *1*, which we denote by y_1, is made up of three sources. The first is the revenue obtained from selling to final demand (f_3), while the second and third consist of the revenue generated by sales of intermediate inputs to firms *2* and *3* respectively (ω_{12} and ω_{13}). On the other, total output of firm *1* is also the sum of its value added, which we denote by v_1, and the intermediate inputs firm *1* buys from firms *2* and *3* (ω_{31} and ω_{21}). Mathematically, this boils down to

$$y_1 = f_1 + \omega_{12} + \omega_{13} = v_1 + \omega_{21} + \omega_{31} \qquad (1)$$

all these variables are measured in current dollars, i.e. they are nominals.

To formalize our two concepts, let $\pi_{1,q}$ be the fraction of final demand of firm *1* that embodies *q* steps along the supply chain. Furthermore, let $p_{1,d}$ be the fraction of value added of firm *1* that is *d* steps away from final demand.

Steps embodied in final demand

We use the second part of the identity (1) to derive $\pi_{1,q}$. That is, of every dollar of nominal output that firm *1* sells to final demand, a fraction $s_{1,v}=v_1/y_1$ is due to value added directly by firm *1* and is thus embodies one step from final demand. Here $s_{1,v}$ is the value added share of firm *1*. This observation means that $\pi_{1,1}=s_{1,v}$. What is left to derive is what determines $\pi_{1,q}$ for $q>1$.

In order to derive $\pi_{1,q}$ for $q>1$ we have to consider where the fraction of output of firm *1* that is not directly attributable to its own value added comes from. A fraction $s_{1,2}=\omega_{21}/y_1$ of output of firm *1* is due to intermediates bought from firm *2*. Similarly, $s_{1,3}=\omega_{31}/y_1$ is the fraction of output of firm *1* due to intermediates bought from firm *3*. The intermediates bought by firm *1* from the other firms have already traveled their own distance along the supply chain and we will need to account for this.

The fraction of output of firm *1* that has traveled two steps is the sum two things. The first is the fraction of output of firm *1* attributable to intermediates of firm *2* times the fraction of firm *2*'s output that embodies one step along the supply chain. Similarly, the second is the fraction of output of firm *1* attributable to intermediates of firm *3* times the fraction of firm *3*'s output that embodies one step along the supply chain[1].

To represent this mathematically, we will have to introduce a bit more notation. Similar to the way we defined it for sector *1*, let $\pi_{j,q}$ be the fraction of output of firm *j* that has traveled *q* steps along the supply chain. The mathematical translation of the previous two paragraphs reads

$$\pi_{1,2} = s_{1,2}\pi_{2,1} + s_{1,3}\pi_{3,1} \quad (2)$$

This can be generalized easily to derive the fraction of output of firm *1* that embodied *q* steps. This equals the fraction of output of firm *1* attributable to intermediate inputs from firm *2* times the fraction of these inputs that embody *q-1* steps plus the fraction of output of firm *1* attributable to intermediate inputs from firm *3* times the fraction of these inputs that embody *q-1* steps. This yields the recursion

$$\pi_{1,q} = s_{1,2}\pi_{2,q-1} + s_{1,3}\pi_{3,q-1} \quad (3)$$

Hence, the distribution of output over the steps embodied in final demand for each sector in the economy can be calculated using a sequence of recursive linear equations. The resulting distribution can be interpreted as the fraction of each dollar of output of a sector that has traveled a particular number of steps along the supply chain to get there. It reflects where along the supply chain the value added embodied in the output of a sector comes from.

Distance from final demand

We use the first part of the identity (1) to derive $p_{1,d}$, where $p_{1,d}$ measures the fraction of value added of firm *1* that takes *d* steps along the supply chain before it reaches final demand. The fraction of value added of firm *1* that takes the minimum of one step to reach final demand is given by the fraction of its output that it directly sells as consumption or capital goods. Let σ_{if} denote the fraction of its output that firm *i* sells to final demand, such that $\sigma_{if}=f_i/y_i$. This means that $p_{1,1}=\sigma_{1f}$.

Value added of firm *1* that takes two steps to final demand either flows through firm *2* or *3* and is then sold directly to final demand. That is, we can write the fraction of value added of firm *1* that takes two steps to final demand as the sum of two components. The first is the fraction of value added of firm *1* that flows to final demand through firm *2*, which is given by the fraction of output of firm *1* sold to firm *2* times the fraction of its output that firm *2* sells directly to final demand. The second is the fraction of output of firm *1* sold to firm *3* times the fraction of its output that firm *3* sells directly to final demand.

Let σ_{ij} denote the fraction of its output that firm *i* sells to firm *j*. This definition implies that $\sigma_{ij}=\omega_{ij}/y_i$. Given this notation, we can write the fraction of value added of firm *1* that takes two steps to reach final demand as

$$p_{1,2} = \sigma_{12}p_{2,1} + \sigma_{13}p_{3,1} \quad (4)$$

[1] Implicit in this derivation is the assumption that the goods that firms *2* and *3* supply as intermediates to firm *1* are the same, and thus embody the same steps, as the goods they sell to final demand. That is, we assume that each firm, and later each sector, produces a homogenous good.

Just like for the steps embodied case, this equation can be generalized to obtain an expression for $p_{1,d}$ for $d>1$. That is, the fraction of value added of firm *1* that takes *d* steps is the fraction of value added of firm *1* that is supplied to firm *2* and subsequently takes *d-1* steps from there plus the fraction of value added of firm *1* supplied to firm *3* that takes another *d-1* steps from firm *3* onwards.

Mathematically, this can be written as

$$p_{1,j} = \sigma_{12} p_{2,j-1} + \sigma_{13} p_{3,j-1} \tag{5}$$

Just like the distribution of output over the steps embodied in final demand for each sector in the economy can be calculated using a sequence of recursive linear equations, the distribution of the steps taken by value added to reach final demand is also determined by a recursive system of linear equations.

A new dimension to address old questions

What is the benefit of considering the two concepts that we introduced above? First and foremost, both of our concepts allow us to map a complicated non-linear supply chain structure into terms that can be interpreted in a one-dimensional sense. That is, if the distance from final demand for a firm increases, then it means that that firm is moving up the supply chain, away from final demand. If the steps embodied in the output of a firm increase, then this captures that the value of the product is added further up the supply chain.

Hence, our concepts of *steps embodied in final demand* and *distance from final demand* allow us to apply our terminology of upward and downward shifts in activity along the supply chain to much more complex supply chains than the linear one we started off with in our first example. It is important to realize that both of our concepts generate a distribution over steps rather than a single number. This is to take into account the many paths a dollar can take along the complex non-linear supply chain.

Having an empirical measure of upward and downward directions in the aggregate supply curve gives us an empirical glimpse at the mechanism that is central to several important economic theories.

First and foremost, there is Adam Smith's (1776) classic assertion that he division of labor is limited by the extent of the market. Stigler (1952) and modern trade theory, among which Yi (2003), emphasize how increases in the size of the market can lead to the specialization of firms and countries in particular parts of the production process. If such a vertical specialization of firms is a predominant force in certain sectors in the U.S. economy, then we should observe a trend in distance from final demand for these sectors. An increasing number of steps in the supply chain is also what is implied by the growth models by Baumgartner (1988) and Kremer (1993).

Secondly, it has been argued that the outsourcing by manufacturing to business services has been an important source of productivity growth in the U.S. manufacturing sector in the past two decades. Ten Raa and Wolff (2001) claim that this process accounts for a third of manufacturing productivity growth in the 1980s and '90s. Ono (2001) presents evidence that suggests that the degree to which this outsourcing takes place is actually limited by the size of the local market that the manufacturers operate in.

Finally, several industry studies have documented marked changes in industry specific supply chains. On the aggregate level, the reduction in inventory to sales ratios, which has been documented among others by McConnell and Perez-Quiros (2000), also suggests that the past two decades has seen substantial changes in the relationships between firms and their suppliers. Brynjolfsson and Hitt (2000) argue that it is information technology that facilitated these changes in the relationship between firms and their suppliers. Gates and Hemingway (1999) contains several examples of how information technology has reshaped the organization of the supply chain for several of the largest U.S. companies.

In spite of all the evidence provided at the industry level and by many anecdotes, whether changes in the U.S. supply chain are an anomaly or are an essential part of the dynamics of the U.S. economy remains is a virtually unexplored question. The reason for this is that answering this question requires mapping U.S. economic data into interpretable descriptive statistics of the U.S. supply chain. In the next section, we show how measures of the two concepts that we introduced above can be distilled from the U.S. input-output tables and be used to provide such descriptive statistics.

3. Using input-output tables to map the U.S. supply chain

In the examples in the previous section we considered the supply chain of a simple economy that consists of three firms. The U.S. economy is obviously a much more complex entity consisting of millions of firms. Unfortunately, economic data on transactions between individual firms are unavailable. In fact, the lowest level of aggregation at which we can get data on the interaction between businesses in the U.S. economy are the input-output tables, which report these interactions for sectors.

In this section we explain the way in which we use the U.S. input-output tables to calculate the *steps embodied in final demand* and the *distance to final demand* for each of the sectors of the U.S. economy in the tables. We do so in four steps. In the first step we explain the major difference between considering the sectors from the input-output tables rather than the firms from our stylized example. In the second step we show how our two concepts can be measured using the IO-tables. We use the third step to show how these measures can be matched with indicators of economic activity and transformed to reflect the supply chain at different levels of aggregation. Finally, we discuss some of the limitations of this approach, including some of the steps along the supply chain that this method does not capture.

In this section, we limit ourselves to the relevant transformations and main results. The details of our transformation of the IO-tables can be found in Appendix B.

From firms to sectors and from closed to open economy

The examples in the previous section considered a closed economy for which we observed the inputs and output of each firm. The U.S. economy is neither a closed economy nor do we observe the inputs and outputs of all its firms. We do observe the inputs and outputs of each sector. Furthermore, we can match up measures of international trade with the IO-tables. Before we proceed, it is important to illustrate how our concepts apply to an open economy for which we only have input-output data for sectors.

To see how the use of sectors rather than firms and how taking into account the fact that imports flow into the U.S. supply chain affect our analysis consider Figure 3. Figure 3 differs from Figure 2, used in our example in the previous section, in two important ways.

First of all, *firms* 1 through 3 have been replaced by *sectors* 1 through 3. This has an important implication. Namely, firms do not sell to themselves. Sectors, however, consist of a collection of many firms.

Many of these firms supply output to each other. Car parts manufacturers provide parts to car manufacturers for example. Both are part of the same sector in the IO-tables, namely 'motor vehicles and equipment'. For this reason, Figure 3 includes ω_{ii} for $i=1,...,3$. This variable represents the sales of output between firms in sector i.

Because we take into account both inter- as well as intrasectoral sales of output, we do measure steps that value added takes along the supply chain within sectors as well as between sectors.

The second main difference between Figures 2 and 3 is that the latter accounts for the use of imports as intermediate inputs by the various sectors of the economy. Imported intermediate inputs are often ignored in input-output analysis. For our analysis here, however, they turn out to be crucial to understand some of the recent supply chain dynamics.

