**Identifying High Resource Consumption Areas of Assembly-Centric Manufacturing in the United States**

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**Abstract**

This paper examines supply chain value added in the US for producing assembly-centric products, which includes machinery, computers, electronics, and transportation equipment, and determines whether costs are disproportionally distributed. The implication being that reductions in resource consumption in some cost areas can disproportionally reduce total resource consumption. Efforts to develop and disseminate innovative solutions to improve efficiency can, therefore, be targeted to these high cost areas, resulting in larger efficiency improvements than might otherwise be achieved. An input-output model is used for this examination and is combined with labor data and data on assets. The top 20 industries, occupations, and industry occupation combinations contributing to production are identified. A sensitivity analysis is conducted on the model using Monte Carlo simulation. The results confirm that costs are disproportionally distributed, having a Gini coefficient of 0.75 for value added and for compensation it is 0.86. *Wholesale trade*, *aircraft manufacturing*, and the *management of companies and enterprises* were the industries with the largest contribution to assembly-centric manufacturing, even when including imports. Energy in the form of electricity and natural gas were discussed separately, but would rank 8$^{th}$ if compared to the industry rankings. In terms of occupation activities, team assemblers, general and operations managers, and sales representatives were the largest occupations. Public entities might use this model and results to identify efficiency improvement efforts that will have the largest impact on industry per dollar of expenditure.

**Introduction**

Public entities have a significant role in the US innovation system (Block and Keller 2016). The federal government has had a substantial impact in developing, supporting, and disseminating numerous innovations and industries, including the Internet, telecommunications, aerospace, semiconductors, computers, pharmaceuticals, and nuclear power among others, many of which may not have come to fruition without public support (Wessner and Wolff 2012). Although the Defense Advanced Research Projects Agency (DARPA), Small Business Innovation Research Program (SBIR), and Advanced Technology Program (ATP) have received attention in the scholarly community, there is generally limited awareness of the government's role in US innovation. The vastness and diversity of US federal research and development programs along with their changing nature make them difficult to categorize and appreciate (Block and Keller 2016), but even the origins of Google are rooted in a public grant through the National Science Foundation (National Science Foundation 2004; Block and Keller 2016). One objective of public innovation is to enhance economic security and improve our quality of life (National Institute of Standards and Technology 2017), which is achieved in part by advancing efficiency in which resources are consumed or impacted by production. For example, the National Institute of Standards and Technology (NIST) has expended resources in supporting the development of the International Standard for the Exchange of Product Model Data (STEP) (Robert D. Niehaus, inc 2014), which reduces the need for duplicative efforts such as re-entering design data. Another effort to advance efficiency is the development of the Core Manufacturing Simulation Data (CMSD) specification, which enables data exchange for manufacturing simulations (Lee et al 2011). In addition to investing in the development of new innovations, public investments are also made in disseminating new processes and innovations. For example, NIST's Manufacturing Extension Partnership (MEP) has been involved in disseminating process improvement innovations. In one instance, MEP aided in reducing labor input for packing by 50 % and lead time by 30 % at a factory in Detroit, MI (Manufacturing Extension Partnership 2017). In other instances, MEP aided in the adoption of ISO standards, training programs, and safety standards to improve quality and reduce costs (Manufacturing Extension Partnership 2017). In many instances, it is the adoption of recently developed ideas and technologies that can have significant impact on efficiency rather than the development of new technologies and ideas.

There are three major impacts that public investment in developing and disseminating innovations has on manufacturing. The first is innovative solutions that produce an efficiency improvement in the production and delivery of functioning products. This amounts to a decrease in the resources needed to produce a particular product. The second impact is an innovative solution that provides an efficiency improvement in achieving end use purposes. Products are manufactured to achieve a purpose such as transportation, communication, or entertainment. In the process of achieving these purposes (i.e., the use of manufactured products), resources are consumed. Automobiles, for instance, consume fuel while televisions and computers consume electricity. Improving energy efficiency along with other characteristics of a product amounts to an efficiency improvement in achieving its end use purpose. Improving the longevity of an automobile, for example, might improve efficiency in achieving end use purpose, as less resources are expended on automobiles per mile traveled. The last impact is that of innovations that achieve new end use purposes, such as a new vaccine or space travel. Together, these three impacts – efficiency in production, efficiency in end use, and new end-use purposes – constitute the major impacts of innovation in manufacturing. This paper focuses on potential efficiency improvements in production, leaving issues in end use purposes for future research.