Imports turn out to be only important for the steps embodied in final demand. For steps embodied in final demand, we treat imports as essentially another sector that supplies its intermediate inputs to U.S. sectors that then produce for final demand. Because we focus solely on the U.S. supply chain in this paper, we do not account for imports that directly flow to U.S. consumers or U.S. firms in terms of capital goods. This treatment of imports implies that they only embody value that has taken two steps or more to reach U.S. final demand.

We can now apply the same reasoning as in the previous section to derive systems of linear recursive equations that allow us to solve for the distributions of steps embodied in final demand and distance from final demand.

Similar to the previous section, let $\pi_{i,q}$ denote the fraction of final demand of sector i that embodies q steps along the supply chain. Furthermore, let $p_{i,d}$ be the fraction of value added of firm i that is d steps away from final demand. ω_{ij} is the amount of intermediate inputs that sector i uses from sector j and f_i is the amount that sector i sells to final demand. Additionally, m_i is the amount of imports that sector i uses as intermediate inputs.

We can write the nominal gross output of sector i, which we denote by y_i, in two ways. The first is as the sum of its sales to final demand and its sales of intermediates to other sectors. The second is as the sum of its value added and its own intermediate inputs bought from both the domestic sectors as well as abroad. This boils down to the identity

$$y_i = f_i + \sum_{j=1}^{n} \omega_{ij} = v_i + \sum_{j=1}^{n} \omega_{ji} + m_i \tag{6}$$

where we have assumed that there are n sectors in the economy. This identity is equivalent to (1) from the previous section.

Again, we use the second part of this identity to derive the *steps embodied in final demand*, i.e. to derive $\pi_{i,q}$. A fraction $s_{i,v}=v_i/y_i$ of every dollar that sector i produces is directly attributable to its own value added and thus embodies one step from final demand. This means that we can initialize our recursion with the realization that

$$\pi_{i,1} = s_{i,v} \text{ for } i=1,...,n \tag{7}$$

The fraction of nominal output of sector i that travels two steps consists of two parts. First there is the part that comes from another sector and had traveled one step to get to that sector. The second is the fraction gross output of sector i that consists of imported intermediates.

Let $s_{i,j}=\omega_{j,i}/y_i$ be the be fraction of sector i's output that consists of intermediate inputs from sector j, i.e. it is sector i's factor share of inputs from sector j. Let $s_{i,m}=m_i/y_i$ be sector i's factor share of imported intermediates. Then the above reasoning implies that we can write

$$\pi_{i,2} = \sum_{j=1}^{n} s_{i,j}\pi_{j,1} + s_{i,m} \text{ for } i=1,\dots,n \tag{8}$$

This is the part of our recursion that takes into account the insertion of imported intermediates into the supply chain.

For the derivation of $\pi_{i,q}$ for $q>2$ we do not directly have to take into account the imported intermediates anymore, because they are contained in the $\pi_{i,2}$'s. That is, $\pi_{i,q}$ for $q>2$ in the case of our open economy can be written in terms of the same recursive equations as in the case of the closed economy example in the previous section. The fraction of nominal output of sector i that travels $q>2$ steps equals the part that comes from another sector and had traveled $q-1$ steps to get to that sector. This can be written, mathematically, as

$$\pi_{i,q} = \sum_{j=1}^{n} s_{i,j}\pi_{j,q-1} \text{ for } i=1,\dots,n \tag{9}$$

which completes the recursion necessary to calculate $\pi_{i,q}$ for $i=1,\dots,n$ and $q=1,\dots,\infty$.

Note that $\pi_{i,q}$ represents the fraction of final demand of sector i that can be attributed to either value added in any of the U.S. sectors as well as imported intermediates q steps upstream. It is possible and, as it turns out, informative, to decompose $\pi_{i,q}$ into the parts attributable to the value added produced by specific U.S. sectors, as well as the part attributable to imported intermediates.

That is, let $z_{i,j,q}$ be the fraction of final demand of sector i that can be attributed to value added generated by sector j, q steps upstream. Furthermore, let $z_{i,m,q}$ be the fraction of final demand of sector i that can be attributed to imported intermediates flowing into the supply chain q steps upstream. These variables allow us to write

$$\pi_{i,q} = z_{i,m,q} + \sum_{j=1}^{n} z_{i,j,q} \tag{10}$$

This decomposition is useful because it allows us to pinpoint exactly where particular inputs flow into the supply chain of a particular sector and what fraction of that sector's final demand they make up. The details of the derivation of both $z_{i,j,q}$ and $z_{i,m,q}$ are in Appendix B.

The recursive equations for the $p_{i,d}$ are the same for our open economy with sectors as for our closed economy example with firms. That is, the fraction of value added of sector i that flows directly to final demand and takes the minimum of one step along the supply chain is equals the fraction of output sold to final demand. We will denote this fraction by $\sigma_{i,f}=f_i/y_i$. This notation allows us write

$$p_{i,1} = \sigma_{i,f} \text{ for } i=1,\dots,n \tag{11}$$

which is the initialization of our recursion.

The fraction of value added of sector *i* that takes *d* steps to reach final demand equals the fraction of output of sector *i* that is sold to other sectors and then takes another *d-1* steps to reach final demand. This is captured by the equation

$$p_{i,d} = \sum_{j=1}^{n} \sigma_{i,j} p_{j,d-1} \text{ for } i=1,\ldots,n \tag{12}$$

Here $\sigma_{i,j}=\omega_{i,j}/y_i$ denotes the fraction of output of sector *i* sold as intermediate input to sector *j*.

The next step is to consider how to implement the above recursive equations using data from the U.S. input-output tables.

Measuring the steps embodied in and distance from final demand

The implementation of the recursive equations (7), (8), (9), (11), and (12) requires the measurement of $s_{i,j}$ and $\sigma_{i,j}$ for $i=1,\ldots,n$ and $j=1,\ldots,n$, as well as the measurement of $\sigma_{i,f}$, $s_{i,m}$, and $s_{i,v}$ for $i=1,\ldots,n$.

Fortunately, the U.S. input-output tables contain data on the sales of intermediate inputs between sectors, i.e. our ω_{ij}'s, as well as data on the levels of nominal output, y_i, value added, v_i, and supplies to final demand, f_i. These data, in principle, allow us to calculate $\sigma_{i,j}$, $\sigma_{i,f}$, and $s_{i,v}$. The problem is that U.S. input-output tables do not distinguish between imported intermediate inputs and those supplied domestically. We impute the amount of imputed intermediates, i.e. m_i, on the basis of three simple assumptions. Because this imputation involves lots of detail on the input-output tables, we explain it in Appendix B.

Given the measures we obtain for the above shares, we can implement the two recursions implied by (7), (8), (9), (11), and (12). Since these recursions are all in terms of linear equations, they are most easily expressed in matrix notation. The relevant matrices for this purpose are the following.

First of all, we define vectors containing $\pi_{i,q}$ and $p_{i,d}$ for each of the sectors. That is, let

$$\boldsymbol{\pi}_q = \begin{bmatrix}\pi_{1,q} & \cdots & \pi_{n,q}\end{bmatrix}' \text{ and } \mathbf{p}_d = \begin{bmatrix}p_{1,d} & \cdots & p_{n,d}\end{bmatrix}' \tag{13}$$

In principle, both *q* and *d* run from *1* to ∞. In practice, however, we can not report on an infinite number of the vectors above. Therefore we truncate the sequence of these vectors by combining all of them for *q* and *d* bigger than a number of steps. That is, we define

$$\boldsymbol{\pi}_{\geq\bar{q}} = \sum_{q=\bar{q}}^{\infty} \boldsymbol{\pi}_q \text{ as well as } \mathbf{p}_{\geq\bar{d}} = \sum_{d=\bar{d}}^{\infty} \mathbf{p}_d \tag{14}$$

Secondly, we combine the value added shares of output, $s_{i,v}$, as well as the factor shares of intermediate imports, $s_{i,m}$, and the shares of output flowing to final demand, $\sigma_{i,f}$, into the following vectors.

$$\mathbf{s}_v = \begin{bmatrix}s_{1,v} & \cdots & s_{n,v}\end{bmatrix}', \ \mathbf{s}_m = \begin{bmatrix}s_{1,m} & \cdots & s_{n,m}\end{bmatrix}' \text{ and } \boldsymbol{\sigma}_f = \begin{bmatrix}\sigma_{1,f} & \cdots & \sigma_{n,f}\end{bmatrix}' \tag{15}$$

Finally, we define the matrices with factor shares, $s_{i,j}$, and sales shares, $\sigma_{i,j}$. These are

$$\mathbf{S} = \begin{bmatrix} s_{1,1} & \cdots & s_{1,n} \\ \vdots & \ddots & \vdots \\ s_{n,1} & \cdots & s_{n,n} \end{bmatrix}' \text{ and } \mathbf{\Sigma} = \begin{bmatrix} \sigma_{1,1} & \cdots & \sigma_{1,n} \\ \vdots & \ddots & \vdots \\ \sigma_{n,1} & \cdots & \sigma_{n,n} \end{bmatrix}' \tag{16}$$

The above matrices allow us to write the recursion of equations (7), (8), and (9), that determines the distribution of the steps embodied in final demand, as follows

$$\boldsymbol{\pi}_q = \begin{cases} \mathbf{s}_v & \text{for} \quad q = 1 \\ \mathbf{S}\boldsymbol{\pi}_{q-1} + \mathbf{s}_m & \text{for} \quad q = 2 \\ \mathbf{S}\boldsymbol{\pi}_{q-1} & \text{for} \quad q = 3, \ldots, \infty \\ \boldsymbol{\iota} - \sum_{q=1}^{\bar{q}-1} \boldsymbol{\pi}_q & \text{for} \quad q = (\geq \bar{q}) \end{cases} \tag{17}$$

where $\boldsymbol{\iota}$ denotes a column vector of ones.

The recursion used to calculate the distribution of distance from final demand can be written as

$$\mathbf{p}_d = \begin{cases} \boldsymbol{\sigma}_f & \text{for} \quad d = 1 \\ \mathbf{\Sigma}\mathbf{p}_{d-1} & \text{for} \quad d = 2, \ldots, \infty \\ \boldsymbol{\iota} - \sum_{d=1}^{\bar{d}-1} \mathbf{p}_d & \text{for} \quad d = (\geq \bar{d}) \end{cases} \tag{18}$$

which is remarkably similar to the recursion for $\boldsymbol{\pi}_q$ of equation (17).

The reason that both of these recursions are so similar is because they can both be interpreted in the same way in terms of discrete time Markov chains. To illustrate the common interpretation of both concepts, we start off by showing how the *distance to final demand* can be interpreted in terms of Markov chains. We then show how the concept of *steps embodied in final demand* has a similar interpretation.

Distance from final demand measures the steps that a dollar of value added generated in a particular sector of the U.S. economy takes along the supply chain before it reaches final demand. Let's consider a dollar of value added for sector i. This dollar moves to final demand, and leaves the supply chain, in the next step with probability $\sigma_{i,f}$. However, with probability $\sigma_{i,j}$ it remains in the supply chain and moves to sector j. From sector j on the path of the dollar of value added is determined in turn by $\sigma_{j,f}$ and $\sigma_{i,k}$ for $k=1,\ldots,n$.