Public entities have scarce resources, therefore, they must prioritize their investments in developing and disseminating innovative solutions to improve efficiency in production by focusing on those cost areas that have a disproportional impact on resource consumption. Companies often do this naturally by examining their accounting books and concentrating on their largest costs rather than their smallest ones. It may seem apparent that those who seek to improve US manufacturing efficiency as a whole would apply similar methods; however, there is limited evidence that this is occurring. For public entities identifying large costs requires economy wide analysis and there is limited research and literature focusing on this topic.

A frequently invoked axiom posits that roughly 80 % of a problem is due to 20 % of the cause, a phenomenon referred to as the Pareto principle (Hopp and Spearman 2008). This paper examines whether costs are disproportionally distributed for assembly-centric products and measures the statistical dispersion using the Gini coefficient (Klein 2002). The paper further seeks to identify those costs that account for a disproportionally high level of resource consumption. Assembly-centric products include machinery, computers/electronics, and transportation equipment. These products were examined as they include what is commonly referred to as high-tech manufacturing. Additionally, they require similar production activities such as the mass transportation of intermediate parts, which may not be required in the production of other types of products. Industry value added and compensation by occupation is used as the measure of cost. From this value the top 20 costs are identified by industry, occupation, and industry/occupation combination. The robustness of these rankings are then examined in a Monte Carlo analysis. The costs from 412 industries and 92 assembly-centric commodities are analyzed. This analysis facilitates prioritizing efficiency efforts in assembly-centric manufacturing by identifying the costs by industry, occupation, and industry/occupation combination. Another contribution is the breakout of energy costs and how energy is used in manufacturing. The purpose of this approach is to facilitate the identification of economy-wide opportunities for efficiency improvements per dollar of expenditure in assembly-centric manufacturing. Public entities, trade organizations, and other change agents that seek to have the largest efficiency improvement possible must prioritize their efforts to develop and disseminate innovations so that they can get the largest increase per expenditure dollar.

The top 20 % of costs include more than 80 industries, 150 occupations, and more than 60 000 industry/occupation combinations, which is difficult to report out in a paper. For this reason, this paper discusses the top 20. Out of more than 400 industries, the top 20 represent 43 % of the costs from assembly-centric manufacturing, suggesting that a significant amount of the cost is concentrated within a small number of industries. Out of 800 occupations, the top 20 represent 21 % of the costs and Out of more than 300 000 industry/occupation combinations, the top 20 represent 5 % of the costs. These categories of cost have a disproportional impact on total cost, creating an opportunity for innovative solutions that have a large impact on cost.

**Background**

To develop and disseminate publicly supported innovative solutions that provide economy-wide efficiency improvements, researchers have suggested that "the supply chain must become the focus of policy management, in contrast to the traditional emphasis on single technologies/industries" (Tassey 2010). A majority of costs are hidden in the supply chain. For example, 83 % of value added for automobile manufacturing is in the supply chain, occurring in establishments other than where the final assembly takes place.[1] The level of analysis in this paper can capture costs from system-level inefficiencies such as those that result from the "bullwhip effect" where variations in demand are magnified through a supply chain (Lee et al 1997; Bray and Mendelson 2012). Efficiency improvements in high cost supply chain entities can reduce unit cost, increase quality, and increase flexibility. These increases can spur growth in employment and value added as the domestic share of global markets expand (Tassey 2010). The McKinsey Global Institute also identifies industry sector level examinations as the key to understanding competitiveness and growth in an economy (McKinsey Global Institute 2010). Additionally, Bhatnagar and Sohal show that industry supply chains have a significant impact on operational competitiveness (Bhatnagar and Sohal 2005). Despite the importance of supply chains, there is limited research on economy-wide issues or costs. There are many individual supply chain studies, such as the RAND study on ammunition supplies for the US military (Butler et al. 2016) or a report by the Australian Logistics Council (2014) that investigates national logistics issues; however, these and other studies either focus on the supply chain of a specific product or a specific issue within the national supply chain.

The US federal government collects and distributes a wide range of manufacturing industry data, including the Annual Survey of Manufactures, economic census, and the National Compensation Survey; however, these datasets alone do not provide an analysis of the system-level supply chain for manufactured goods. For example, a major data source on national manufacturing, the Annual Survey of Manufactures, is an invaluable resource; however, by itself the insight it provides is limited, as it has a limited number of cost categories, has limited information about supply chain costs, and no information

[1] Calculated using Input-Output analysis of the BEA Benchmark data.

about the types of labor in each industry. Assembly-centric products require raw materials, material refining, and intermediate components, which require buildings, machinery, and laborers. Data on manufacturing activity provides insight into the total production of raw materials, material refining, and intermediate components along with the total capital assets such as buildings and machinery; however, these items are used for multiple purposes. For example, metal is used in the construction of buildings and intermediate components are used in the maintenance and repair of old products. Additionally, raw materials, metal, and intermediate components might be produced for export rather than for domestic finished goods production. Moreover, domestic data alone provides limited insight into the resources required to produce assembly-centric products. Without an input-output model or similar analyses, there is limited understanding concerning the use and costs of resources for manufacturing at a national level and there is minimal understanding of the supply chain for such products.