In this sense, one can interpret the sector where a dollar is along the supply chain as the *state* of that dollar and the supply chain itself as a Markov chain. Final demand is also a state in this chain. It is a very special one, however, since a dollar that reaches final demand will not flow back to the sectors in the supply chain. In Markov chain terminology, final demand is known as an absorbing state. The shares $\sigma_{i,f}$ and $\sigma_{i,j}$ can simply be interpreted as the transition probabilities that determine the path of a dollar moving down the U.S. supply chain towards the absorbing state of final demand.

Given this interpretation, $p_{i,d}$ is the probability that a dollar flows from sector i to final demand in d steps. It is the d-step transition probability from sector i to final demand. The equation that determines multi-step transition probabilities in discrete time Markov chains is known as the Chapman-Kolmogorov equation. Thus, the recursion of equation (18) is a form of the Chapman-Kolmogorov equation.

The recursion in (17) is similar to (18) because it can also be interpreted as a form of the Chapman-Kolmogorov equation. This is because $\pi_{i,q}$ can be considered a q-step transition probability. To see why, consider a dollar of output of sector i. With probability $s_{i,v}$ this dollar was added in value in sector i itself and did not come from further up the supply chain. With probability $s_{i,m}$ this dollar came from imported intermediates one step up the supply chain from sector i. With probability $s_{i,j}$ this dollar was part of output of sector j one step up the supply chain.

Again, we can interpret the sector where a dollar is along the supply chain as the *state* of that dollar and the supply chain itself as a Markov chain. Contrary to for $p_{i,d}$, in this case we track the movement of the dollar *up* the supply chain rather than *down*. Here, being part of value added is also a state. This is a special state, since a dollar that is part of value added of a sector does not come from further up the supply chain. Hence, value added is the absorbing state here. The second absorbing state is imports. That is, a dollar that is part of imports does not flow any further up the U.S. supply chain either. The shares $s_{i,v}$, $s_{i,m}$, and $s_{i,j}$ in this case represent the transition probabilities of a dollars origin up the supply chain.

We can interpret $\pi_{i,q}$ as the probability that a dollar of output for sector i originated in terms of value added of imports q steps up the supply chain. In the context of our imports Markov chains, this is the q-step transition probability from sector i to the state of value added.

Matching results with indicators of economic activity

So far, our focus has been on the derivation of the distributions of *steps embodied in final demand* and *distance to final demand*. These distributions provide us with a measure of where in the supply chain value added embodied in products is generated and how far up the supply chain a sector is located.

However, we are not interested in sectors themselves but in the economic activity associated with them, jobs and dollars. Hence, measuring economic activity along the supply chain requires matching measures of sector-specific economic activity with our estimates of steps embodied in and distance from final demand.

In this paper, we focus on two dimensions of economic activity, namely nominal value added and employment. For the latter, we distinguish between overall employment and occupational employment.

In principle, our measures $p_{i,d}$ and $\pi_{i,q}$ already give a distribution of value added of sector i over the supply chain. Because the IO-tables that we use contain more than 150 sectors, studying these distributions for each sector separately is a Herculean task. For this reason, we need a method to aggregate our results over different groups of sectors. Let G denote the set of sectors that make up such a group, then we calculate

$$\pi_{G,q} = \sum_{i \in G} \pi_{i,q} f_i \Big/ \sum_{i \in G} f_i \quad \text{and} \quad p_{G,d} = \sum_{i \in G} p_{i,d} v_i \Big/ \sum_{i \in G} v_i \tag{19}$$

Here, we weigh $\pi_{i,q}$ by final demand because we are interested the steps embodied in that part of nominal output that flows to final demand. The distances from final demand are weighed by value added because these distances represent the distance of dollars of value added of each sector from final demand.

On the employment side, we consider where along the supply chain people are employed. To answer this question, we match our results on distance from final demand up with data on sectoral employment levels[2]. Let n_{io} be the number of employees with an occupation *o* in sector *i*. Let $v_{0,d}$ be the fraction of workers of occupation *o* employed *d* steps from final demand, then we calculate

$$v_{o,d} = \sum_{i=1}^{n} p_{i,d} n_{i,o} \Big/ \sum_{i=1}^{n} n_{i.o} \tag{20}$$

This is basically the occupational distribution of distance from final demand. The total employment distribution is just a weighted average of these distributions over all the occupations.

Even though we only focus on current dollars and jobs in this paper, it is easy to see how the above aggregation method can be used to measure the location of many other dimensions of economic activity along the supply chain, like inventories, productivity growth, etc.

Limitations of the methodology

Normally, the limitations of the empirical approach taken in a paper are discussed after the results are presented. In this paper we introduce the new concept of steps along the supply chain. In order to put our results in the right perspective, it is important to discuss the steps that are not captured by our method before we present our results. Since the emphasis in this subsection is on the downside, we will simply focus on the steps that we are not able to measure. There are two important types of steps that we are not able to capture here.

The first are steps between manufacturers and retailers, wholesalers, as well as the transportation sector. Input-output tables do not count the goods that retailers and wholesalers buy and subsequently sell as intermediate inputs to these sectors. Only goods that are 'used' in the production process of these sectors are counted as intermediates. It is easiest to consider this in an example. Suppose RCA produces a TV in the U.S. and sells it to Wal-Mart for \$100. Wal-Mart, in its turn, turns a sticker into a \$110 price-tag and subsequently sells the TV at that price. In this case, nominal output of RCA supplied to final demand is the \$100 at which it sold the TV to Wal-Mart, while Wal-Mart's supply to final demand is the \$10 that it adds in value to the TV. That is, because Wal-Mart does not change the physical characteristics of the TV it is not accounted for as an intermediate input in its production process. The sticker on which the price-tag is printed is an intermediate input, since it is converted into a price-tag during the production process.

Because of this definition of intermediate inputs used in the input-output tables, our method does not capture steps from producer to transportation to retailers. The produced goods are accounted for as directly supplied to final demand, in spite of them changing hands on their way to their consumer. These changes of hand go unmeasured.

The second type of steps along the supply chain that go unmeasured using our method are intermediate steps that are done abroad. For example, consider the production of a Motorola cellphone. The phone is assembled in the U.S. out of intermediate inputs produced abroad. Such intermediate inputs are accounted for

[2] A description of our employment data sources can be found in Appendix A.

in our method as having traveled two steps if the phone is sold to final demand. However, some of these intermediate inputs that are imported might themselves contain intermediate inputs that are produced in the U.S.. Hence, they actually embody more than the one step along the U.S. supply chain that we count them for.

The problem is that we simply can not track the path of U.S. exports once they go abroad. Hence, we are not able to account for what part of U.S. imports embodies value added that can be traced back to previous steps along the U.S. supply chain.

In spite of these limitations, our methodology still allows us to trace the path of intermediate inputs through the U.S. economy in a way that reveals important characteristics of the U.S. supply chain. It is just important to bear these limitations in mind when interpreting our results in the next section.

4. Empirical results

Figures 4 and 5 provide a characterization of the aggregate U.S. supply chain according the "distance from final demand" and "steps embodied" concepts described above. Figure 4, the "distance" measure, plots steps from final demand against the percentage of economy wide value added (GDP). We plot the distributions for the years 1983, 1987, 1992, 1997 and 2000, since these correspond to the benchmark I-O tables[3]. Looking first at the shape of the distribution in 1983, we can interpret the bars as the fraction of a dollar of aggregate value added that traveled a particular number of steps before reaching final demand. So, in 1983, about sixty-one cents of each dollar of value added was only one step from final demand. The finding that much of the value added is generated immediately before a good goes to its final use is unsurprising. For example, a machine tool manufacturer generates a considerably larger share of the value added of the machine tool than does the steel manufacturer. On average, we find that between 60-70% of value added is generated in that final step. This observation regarding the shape of the distribution of value added across the supply chain holds in every year in our sample.

Turning now to a comparison of the changing shape of the distance distributions over time, we find that there has been a slight shift in value added toward a larger fraction being generated only one step from final demand[4]. Since the behavior of aggregate value added may mask changes that are taking place within sectors, it is useful to examine the disaggregate distributions as well and we do this below.

Figure 5 plots the "embodied" distributions for the aggregate economy over time. The height of the bars is interpreted as the fraction of a dollar of final demand that embodies a particular number of steps. Note again that the general shape of the distribution is such that most of final demand embodies only one step. Here it is difficult to discern any change in the distribution over time. In other words, a dollar of final demand in 2000 embodies roughly the same number of steps as did a dollar of final demand in 1983.

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[3] 1983 is not actually a benchmark year, we use it because we do not have any data for the benchmark year 1982.

[4] At this stage our analysis does not allow us to say anything about the whether a particular change in the distribution is statistically significant, so we will proceed only with qualitative comparisons.

Distance from Final Demand – A Look at the Sectors

Figures 6 through 8 show the distributions of value added in the non-manufacturing sectors, the non-durable manufacturing sector and the durable manufacturing sectors respectively. These plots uncover some heterogeneity in the changes across sectors over time. We can see from Figure 6 that there appears to be a slight tendency for distance from final demand to decrease in the non-manufacturing (measured here as services, transportation, utilities, communications and FIRE), while there is no strong tendency over time for distance to change in nondurable manufacturing (Figure 7). Figure 8, however, reveals a tendency for distance to increase in the durable manufacturing sector. In particular, we see that the fraction of value-added generated in the step prior to final demand in 2000 has fallen relative to all the other years in our sample, while the fraction generated in steps further from final demand has risen relative to past years. It appears that the largest offsetting increases in value-added occurred at steps 2 and 3, rather than at steps larger than 3. A shift upstream in value added such as this could reflect a number of phenomenon, including more outsourcing by downstream industries or changes in the production process that reflect changes in the underlying composition of goods being produced. At this stage we are simply characterizing the movements in the distribution over time, and further work is needed to attach an interpretation to these movements.

Finally, it is also interesting to compare the shape of the distributions for the durable and nondurable manufacturing sectors to the shape for the economy as a whole shown in Figure 4. While we still find that the largest share of value-added is generated closest to final demand, there is also a sizable fraction of value-added that is created two steps away from final demand. On the other hand, the distribution of non-manufacturing looks virtually identical to the economy-wide distribution.

We can compute similar distributions for each of the three-digit durable and non-durable industries in our data set. The results are striking, and largely corroborate the aggregate findings. As a first pass, we compare the distributions in 2000 with the distributions in 1983. Starting first with the 58 durable goods industries in our sample, we find that only 28 showed an increase in the share of value-added that was generated one step from final demand, and the same number showed an increase in the share generated two steps from final demand. The number of industries reporting increases reaches a maximum of 41, at steps 5 and 7, though 36 are still showing increases at step 11. This indicates that the shift in the proportion of value-added being generated further up the supply chain is a fairly widespread phenomenon across the durable goods sector. The nondurable industries paint a slightly different picture. We see 29 out of 40 industries showed an increase in the share of value-added generated at the step immediately before final demand. However, there is a significant drop off to only 14 and 17 industries showing in increase in the share of value-added at steps 2 and 3, respectively, after which the number levels off to approximately 25 industries showing a greater share of value added generated upstream.

Steps Embodied in Final Demand – A Look at the Sectors

As was noted above, the aggregate data reveal no obvious movements in the number of steps embodied in a dollar of final demand over time. Figures 9 through 11 show the steps embodied by broad sector of the economy, as shown above for distance. Figure 9 shows that there is little movement in the distribution of steps embodied in non-manufacturing final demand, and this is consistent with the behavior of the aggregate economy. In Figure 10, however, we see that there has been a tendency toward non-durable manufacturing final demand embodying fewer steps over time. In 1983, 30 cents of every dollar of non-manufacturing final demand embodied only one step, and approximately another 30 cents embodied two steps. In 2000, however, over 40 cents of every dollar embodies only one step, and again, about 30 cents embodies two steps. Looking at steps greater than 2, we see that the increase in the fraction of a dollar that embodies only one step was met by a decrease in the fraction taking 3 or more steps (the fraction taking two steps was roughly constant). One potential interpretation of this finding is that the supply chain for nondurable goods has shrunk over time. Figure 11 shows the steps embodied in durable final demand, and here we see a slightly different picture. There has been a subtle tendency for the fraction embodying only one step to decline over time, while the fraction embodying 2 steps has risen. It is difficult to discern any clear pattern for steps larger than 2. One interpretation of this picture is that the supply chain for output of the durable goods sector has lengthened somewhat over time, though the most "action" occurs in the shares taking one or two steps, rather than in the longer steps.

To understand what is going on in each of these sectors, we redid this exercise at the four-digit industry level within manufacturing durables and nondurables. The findings suggest that the conclusion we draw from the aggregate pictures are borne out at the industry level as well. In particular, of the 39 nondurables industries for which we computed these distributions over time, 38 show an increase in the share of final demand that embodied only one step (only tobacco had a decrease), 32 had an increase in the share of final demand that embodied only two steps, while only one industry (pharmaceuticals) show an increase in the share for steps 3 to 11. Thus there is a clear picture of nondurables output embodying fewer steps now than before, implying perhaps that there is less outsourcing (or greater horizontal integration) taking place in this industry. Before reaching such a conclusion, however, we need to consider carefully how international trade may affect our calculations and hence our interpretation. This will be discussed in detail below.

In contrast, the calculations for the durable industries suggest that the aggregate tendency for durables output to embody more steps now than before is evident within many industries. We can see this in two ways. First, we examine how many industries experienced an increase in the share of their final demand that embodied only one step. Of the 58 four-digit industries we examined 14 had a drop in the share that embodied one step, and it is informative to list the industries for which this is the case.

- Wood buildings and mobile homes
- Computer and office equipment
- Electrical industrial apparatus
- Household audio and video equipment
- Communications equipment
- Electronic components and accessories
- Miscellaneous electrical equipment
- Motor vehicles and equipment
- Ship and boat building and repairing
- Search and navigation equipment
- Measuring and controlling devices

- Medical equipment, instruments and supplies
- Watches, clocks and parts

Many of these industries are generally considered part of the tech sector. 46 industries had their share of final demand embodying two steps go up. The number that saw an increase in their share of final demand embodying 3 or 4 steps drops to 14 and 12, respectively, while the number seeing an increase in the share embodying 6 or more steps (out to 11) levels off at around 40 out of 47. Thus, while there was a fairly widespread tendency for the share of final demand embodying only one step in the durables sector to grow (though the tendency is not nearly as widespread as in the nondurables sector), there is also an important tendency for the share embodying 5 or more steps to grow as well. We observe no such tendency in the nondurables sector.

Steps Embodied in Final Demand – The Role of Imports

As noted in Section 3 above, one has to be careful to account for imported intermediate inputs in counting steps embodied in final demand. Our analysis treats "imports" as its own sector that supplies intermediate inputs to domestic sectors producing for final demand[5]. Implicit in this treatment, is the assumption that imports only embody value that has taken two or more steps to reach final demand. When we are counting steps, as we did in Figure 5 for the aggregate economy and Figures 9 through 11 for the sectors, we are counting steps embodied in the output of sectors that used these imported intermediate inputs that by assumption traveled 2 or more steps. Thus these pictures do not give us a feeling for how many steps are embodied in the fraction of final demand that can be attributed only to domestically produced value added. In order to gauge how much the inclusion of imported intermediate inputs is affecting the number of steps embodied, we can essentially calculate the fraction of final demand due to value added from the "imports" sector for each step, and then remove this fraction from our calculations.

It turns out that making this change to the analysis has an important effect on the results, and for clarity of exposition, we'll show both steps of the process. First, Figures 12 through 15 show where along the supply chain imports contribute to aggregate, nonmanufacturing, nondurable manufacturing and durable manufacturing final demand, respectively. There are a few things to notice about these figures. First, in all cases, imports do not contribute to final demand that travels only one step (this is by construction). Second, most of the value added from this sector occurs at step 2 rather than at higher steps. Finally, in some sectors, there has been a shift in the shape of this distribution over time. Namely, all industries reflect a pronounced tendency for the value added of the import sector to flow downstream—i.e, the difference between height of the bars at steps 2 and 3 in 2000 is larger than the difference between the height of the bars at steps 2 and 3 in 1983. One potential interpretation of this is that the U.S. is importing more final goods now than before. The phenomenon is most pronounced in the aggregate, nonmanufacturing and durables sectors, but is evident in nondurables as well.

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[5] Recall that imports of final goods are excluded from our analysis since we are interested in characterizing the supply chain that produces the output of domestic industries.

It is possible to adjust the steps embodied calculations so that we are counting steps only for domestically produced value added. These adjusted distributions are shown in Figures 16 through 19. To make the interpretation of these charts comparable to the others, we have normalized by the final demand produced only by domestic factors rather than the final demand concept used in the earlier charts (recall that while the final demand concept used in earlier charts does not include imported final goods, it does include the value added generated by imported intermediates. The concept used in these normalized charts, then, does not include either). The result that nondurable output tends to embody fewer steps now than before is unchanged by the import adjustment, as is the result that there is little tendency for aggregate or nonmanufacturing steps to change. What does change a bit, however, is our previous result indicating that durables output (in the aggregate) tends to embody more steps now than before. The adjusted distributions do not reveal any tendency for the number of steps embodied in durables final demand move in one direction or the other over time.

Employment Along the Supply Chain

In this section, we compute the distribution of employment in the aggregate and across sectors for distance from final demand. The way to think about this exercise is as being identical to the one for value-added above, except that we are interested in analyzing employment shares rather than value-added shares. Figure 20 reports the results for the aggregate economy. These look similar to those we obtained for the value-added exercise in that this is little evidence of any shift in the share of employment along the supply chain. Also, we note that the distribution of employment at any point in time looks similar to the distribution for value-added in that the bulk of employment occurs in the activities that take place only one step from final demand. Again, this is largely related to the importance of the service sector in aggregate employment data.

When we turn to the more disaggregated data, the picture changes slightly. In Figure 23, we find that there has been a tendency for employment in the durables manufacturing sector to locate more upstream over time. We can see this by noting that the height of the bar at step 1 is lower for 2000 than in all other years, while the height of the bar at step 2 for 2000 is higher than in all other years. We observe no such tendency in either the non-durable manufacturing sector or in the non-manufacturing sector (Figures **22** and 21).

The results we've presented to this point allow us to paint a picture of the changes in the US supply chain using a broad brush. That picture, with a few important exceptions, is one of relative constancy. In particular, we don't notice that aggregate or broad sector final demand embodies significantly more steps now than it used to, and in fact it appears to go in the other direction. This would suggest that the supply chain, as considered from the vantage point of steps embodied, has not changed very much over time at the aggregate level. From the vantage point of distance from final demand, we have captured a little more variation across sectors. In particular, it does appear that the durable good sector generates value added further upstream now than it used to, while we don't find that in the rest of the economy.

Also, when we examine these phenomena at the two-digit level, we begin to uncover more movement over time, both in the durable and nondurable sectors. The durables industries show a tendency for both steps embodied and distance to rise over time. In the nondurables industries, there is a tendency for distance to rise in the sense that more industries show more "mass" at the steps greater than 5 now than did before, however, it is also true that most nondurable industries showed an increase in the fraction of value added generated only one step from final demand. There is a also a clear tendency for nondurables output to embody fewer steps now than before.

Where did the changes occur over the last two decades?

One drawback to the aggregate and broad sector analysis considered above is that we cannot account for changes in the composition of output over time that might affect our results (in other words, the supply chain could be changing in an important way, but the composition of goods could be changing in a way that offsets it in the aggregate data). Also, the aggregate analysis may simply mask a phenomenon that is taking place but does not in the end (or yet) have important implications for aggregate behavior. In order to address these shortcomings of the aggregate analysis, in this section we present results from a more targeted effort to determine whether and where there have been important changes in the supply chain. We begin by taking the broad components of final demand (durables consumption, nondurables consumption and investment) rather than using aggregate final demand, and asking sector by sector whether there has been a change in either the value added of the domestic sectors to these components of demand, and whether there has been a change in *where* the value added is generated along the supply chain.

Table 1 shows the contribution of value added, by broad components of final demand and by individual goods, for each of the broad sectors of the economy for the years 1983 and 2000[6]. We chose our sectors in such a way as to focus on sectors for which we might expect some change in their value added or position along the supply chain. For example, we look at "services ex business services" and "business services ex personnel supply services" and "personnel supply services" all separately because there is an abundance of anecdotal evidence that these sectors are increasingly sectors to which firms outsource tasks that they would have previously done themselves. The top panel lists the broad components, while the bottom panel lists individual goods. The goods listed here are just a sample chosen to give us a feel for how the data look at the disaggregate level.

Looking first in the top panel at durable goods PCE, for example, we see that the contribution of value added of manufacturing durable goods is around 29% in 1983, and drops to 20% in 2000. On the other hand, the personnel services share of value added almost triples over that time period (albeit the contribution of this sector to durables PCE is considerably smaller than the contribution of durables manufacturing). There is also a substantial increase in the contribution of "business services ex personnel supply services" to value added in durable goods PCE, though virtually no change in the contribution of "services ex business services". Turning to the bottom panel, we can examine the shares of value added of an individual good such as new autos. Here we see virtually no movement in the shares of value added by any of the sectors except for the personnel services and "business services ex personnel".

It is striking to note that personnel services contribution generally increases by a factor of three or four for each of these individual goods and each of the broad service categories. There is also a notable increase in the share of value added contributed by business services ex personnel across each of these goods and

[6] Note that these contributions do not sum to one because the value added of the import sector is excluded.

consumption and investment categories. For instance, the share of "business services ex personnel" in private investment increases threefold, while the share of personnel services increases over fivefold. These increases in shares of value added coming from this sector suggest that at least some of the anecdotal discussion of the increasing importance and breadth of these sectors in the overall economy have some merit.