Establishments look at performance across a variety of factor inputs, including transportation, worker skills, materials, components, and energy to remain competitive. In order for domestic manufacturing to remain vibrant, it can be argued that a nation must consider these issues as well, but at a larger scale (McKinsey & Company 2012). This analysis uses input-output analysis, a systems level approach, to identify economy wide opportunities for efficiency improvement in manufacturing, a matter that is lacking in the literature to date. The analysis crosses multiple industries, occupations, and supply chains. Input-output analysis reveals inter-industry relationships through a system of linear equations. It characterizes an industry's product throughout the economy, thus, revealing the supply chain. This effort might be analogous to a company estimating and examining its accounting books to identify high cost areas. For example, Dell identified significant cost increases in one of its intermediate production steps. It assembled a team to identify the root causes of these costs and was able to successfully reduce it (Simchi-Levi et al 2008). Companies such as Dell and others track and analyze their cost data to identify high cost areas where efficiency improvements might be made to remain a competitive business. Public efforts that seek to improve economy-wide efficiency and competitiveness in manufacturing would benefit from similar cost data; however, unlike a company, a representative cost breakdown is not readily available. Measuring assembly-centric production at the macro or economy wide level poses slightly different challenges than an individual company might face, as it requires tracking multiple products being produced by multiple companies each with their own supply chain. The result is that data are collected from sample surveys, takes years to assemble, and must be combined for analysis. The approach in this paper is consistent with calls for system-level productivity and examining supply chains to achieve efficiency improvements in manufacturing. The resulting economy-wide efficiency improvements may lead to increases in long term economic growth, per capita income (Weil 2005), employment, and innovation (Tassey 2010). Input-output analysis allows us to break apart a product into its costs by establishment, occupation, and industry/occupation combination. The results can aid in identifying innovative solutions that have a high impact on efficiency.

Although input-output analysis is, typically, used to examine the impact of changes in demand, there is some precedent for using these models for examining supply chains. Albino et al. (2002), for example, develop an input-output approach on production processes to investigate supply chain flows. Lu et al. (2007) provide a model to plan production, procurement, and distribution using input-output models. Each of these, however, focuses on the individual company or supply chain level, studying enterprise input-output accounts. Despite these applications, there seems to be limited use of input-output models to motivate efforts to develop and disseminate innovations.

This analysis uses data from previous years to estimate current industry activity, which results in some uncertainty. In order to account for this uncertainty, a probabilistic sensitivity analysis was conducted using Monte Carlo analysis (which can also be used for numerical integration and optimization problems). Examinations of uncertainty in environmental Input-Output analysis have used both fuzzy set theory and stochastic models (Raina and Thomas 2012; Egilmez et al 2016; Beynon and Munday 2007; Beynon and Munday 2005; Temurshoev 2015); however, with there being limited in-depth examinations of uncertainty, there is not a consensus on a specific approach (Diaz and Morillas 2011). Monte Carlo analysis is based on works by McKay, Conover, and Beckman (1979) and by Harris (1984) that involves a method of model sampling. Monte Carlo simulation methods are superior to deterministic modeling for our purposes because deterministic modeling uses single-point estimates while Monte Carlo generates a probability distribution for every single variable of interest and allows for a comprehensive comparison of those probabilities.

**Data and Methods**

This paper uses input-output analysis and Monte Carlo analysis to examine the costs of assembly-centric commodities. Input-output analysis is used to estimate the costs and Monte Carlo analysis is used to test the robustness of the results. These approaches build of Thomas and Kandaswamy (2015) are discussed below. A number of data sources are needed for tracking costs, including input-output data from the Bureau of Economic Analysis (BEA), energy use data from the Energy Information Administration (EIA), asset purchases from the Annual Survey of Manufactures (ASM), employment and wage data from the Bureau of Labor Statistics, and construction cost data from RS Means. As illustrated in Figure 2A, these datasets are mapped together based on the North American Industry Classification System (NAICS), which categorizes establishments based on their products and processes, and the Standard Occupation Classification system (SOC), which categorizes labor by occupation. As illustrated in Figure 2B, value added represents the total cost, which is broken into compensation, taxes, and gross operating surplus. Each of these and their subcategories can be calculated for each industry NAICS code, seen on the Y-axis to the left. Compensation can further be decomposed into Standard Occupation Classification System categories. Gross operating surplus can be decomposed into net operating surplus, a profit like measure, and depreciable assets such as buildings and machinery. All of the categories in the X-axis are calculated by the NAICS categories on the Y-axis. This paper primarily discusses value added, compensation, and depreciable assets (i.e., buildings and machinery) by NAICS code categories.