Our examination of the shares of value added suggested that there have not been significant changes in the shares of value added over time, apart from the changes in the business services sector (and obviously some small offsetting changes in other shares for sectors which account for a much larger share). We can use our analysis to ask whether there have instead been important changes in where along the supply chain the value added of these sectors is generated. The results of this exercise, for the same broad spending categories, individual goods and sectors, are shown in Table 2. For each sector, we compute the share of its value added that embodies a particular number of steps. For example, we know that in 1983 the durable goods sector accounted for 34.59% of value added of new autos. We can take that contribution and ask ourselves what the distribution of steps embodied in that contribution looks like both at a point in time and over time. Looking at Table 2, we see that 53% of durables share of autos value added embodied one step, while 32% of it embodied two steps. Staying with the example of autos, we can also see that there has been an increase in the number of steps embodied in durables value added to autos. Specifically, the share of total value added of the durables sector to new autos that embodies only one step (i.e., is supplied directly to final demand) has dropped from 53% to 47%. This drop in the share embodying only one step is offset by increases in the shares embodying two or more steps. The share of durables value added embodying only one step drops for most of the goods and components of spending we examine. A movement such as this in the distribution of steps embodied is consistent with a story in which durables is outsourcing more of its tasks to other sectors[7].

It is also interesting to examine the behavior of the distribution of steps embodied in the value added of the personnel supply services sector. First of all, we see that this sector rarely supplies to final demand, in fact only in the case of Other PCE, which includes services, and software. Second, there is very little movement in the shape of the distribution of steps embodied for this sector. This makes intuitive sense. This sector is not likely to outsource to other sectors, but instead is likely to be outsourced to. Hence we would not expect to see the distribution of steps embodied in its value added changing over time. Turning from the "embodied" concept back to the distance concept, Figure 24 shows that there has indeed been a shift upstream in the distance of value added of the personnel supply sector. This is consistent with the idea that this sector is being outsourced to more now than before.

As part of our more detailed investigation, we can also look at the location of various occupations along the supply chain. Figure 25 shows this distribution for a few occupations as an intuitive check on our methodology. It is reassuring to note that we find that loggers tend to work upstream, while social scientists and health care professionals tend to work downstream. In future analysis we plan to explore the extent to

[7] Recall that our aggregate analysis above showed no real tendency for the distribution of steps embodied in durables to grow, though the two digit results did reflect such a tendency.

which there have been important movements in the share or position of these occupations along the supply chain.

It is important to note that we view the analysis at this stage as preliminary, and in future work we will examine these issues in a consistent statistical framework in which we can control for factors such as changes in the business cycle over time.

5. Conclusion

We introduced a new methodology that allows us to express the U.S. input-output relationships in terms of steps along the supply chain. This allowed us to consider which U.S. economic activities have moved up and which have moved down the supply chain.

We applied this methodology to a sequence of input output tables that contain 174 sectors of U.S. economic activity for 1983-2000. Doing so allowed us to consider which parts of the U.S. supply chain have been fairly stable and which parts have changed over time.

Our results suggest that, on the aggregate level, the shape of the U.S. supply chain has not changed drastically. However, looking at it so coarsely turns out to blur some of the more interesting details. There are two of these details that specifically stand out from our results. First of all, manufacturing activity seems to have moved upstream. Most importantly, the contribution of business services value added to final demand has more than doubled, with personnel supply services quintupling their contribution and also moving up the supply chain.

The increased reliance of manufacturing sectors on business services, i.e. manufacturing outsourcing to services, has been documented before, like in Ten Raa and Wolff (2001) and Estevao and Lach (1999). However, our analysis suggests that this pattern goes far beyond the manufacturing sector.

In many respects, our results are a first pass at interpreting economic activity along the supply chain. Our methodology is applicable to a much broader range of economic indicators, beyond employment and value added, than that we consider here. Hence, the evidence presented in this paper is only the tip of the iceberg of the issues that our methodology allows us to address.

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A. Data sources

The analysis in this paper uses three datasets: the Input-Output (IO) accounts, the Current Employment Statistics (CES), and the Occupational Employment Statistics (OES), all from the Bureau of Labor Statistics. The following is a description of this data.

Input-Output Accounts

The BLS imputes annual Input-Output tables for 1983 to 2000 from the benchmark tables provided by the BEA and from national accounting measures. This paper uses the annual nominal Make, Use and Final Demand tables in order to compute value added, final demand and distance measures. These tables are explained in Chentrens and Andreassen (2003)[8].

Current Employment Statistics

The CES data is used in order to obtain total employment in the overall economy as well as employment in individual sectors. As the current CES is calculated using NAICs codes, this analysis uses the discontinued National Employment, Hours, and Earnings tables, which are calculated in SIC codes, but only contain data until 2003[9].

Where available, employment in 3-digit SIC sector detail is used. Unfortunately, however, the CES does not contain data for all 3-digit SIC sectors, though it does contain complete data for all 2-digit sectors. Thus where data was not available in 3-digit detail, more aggregated information is used.

In addition, in general, data in the CES is available to 1983 (where this analysis begins) and prior. However, for 10 of the sectors, data is available only after 1988. For the missing 5 years, the employment in these sectors was imputed by assuming that it grows at the same rate as employment in the overall economy.

Occupational Employment Statistics

The OES data is used to calculate the number of workers in different occupations employed in the sectors of the economy. For the years 1988 to 1996, the OES only collected data for industries on a three-year cycle. Therefore occupational data would be available for a particular industry only once every three years. There is no data available for the year 1996, and economy-wide data is available for the years 1997 and 1998. (Subsequent to 1998, the occupational divisions on the survey were changed to reflect the Standard Occupational Codes.)

In order to impute data for the two years that an industry is not included in the three-year cycle, occupational employment within the industry is assumed to grow at a constant rate. This assumption is also made to impute data for the year 1996.

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[8] Additional information on the data can be found at http://www.bls.gov/emp/empind3.htm.

[9] The underlying data for these tables can be found on the BLS website at ftp://ftp.bls.gov/pub/time.series/ee/.

B. Input-Output analysis details

In this section we explain the computational details of the way we transform the input-output tables that we omitted from the main text.

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Table 1. domestic requirements (cents per dollar of final good)

Final goods category	Year	Durable Goods	Nondurable Goods	Services (Ex. bus svcs)	Business Services (Ex. Personnel)	Personnel Services	Trans.	Other
Durable Goods PCE	1983	28.71	11.26	9.13	2.06	0.20	3.30	41.42
	2000	20.27	6.75	9.18	3.07	0.79	2.23	34.38
Nondurable Goods PCE	1983	2.80	22.97	9.27	2.00	0.17	2.99	48.45
	2000	3.81	24.05	11.90	3.19	0.93	2.39	46.43
Other PCE	1983	5.69	2.53	66.88	2.14	0.23	2.62	18.76
	2000	7.14	3.07	71.84	3.26	1.06	2.40	15.99
Private Investment	1983	39.13	2.11	6.58	3.81	0.16	1.88	17.35
	2000	41.31	6.40	11.71	13.66	1.13	2.48	23.50
Final Good								
New Autos	1983	34.59	6.07	7.42	1.53	0.18	4.08	25.28
	2000	36.21	6.40	8.48	2.13	0.88	3.65	22.90
Video/Audio Equipment	1983	23.38	4.47	15.70	1.88	0.17	1.66	39.84
	2000	22.80	4.70	17.22	2.63	0.85	1.58	37.49
Clothing and Luggage	1983	1.60	32.55	7.63	3.17	0.18	1.71	43.26
	2000	2.19	26.50	9.76	4.66	0.91	1.41	45.46
Construction Equipment	1983	45.59	2.72	7.57	1.58	0.18	3.66	22.78
	2000	45.33	4.36	11.31	2.53	1.02	4.65	24.77
Communication Equipment	1983	56.89	2.40	8.00	1.59	0.18	1.22	18.97
	2000	49.93	3.19	11.29	2.34	0.91	1.17	20.58
Computer Hardware	1983	39.62	1.54	6.18	1.63	0.19	1.02	26.23
(consumption + investment)	2000	40.36	5.71	8.92	2.51	1.00	1.69	29.85
Computer Software	1983	6.85	4.71	13.17	38.52	0.29	1.86	26.30
(consumption + investment)	2000	6.56	3.44	13.18	52.50	1.37	1.03	16.27

Table 2. The Distribution of Steps Embodied in the Value Added Contribution of Sectors to Final Goods

		Durables					Nondurables					Serv. Ex. Bus. Serv.					Bus Serv. Ex. Personnel					Personnel					Transportation					Other				
Final goods category	Year	1	2	3	4	5+	1	2	3	4	5+	1	2	3	4	5+	1	2	3	4	5+	1	2	3	4	5+	1	2	3	4	5+	1	2	3	4	5+
	1983	65	25	8	2	1	37	38	16	7	3	12	48	23	11	6	5	55	24	11	5	0	55	27	12	5	23	34	24	13	6	63	18	10	5	3
Durable Goods PCE	2000	57	27	10	4	2	31	38	19	8	4	14	48	22	11	5	22	48	18	8	4	0	55	27	13	6	36	29	20	11	5	74	14	7	3	2
	1983	26	30	24	13	6	62	23	9	4	2	14	43	24	13	6	2	63	20	9	5	0	57	25	12	6	25	33	22	13	7	59	21	11	6	3
Nondurable Goods PCE	2000	29	31	22	12	6	67	22	7	3	1	16	45	23	11	5	3	65	20	8	4	0	58	25	11	5	30	33	21	11	5	70	17	8	3	1
	1983	57	27	10	4	2	0	57	27	11	5	82	13	3	1	0	17	54	21	6	2	24	47	20	6	2	57	21	12	6	3	45	33	14	6	3
Other PCE	2000	48	28	14	7	3	6	53	25	11	5	79	15	4	1	1	16	54	21	7	3	7	57	25	8	3	59	21	12	6	3	52	29	12	5	2
	1983	74	20	5	1	0	0	44	35	16	6	28	39	20	9	4	63	22	10	4	1	2	59	25	10	4	32	29	21	12	5	48	30	13	6	3
Private Investment	2000	65	23	8	3	1	19	41	23	11	5	22	40	22	11	5	79	12	5	2	1	2	56	25	12	5	28	31	23	13	6	47	28	14	7	3
Final good																																				
	1983	53	32	11	3	1	1	51	30	13	5	2	47	29	15	7	1	40	34	17	7	0	43	33	16	7	29	31	22	12	6	38	30	17	9	5
New Autos	2000	47	33	13	5	2	1	46	30	16	7	2	40	30	18	10	2	39	32	18	9	0	40	33	18	9	33	29	21	12	6	42	27	17	9	5
	1983	56	33	8	2	1	8	47	28	12	5	55	27	11	5	2	3	60	24	9	4	0	58	27	11	5	22	30	26	15	7	72	15	8	4	2
Video And Audio Equipment	2000	44	40	11	4	1	3	46	32	14	6	50	27	13	7	3	4	57	24	11	5	0	52	28	13	6	22	27	27	16	8	75	13	7	3	2
	1983	4	42	29	17	9	61	24	9	4	2	5	53	23	12	7	2	73	16	6	3	0	56	27	12	6	10	32	28	19	11	68	15	9	5	3
Clothing and Luggage	2000	10	35	29	17	9	67	22	7	3	1	6	54	24	11	5	3	75	15	5	2	0	58	27	11	5	15	36	27	15	7	77	13	6	3	1
	1983	70	23	5	1	0	0	58	27	11	4	32	32	20	10	5	0	55	29	11	4	0	57	27	11	4	38	28	20	10	4	46	28	15	7	3
Construction Equipment	2000	65	24	7	2	1	9	43	27	15	7	31	32	20	11	5	0	55	27	12	6	0	54	27	13	6	50	25	14	7	3	53	24	13	7	3
	1983	82	14	3	1	0	6	46	30	13	5	32	38	18	8	3	0	61	26	9	3	0	63	25	9	3	15	36	27	15	7	47	32	13	6	3
Communication Equipment	2000	73	19	6	2	1	3	43	31	16	7	33	35	18	9	4	0	57	27	11	5	0	57	27	11	5	20	28	26	17	9	56	24	12	6	3
	1983	71	22	5	1	0	17	37	24	15	7	7	52	27	11	4	0	56	30	10	3	0	60	27	9	3	14	42	25	13	6	54	30	10	4	2
Computer Hardware	2000	54	31	10	3	1	3	45	31	14	6	7	39	30	16	8	1	46	31	15	7	0	47	31	15	7	24	21	27	18	9	50	28	13	6	3
	1983	40	40	14	5	2	37	36	17	7	3	38	40	14	5	2	92	6	1	0	0	16	61	15	5	2	33	33	19	10	5	56	26	11	5	2
Computer Software	2000	16	49	23	9	3	20	40	24	11	5	24	49	17	7	3	93	5	1	0	0	6	68	17	6	3	23	33	24	14	7	48	31	13	5	2