*Input-Output Analysis*: Within an input-output model, economies of scale are ignored; thus, the model operates under constant returns to scale. The model also assumes that a sector uses inputs in fixed proportions. These issues are, typically, relevant to analyses that examine the impact of a change in demand. This paper is not seeking to predict the impact of a change in demand, but rather seeks to track the resources used for the production of particular goods; therefore, ignoring economies of scale and assuming sectors use inputs in fixed proportions has limited impact on the underlying analysis. The input-output model provides the goods and services that are used up in the production process; thus, capital investments are excluded and will be examined separately. The analysis utilizes the BEA Benchmark input-output tables, which has data for over 350 industries (Bureau of Economic Analysis 2014). This data includes Make tables, which show the production of commodities (products) by industry, and Use tables, which show the components required for producing the output of each industry. The data is categorized by altered codes from the North American Industry Classification System (NAICS).

This paper uses an industry-by-commodity input-output format as outlined in Horowitz and Planting, which accounts for the fact that an industry may produce more than one commodity or product such as secondary and by-products (Horowitz and Planting 2006; Miller and Blair 2009; European Commission 2008). An input-output analysis develops a total requirements matrix that when multiplied by the vector of final demands equals the output needed for production. The total requirements matrix is developed using the methods outlined in Horowitz and Planting (2006):

Equation 1

$$X = W(I - BW)^{-1} * Y$$

Where:

$X =$ Vector of output required to produce final demand

$Y =$ Vector of final demand

$W = (I - \hat{p})V\hat{q}^{-1}$

$B = U\hat{g}^{-1}$

$I =$ Identity matrix

$p =$ "A column vector in which each entry shows the ratio of the value of scrap produced in each industry to the industry's total output."

$U =$ "Intermediate portion of the use matrix in which the column shows for a given industry the amount of each commodity it uses—including noncomparable imports, scrap, and used and secondhand goods. This is a commodity-by-industry matrix."

$V =$ "Make matrix, in which the column shows for a given commodity the amount produced in each industry. This is an industry-by-commodity matrix. V has columns showing only zero entries for noncomparable imports and for scrap."

$g =$ "A column vector in which each entry shows the total amount of each industry's output, including its production of scrap. It is an industry-by-one vector."

$q =$ "A column vector in which each entry shows the total amount of the output of a commodity. It is a commodity-by-one vector."

$\widehat{\ }$ "A symbol that when placed over a vector indicates a square matrix in which the elements of the vector appear on the main diagonal and zeros elsewhere."

The total requirements matrix $W(I-BW)^{-1}$, which shows the total output required to meet a given level of final demand, is multiplied by final demand in the input output data to estimate the total output. The output required to produce a particular level of final demand can be calculated by altering final demand to $Y'$. For this analysis, $Y'$ has the total final demand for assembly-centric products and zero for other products.

Value Added Analysis: Value added is calculated by assuming the proportion of output needed to produce a commodity is the same proportion of value added, which is consistent with methods proposed by Miller (2009). The proportions calculated using the input-output analysis are then multiplied by the value added and scaled to 2014 dollars using the estimate of gross output for that year:

Equation 2

$$VA_{z,Y',2014} = \frac{x_{z,Y',2007}}{x_{z,2007}} * VA_{z,2007} * \left(\frac{x_{z,2014}}{x_{z,2007}}\right)$$

Where

$VA_{z,Y',2014} =$ Value added from industry $z$ with final demand $Y'$ in 2014

$x_{z,2007} =$ Total output for industry $z$ in 2007

$x_{z,2014} =$ Total output for industry $z$ in 2014

$x_{z,Y',2007} =$ Output for industry $z$ with final demand $Y'$ in 2007

$VA_{z,2007} =$ Total value added from industry $z$ in 2007

Imports are calculated in a similar fashion, where the proportion of total output used from a particular industry is the same for imports.

Energy Analysis: The BEA input-output data provides estimates of energy use but not the requisite detail in how the energy is used, which is an important issue in tracking industry operations. In order to better understand energy use, the Manufacturing Energy Consumption Survey (MECS) was used to breakout the BEA data to show not only how much energy is used, but what it is used for. The Energy Information Administration collects energy data on a quadrennial basis and samples approximately 15 500 establishments drawn from a nationally representative sample frame that includes 97 % to 98 % of the manufacturing payroll (Energy Information Administration 2010). Energy data is categorized by the NAICS codes and end use. The U.S. Energy Information Administration (EIA) distinguishes between two types of energy usage in manufacturing – "energy consumed for fuel and energy consumed for feedstock" (Energy Information Administration 2010). Energy consumed for fuel is described aptly by its title whereas energy used as feedstock is “energy used as a raw material for purposes other than for heat, power, and electricity generation” (Energy Information Administration 2010). For this analysis, the EIA energy data has been mapped to the 2007 Benchmark make and use tables in order to expand out the input-output analysis. In instances where the EIA NAICS codes did not match the BEA NAICS codes, the proportions of energy use at the next NAICS level of detail was used. The BEA benchmark code of *coal mining* was expanded to include seven categories:

| | |
|---|---|
| 212100 | Coal mining |
| 212100-A | Indirect Uses-Boiler Fuel |
| 212100-B | Process Heating |
| 212100-D | Machine Drive |
| 212100-F | Other Process Use |
| 212100-G | Facility HVAC (g) |
| 212100-K | Conventional Electricity Generation |

The BEA benchmark NAICS code for *electric power generation, transmission, and distribution* was expanded to thirteen categories:

| | |
|---|---|
| 221100 | Electric power generation, transmission, and distribution |
| 221100-A | Indirect Uses-Boiler Fuel |
| 221100-B | Process Heating |
| 221100-C | Process Cooling and Refrigeration |
| 221100-D | Machine Drive |
| 221100-E | Electro-Chemical Processes |
| 221100-F | Other Process Use |
| 221100-G | Facility HVAC (g) |
| 221100-H | Facility Lighting |
| 221100-I | Other Facility Support |
| 221100-J | Onsite Transportation |
| 221100-K | Other Nonprocess Use |
| 221100-L | End Use Not Reported |

*Natural gas distribution* was expanded into ten categories:

| | |
|---|---|
| 221200 | Natural gas distribution |
| 221200-A | Indirect Uses-Boiler Fuel |
| 221200-B | Process Heating |
| 221200-C | Process Cooling and Refrigeration |
| 221200-D | Machine Drive |
| 221200-F | Other Process Use |
| 221200-G | Facility HVAC (g) |
| 221200-I | Other Facility Support |
| 221200-K | Conventional Electricity Generation |
| 221200-L | Other Nonprocess Use |

Energy consumed for purposes other than for heat, power, and electricity generation remained in the base category (e.g., *coal mining: NAICS 212100*). The result of expanding the make and use tables is that the energy consumed for similar purposes (e.g., process heating) is tracked through multiple industries for a selected final product, which in this case is assembly-centric goods. For example, an analysis of automobile manufacturing would reveal not only the process heating in the automobile manufacturing industry, but also the process heating within the metal foundries for the metal that went into the automobiles produced.

An additional issue regarding energy involves the use of industry categorizations. Value added is generally the best metric for measuring industry activity; however, it can somewhat disguise energy costs in this case as the value added is broken up into different industries. For instance, the cost of purchased electricity is broken into the mining of coal, extraction of gas, and generation of electricity. The analysis in this paper also breaks energy up further into its end use. Due to these complications, it is useful to discuss energy separately. To estimate energy use, the value added from electric power generation, transmission, and distribution needs be calculated along with the value added that contributes to it. To address this issue, an estimate of the aggregated impacts of energy are examined. This is done by estimating the output for $Y''$ with final demand for "*electric power generation, transmission, and distribution*" equal to 1 and demand for all other commodities in $Y''$ set to zero. This allows us to calculate the value added from each industry to produce a unit of value added from assembly-centric manufacturing:

Equation 3

$$VA_E = \frac{\left[\sum_{i=1}^{n} VA_{i,Y''}\right] - VA_{E,Y''} - VA_{N,Y''}}{VA_{E,Y''}}$$

Where

$VA_E =$ Indirect value added per percentage point of direct value added from *electric power generation, transmission, and distribution*

$VA_{E,Y''} =$ Value added from the *electric power generation, transmission, and distribution* for final demand $Y''$

$VA_{N,Y''} =$ Value added from the *natural gas distribution* industry for final demand $Y''$

A similar calculation can be made for natural gas where final demand for $Y''$ is set to 1 for *natural gas distribution* and zero for all other commodities:

Equation 4

$$VA_N = \frac{\left[\sum_{i=1}^{n} VA_{i,Y''}\right] - VA_{E,Y''} - VA_{N,Y''}}{VA_{N,Y''}}$$

Where

$VA_N =$ Indirect value added per percentage point of direct value added from natural gas

Once we have distinguished between the dual uses of energy in the manufacturing sector, we can note that the energy use categories provided include: indirect uses-boiler fuel, process heating, process cooling and refrigeration, machine drive, electro-chemical processes, other process use, facility HVAC, facility lighting, facility support, onsite transportation, other non-process use, and end use not reported. Electric power generation, transmission, and distribution from the BEA data is broken into these categories by portioning out coal mining, electricity generation, and natural gas distribution by proportions calculated from the EIA. Unfortunately, this does not fully account for the energy value *added*, as oil and gas extraction cannot be broken out using this method; therefore, gasoline, diesel, and other such fuels are not broken out.