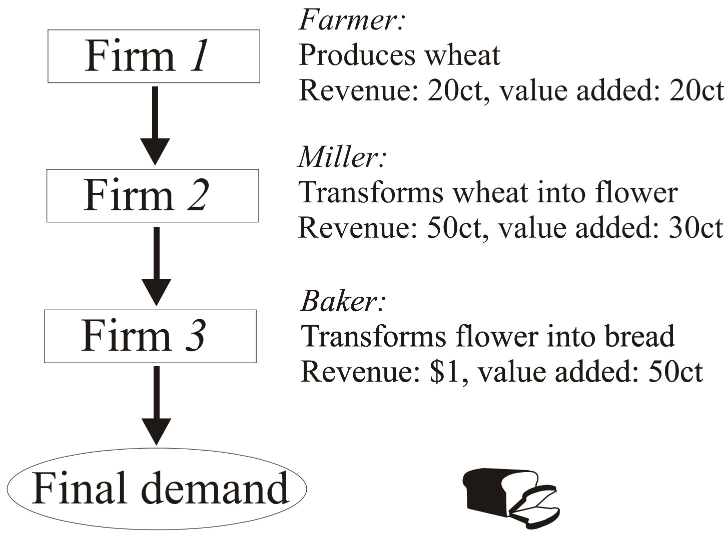


Figure 1. An example of a linear supply chain

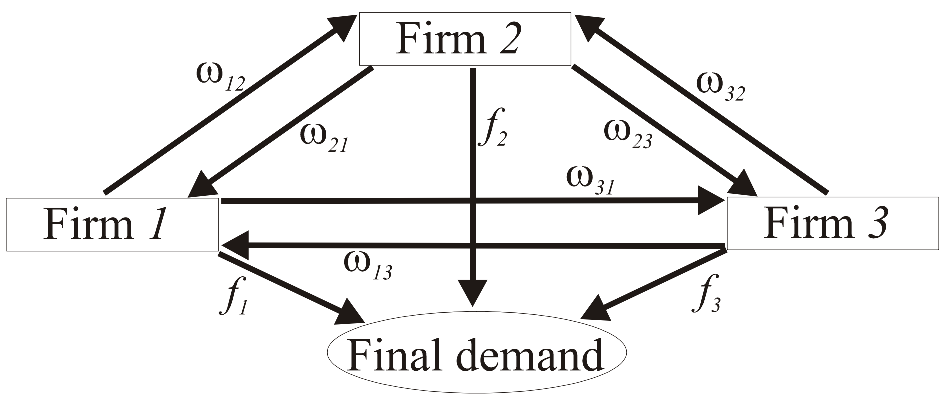


Figure 2. A non-linear supply chain with three firms

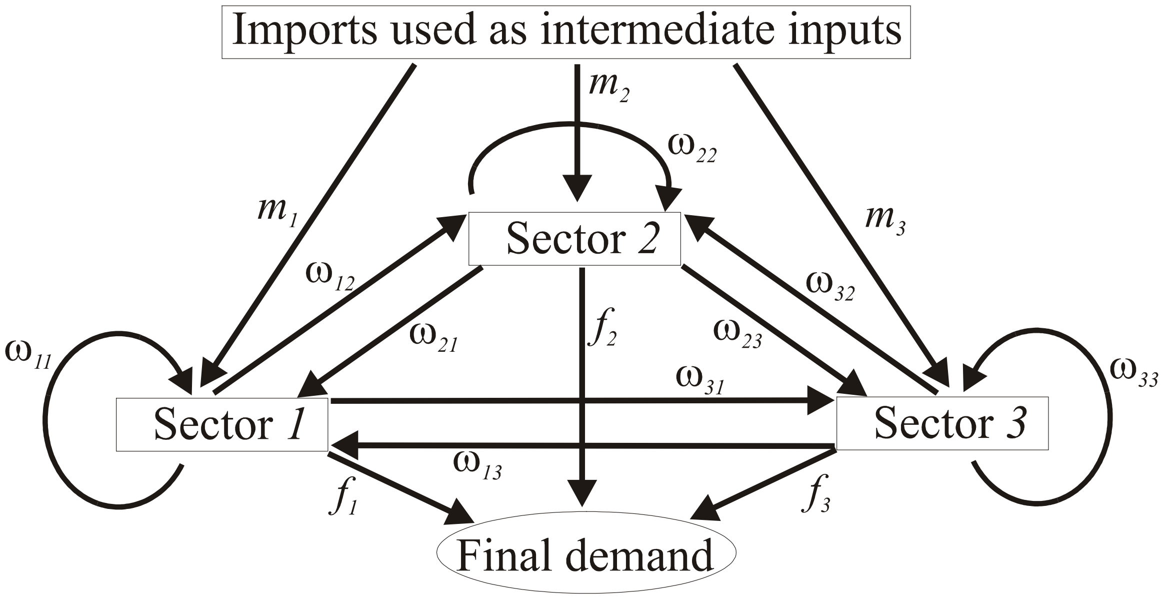
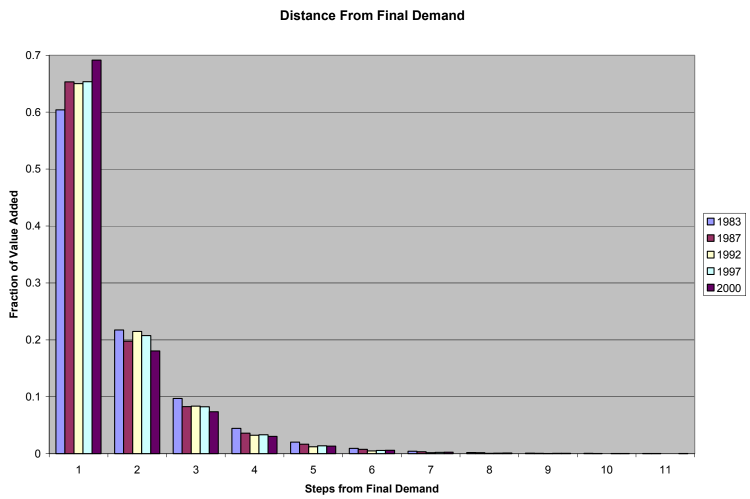


Figure 3. A non-linear supply chain with three sectors and intermediate inputs



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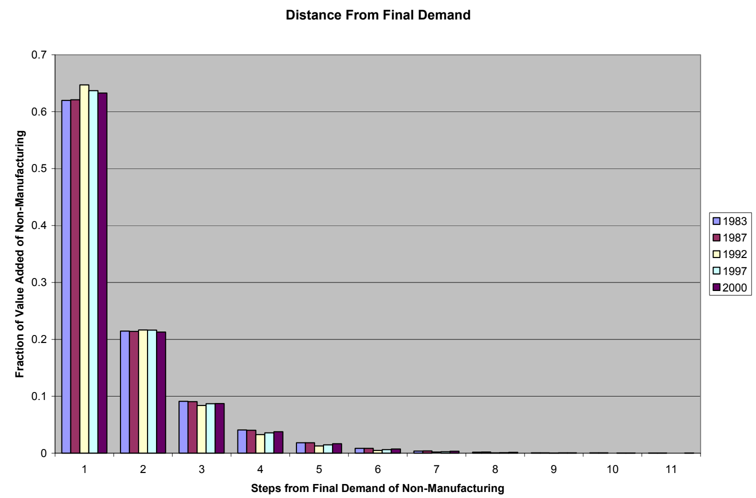

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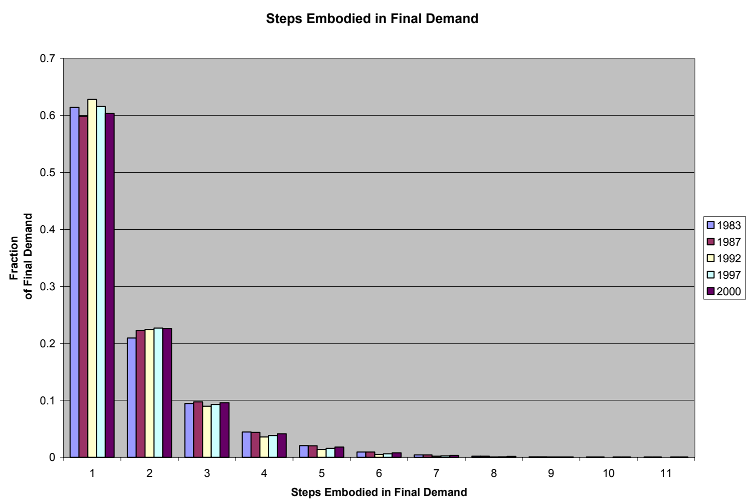

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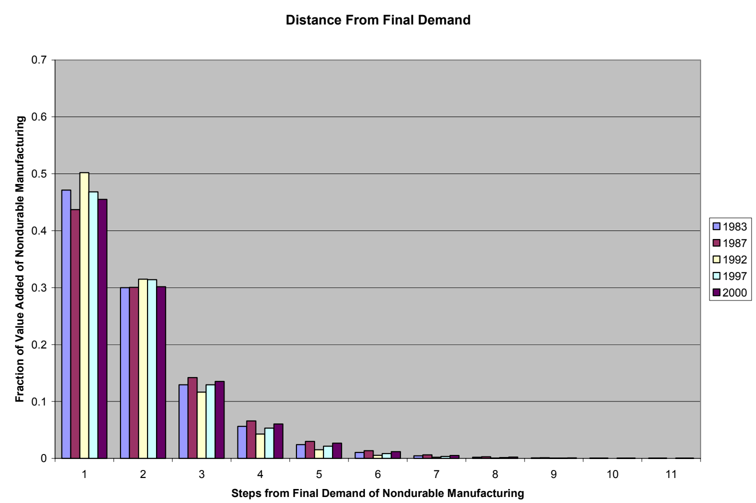