It should be noted that there exists another method for measuring energy consumption in the manufacturing process. Borrowing from the field of chemical analysis, "pinch analysis" has been applied to manufacturing activities, particularly at the production planning stage (Mohr et al 2012). The demand for pinch analysis grew dramatically in the first decade of the twenty-first century among manufacturers as variable costs sharply increased and companies sought to minimize costs.

A McKinsey report titled "Manufacturing Resource Productivity" by Stephan Mohr, Ken Somers, Steven Swartz and Helga Vanthournout describes pinch analysis. Basically, the analysis consists of "calculat(ing) the thermodynamically minimum energy required and evaluat(ing) actual consumption relative to this theoretical limit" (Mohr et al. 2012). The McKinsey report situates pinch analysis in the broader context of "lean manufacturing" techniques but that is not the focus of this report. What is important to note in this context is that BEA data aggregation can conceal very important facets about underlying efficiencies in the manufacturing industry and that techniques like "pinch analysis" can be used to focus in more narrowly on important information that might be otherwise lost.

Occupation Analysis: In order to examine labor activity, Bureau of Labor Statistics employment data from the Occupational Employment Statistics (OES) is matched with the BEA IO NAICS categories. The OES is categorized by industry by occupation. It includes over 800 occupations categorized by the Standard Occupation Classification (SOC) system and over 450 industries classified by NAICS; however, archived data covers fewer industries (Bureau of Labor Statistics). The data is gathered through surveys and covers full-time and part-time wage and salary workers in nonfarm industries. For this analysis, the Bureau of Labor Statistics employment data has been mapped to the detail level found in the 2007 Benchmark Input-Output data. In instances where the NAICS codes for the occupation data did not match that of the input-output data, the values were estimated. When the BEA data had a NAICS code at a lower level of detail than the occupation data, the occupation data was aggregated up to the BEA level of detail. If the occupation data was at a lower level of detail, then the BEA levels were estimated by assuming the proportion of the cost of compensation in the BEA was the same as that for employment. This provides an estimate of occupational employment by industry at the NAICS level of detail. To estimate the hours of labor, these estimates are multiplied by the average hours per week for each occupation and, then, multiplied by the total weeks per year. These hours are then multiplied by wages per hour and adjusted to match the BEA estimates of compensation assuming the BEA proportions of labor are the same as that calculated using BLS data. When examining a specific product commodity such as automotive manufacturing, the input-output calculations are used to estimate the output from each industry required to produce the given product. The proportion of the total output needed from each industry is multiplied by the occupational employment for each industry to estimate the amount of labor, which is consistent with methods proposed in Miller (2009). The result is a matrix of the amount of labor needed, categorized by NAICS by occupation, to produce the relevant commodity.

Equation 5

$$C_{z,s,Y\prime} = \frac{x_{z,Y\prime}}{x_z} * C_{z,s,} * \left(\frac{E_{z,s} * LH_s * W_{z,s}}{\sum_{i=1}^{n} E_{z,i} * LH_s * W_{z,i}}\right) * \left(\frac{x_{z,2014}}{x_{z,2007}}\right)$$

Where

$C_{z,s,Y\prime}$ = Compensation for occupation s in industry z with final demand $Y'$

$C_{z,s,}$ = Total compensation for occupation s in industry z

$x_z$ = Total output for industry $z$

$x_{z,Y\prime}$ = Output for industry $z$ with final demand $Y'$

$E_{z,s}$ = Employment for industry z and occupation s

$LH_s$ = Labor hours per employee for occupation s

$W_{z,s}$ = Hourly wages per employee for industry z and occupation s

Buildings and Machinery: Depreciable assets are measured in a similar fashion to that of labor. The proportion of output estimated from the input-output calculations is multiplied by the total depreciable assets for that industry, resulting in an estimate of depreciable assets utilized for the production of the commodity being examined. The data for depreciable assets is taken from the Economic Census, which is classified by NAICS codes. An estimate for buildings and machinery/equipment is made by utilizing RS Means data. The total square footage of manufacturing space from the Manufacturing Energy Consumption survey is multiplied by the average construction cost per square foot from RS Means (RS Means 2005). This is assumed to be the buildings share of depreciable assets with the remaining amount assumed to be machinery/equipment:

Equation 6

$$DB_{z,Y'} = \frac{x_{z,Y',2007}}{x_{z,T,2007}} * (SF_z * RM)$$

Equation 7

$$DM_{z,Y\prime} = \left[\frac{x_{z,Y',2007}}{x_{z,T,2007}} * DA_z\right] - DB_{z,Y'}$$

Where

$DB_{z,Y',MB}$ = Depreciable building assets from industry $z$ associated with final demand $Y'$ in 2014

$DM_{z,Y\prime}$ = Depreciable machinery assets from industry $z$ associated with final demand $Y'$ in 2014

$x_{z,T,2007}$ = Total output for industry $z$ in 2007

$x_{z,Y',2007}$ = Output for industry $z$ with final demand $Y'$ in 2007

$SF_z$ = Estimated square feet of manufacturing floor space for industry z

$RM$ = RS Means estimated construction cost per square foot of manufacturing floor space

$DA_z$ = Gross value of depreciable assets (end of year) from the annual survey of manufactures

A similar calculation is made for the purchase of new and used capital assets, where the proportion of output estimated from the input-output calculations is multiplied by the value of new and used capital assets purchased.

Equation 8

$$CE_{z,Y',MB} = \frac{x_{z,Y',2007}}{x_{z,T,2007}} * CE_{MB}$$

Where

$CE_{z,Y',MB}$ = Capital expenditures by industry z with final demand $Y'$ on MB, where MB is either machinery or buildings

$x_{z,T,2007}$ = Total output for industry $z$ in 2007

$x_{z,Y',2007}$ = Output for industry $z$ with final demand $Y'$ in 2007

$CE_{z,MB}$ = Total capital expenditures by industry z on MB, where MB is either machinery or buildings

One challenge of examining depreciable assets is that they are long term investments; thus, it is difficult to compare them directly to the cost of those items that are used up in production. In accounting, the cost of depreciable assets is spread out over years. The annual estimates depend on the method of depreciation and the estimated useful life of the assets. A simple method would be to use straight-line depreciation and divide the acquisition cost by a selected useful life (e.g., 10 years for machinery and 30 years for buildings). This paper discusses the acquisition cost of assets, leaving the topic of estimating annual depreciation for future research.

*Monte Carlo Analysis*: As mentioned previously, this analysis uses data from previous years to estimate current industry activity, which results in some uncertainty. In order to account for this uncertainty, a probabilistic sensitivity analysis was conducted using Monte Carlo analysis. This technique is based on works by McKay, Conover, and Beckman (1979) and by Harris (1984) that involves a method of model sampling. It was implemented using the Crystal Ball software product (Oracle 2013), an add-on for spreadsheets. Specification involves defining which variables are to be simulated, the distribution of each of these variables, and the number of iterations performed. The software then randomly samples from the probabilities for each input variable of interest.

Monte Carlo methods use repeated random sampling to draw insights into some phenomena of interest. The important thing to note about Monte Carlo is that the simulation methods do not require true randomness to draw conclusions. A bounded or constrained domain of values that approximate pseudo-randomness can be, and in practice often are, used with Monte Carlo simulations. This method is particularly useful for sensitivity analysis because it can trace variations to a particular input. By moving away from deterministic sampling, Monte Carlo provides a more accurate probabilistic picture. The avoidance of deterministic modeling also means that instead of doing simulations with a single point, a range of probabilities covering all scenarios can be incorporated.

For this analysis, the largest 30 industries, as measured by value added contributing to assembly-centric manufacturing, is varied using a triangular distribution (see Table 1). The top 30 are varied so that the identification of the top 20 has significant robustness. The lower bound is 25 % below the calculated value while the upper bound is 25 % above it. These 30 industries represent 54 % of the value added for assembly-centric manufacturing. The most likely value is the calculated base case value. The remaining industries are varied together by +/- 10 %. These distributions apply to the industry, occupation, industry-occupation, and depreciable assets examinations. For the industry occupation combination, the top 20 industry occupation combinations were varied by +/- 25 %, which tests the results under significant error with wide boundaries. Although different levels of variation could be selected, it has been shown that this level of error is reasonable (European Science and Technology Observatory 2006; Temurshoev 2015). The industries included in the Monte Carlo analysis are listed in Table 1. This simulation contained 10 000 iterations.