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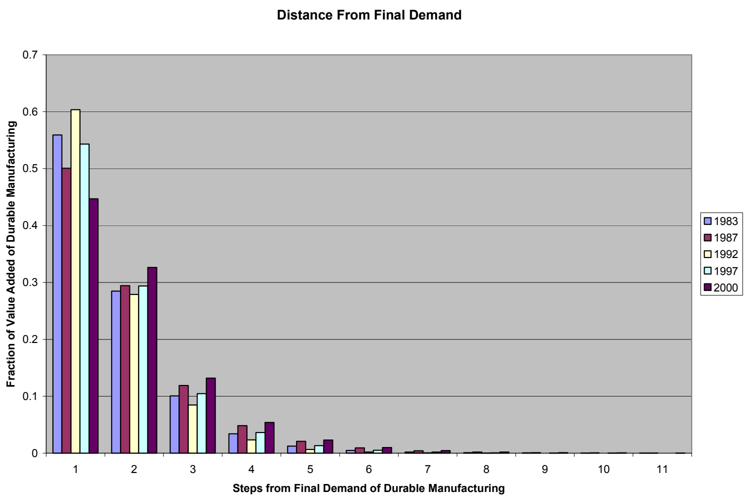

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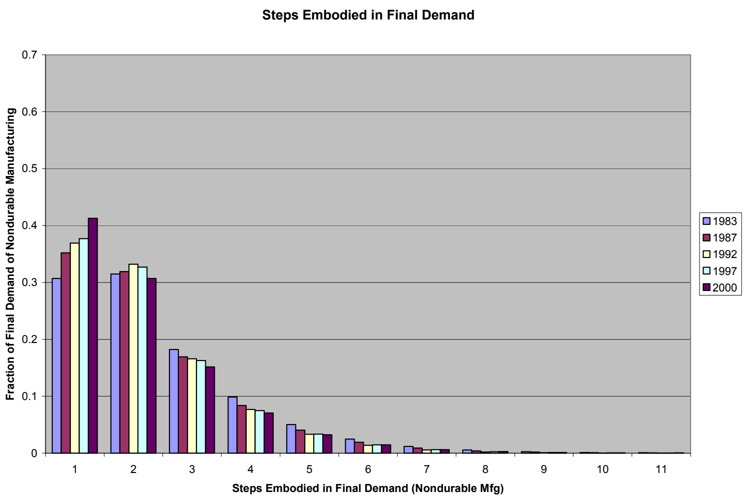

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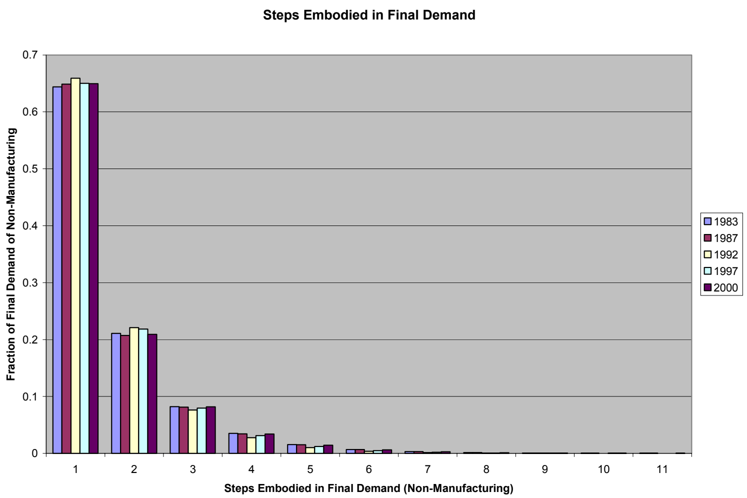

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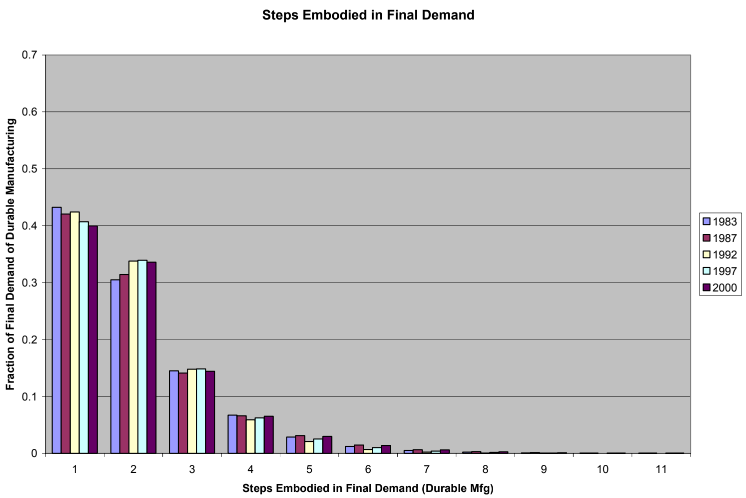

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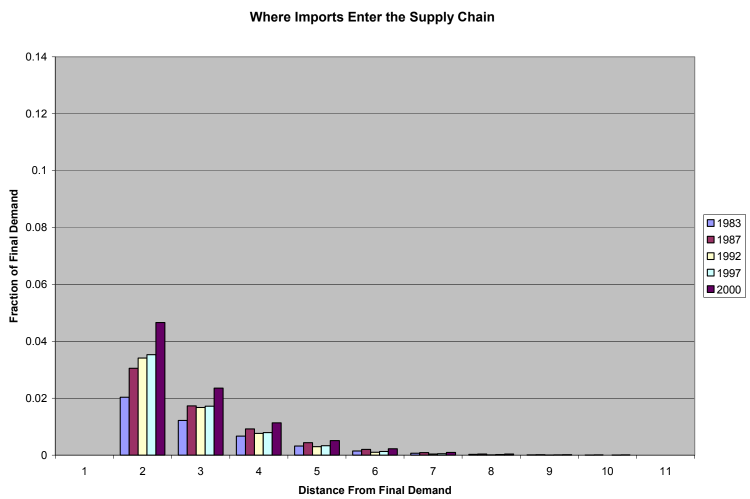

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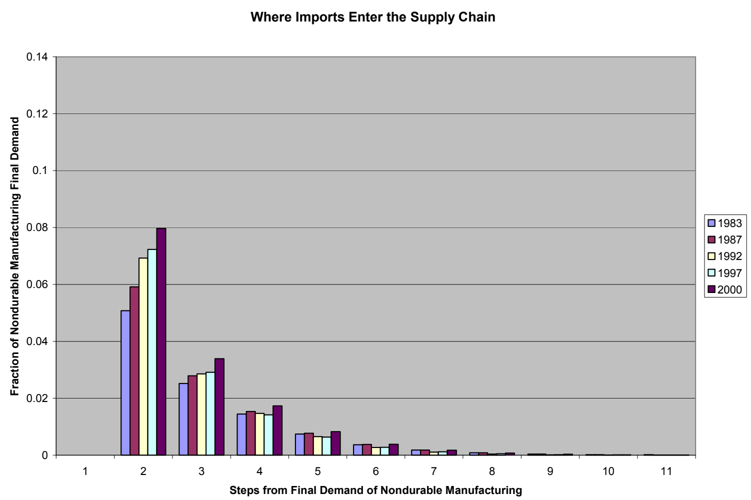

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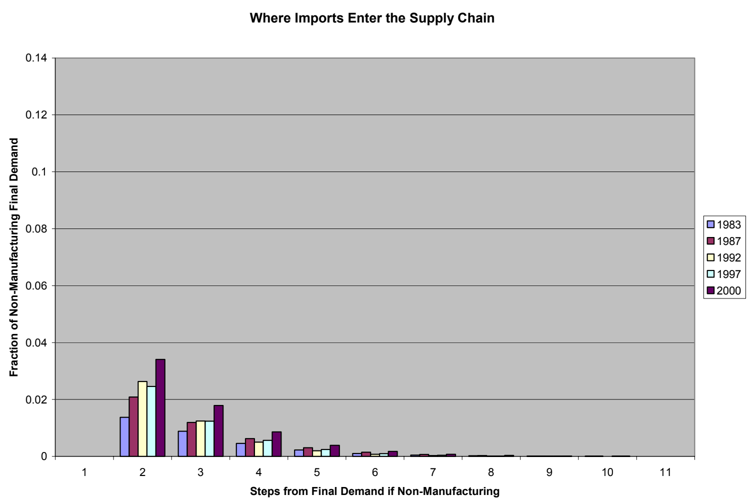

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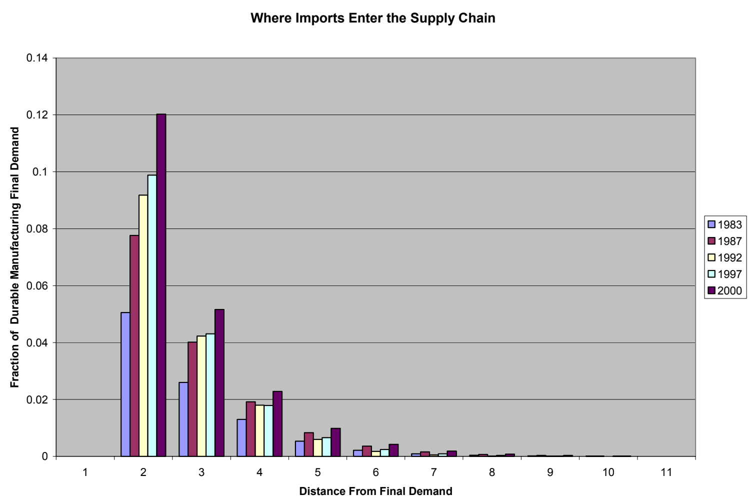

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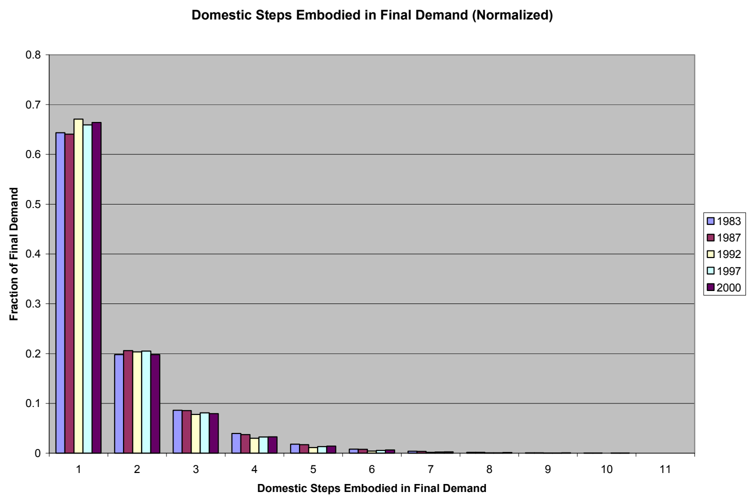

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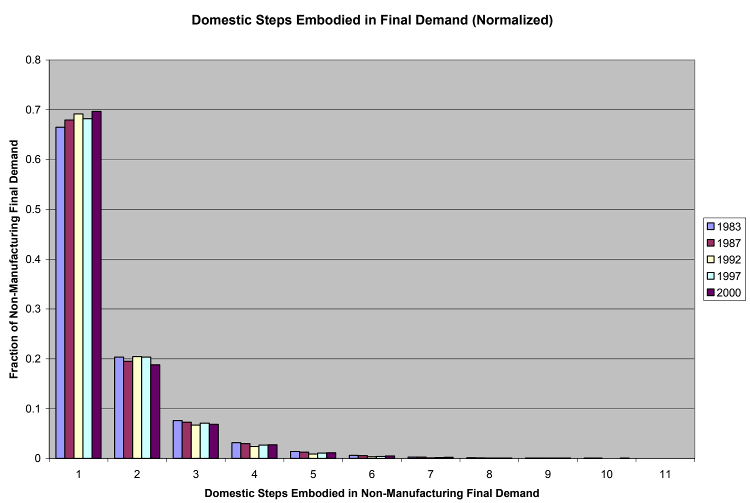

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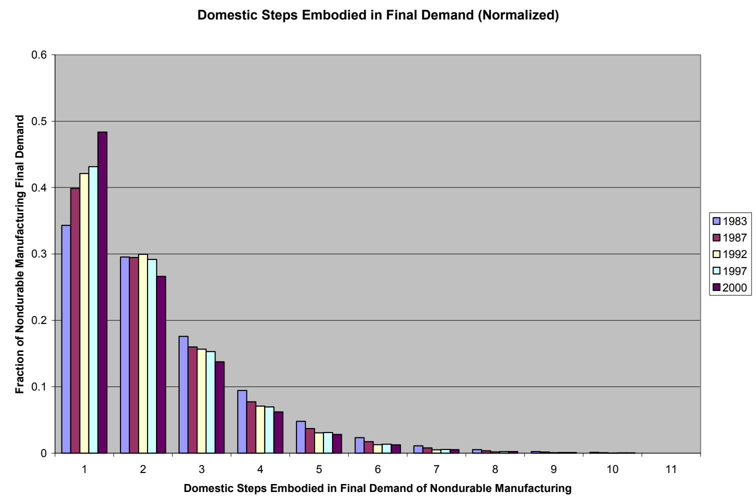

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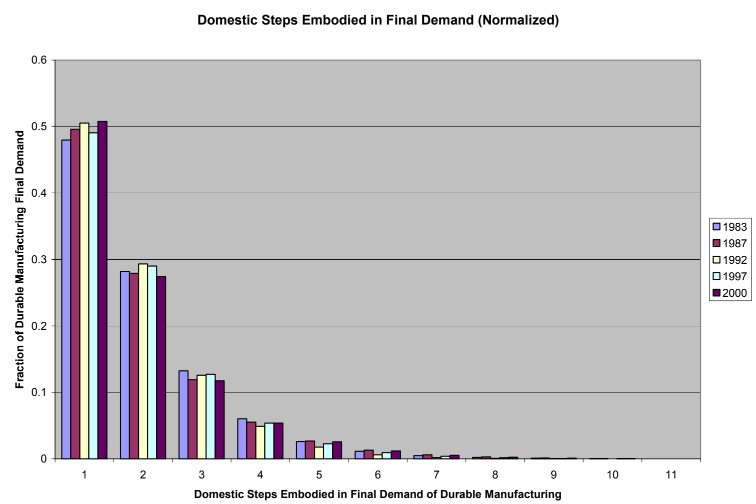

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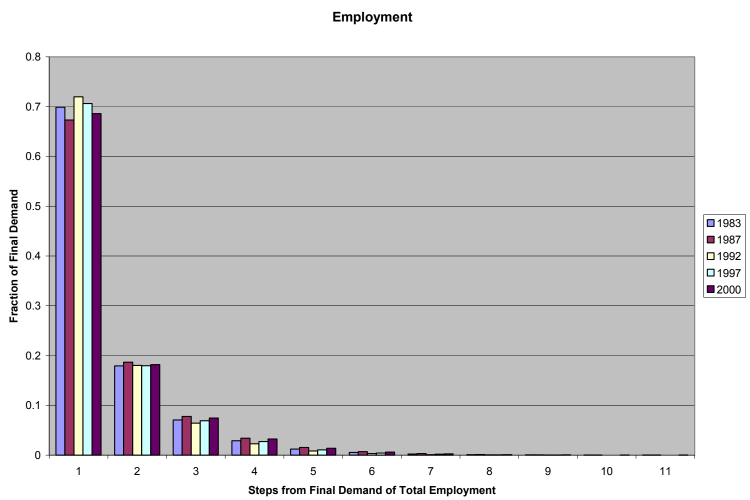

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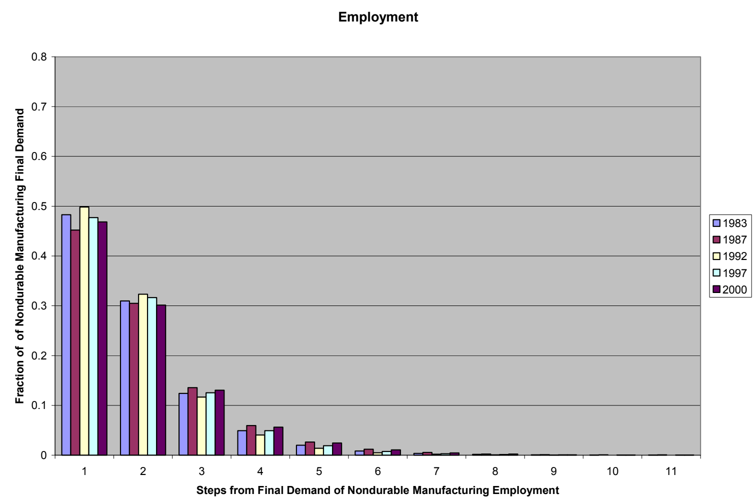

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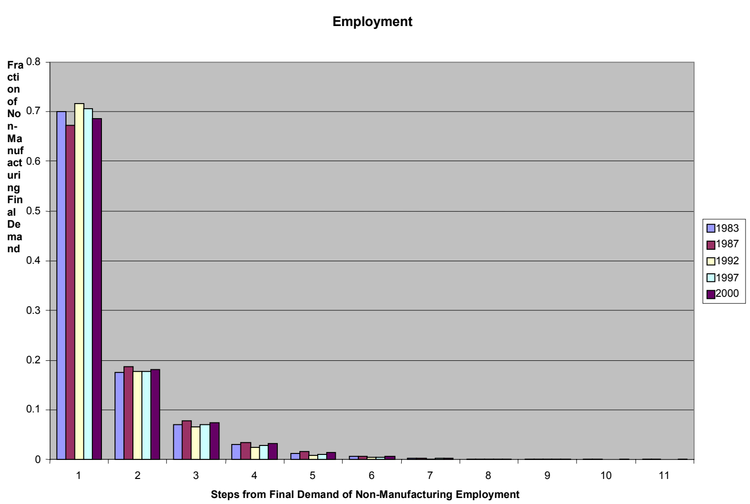

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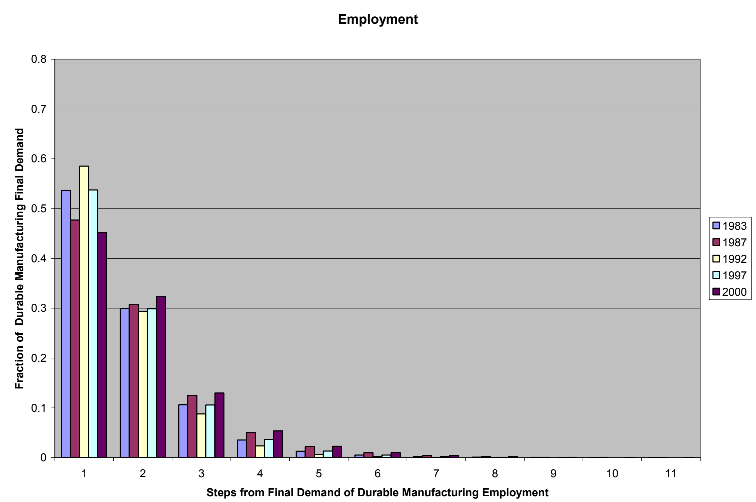

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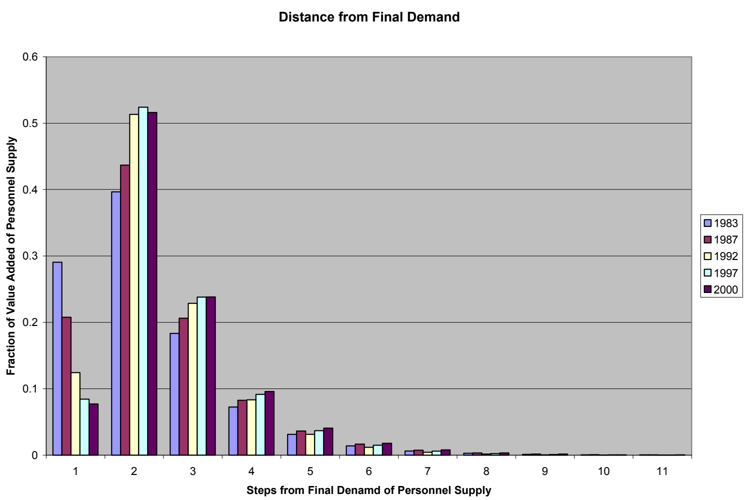

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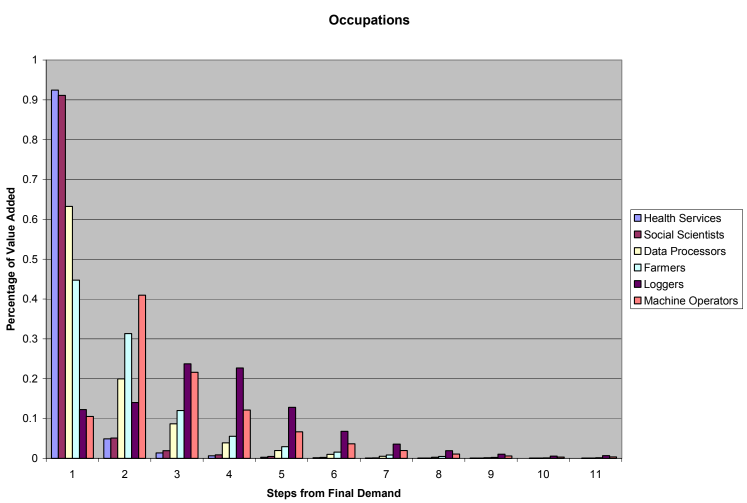

Figure 25.