**Results**

This paper examines supply chain value added in the U.S. for producing assembly-centric products. An input-output model is used for this examination and is combined with labor data and data on assets. A sensitivity analysis is conducted on the model using Monte Carlo simulation. Figure 3 illustrates the data and the value added for assembly-centric manufacturing. On the left of the figure are the assembly-centric commodities, including machinery, transportation equipment, and computers/electronics. The dollars associated with these products flows from the purchase of the commodities on the left to the industries that contributed to the commodity. From the industries it flows to owners/investors in the form of gross operating surplus, to employees in the form of compensation, and to the government in the form of taxes (note that only taxes on production are represented). Figure 3 is a summary of the data, as there are over 350 industries and 800 occupations. The model facilitates estimating value added for industry and occupation combinations for each commodity examined. That is, an estimation of the value added of a particular occupation from a particular industry can be estimated for a selected commodity. A breakout of the largest 20 resource areas by industry, occupation, and industry occupation combination is discussed below. Also discussed is the top 20 depreciable assets broken out into building assets and machinery assets. As discussed previously, Figure 2B illustrates the data categorization. The tables discussed below follow this categorization.

As seen in Figure 4, the distribution of industry cost is consistent with Pareto's principle where 80 % of the cost is due to 20 % of the cause (80$^{th}$ percentile). The x-axis in the line graph is the percentile of industry cost while the y-axis is the cumulative percent cost; therefore, the far left of the line graph represents those industries where the highest cost occurs while the right side represents those with the least impact. As one moves from left to right, the line represents the cumulative cost of industries, ranked from highest to lowest, aggregated together. If you move to the 80$^{th}$ percentile on the x-axis, which accounts for the top 20 % of industries by cost, one can see that the line graph corresponds with nearly 80 % of the total cost from assembly-centric products. For occupations, the 80th percentile accounts for over 90 % of the occupation costs. The Gini coefficient for the industry line (i.e., value added) in this figure is 0.75 and for the occupations (i.e., compensation) it is 0.86, suggesting very unequal distribution.

*Industry*: For each iteration of the Monte Carlo analysis, the largest 20 industries (4.9 %) out of the 405 contributing to assembly-centric products, are identified. These 20 industries represent 46 % of the total value added associated with assembly-centric products. The number of times an industry was identified as being in each rank (i.e., rank 1 through 20) is shown in Table 2. *Wholesale trade* (NAICS 420000) was identified as the largest contributor to value added for 9985 iterations or 99.9 %, meaning that wholesale trade contributes more to assembly-centric products than each of the assembly-centric industries. In addition to *wholesale trade*, a number of other non-manufacturing industries appear in the top 20, including *management of companies and enterprises* (NAICS 550000), *oil and gas extraction* (NAICS 211000), *truck transportation* (NAICS 484000), *legal services* (NAICS 541100), *monetary authorities and depository credit intermediation* (NAICS 52A000), and *employment services* (NAICS 561300). It is important to remember that oil and gas extraction includes more than energy, it is also the raw material for other items such as plastic. *Aircraft manufacturing* (NAICS 336411), which includes the final assembly of an aircraft, was the second largest contributor to assembly-centric manufacturing for 8828 iterations (88.3 %), more than any other industry. Management of companies and enterprises was the third largest for 8085 iterations (80.9 %). On the right of the table is the baseline estimate of value added for the industry. The top three had a value added of \$73.5 billion, \$49.2 billion, and \$41.2 billion. The Monte Carlo analysis had 30 industries being identified as being among the top 20 with 21 of them being manufacturing industries.

One issue with measuring only US value added is that the cost of imported intermediate goods and services is not measured. Table 3 provides the frequency of each industry's contribution to assembly-centric products, similar to Table 2, except that imports are included. The boundaries of this analysis is to examine US activity; therefore, imports are treated as an external cost. That is, the supply chain of imported goods is not broken out, but rather treated as a unit cost. As seen in Table 3, wholesale trade remains the largest, followed by aircraft manufacturing and the management of companies and enterprises.

Table 4 provides value added estimates for assembly-centric products by industry groupings with and without imports. Transportation equipment is the largest contributor, but it is important to remember that this includes the manufacture of airplanes, automobiles, and trains. Figure 5 provides a cumulative probability graph for value added and value added with imports from the Monte Carlo analysis results.

*Occupation*: For each iteration of the Monte Carlo analysis, the largest 20 occupations (2.4 %) out of 820 total contributing to assembly-centric products, was identified. The top 20 occupations from the base case represent 22 % of valued added and 40 % of compensation associated with these products. Note that total compensation accounts for 56 % of the value added for assembly-centric products. The remaining 44 % is gross operating surplus, which goes to the owners and investors, and taxes on production. *Team assemblers* was identified as the largest occupation in all of the Monte Carlo iterations and accounted for \$27.24 billion of the base case value added, as seen in Table 5. *General and operations managers* was identified as being the second largest for all iterations and accounted for \$23.23 billion of the base case value added. *Wholesale and manufacturing sales representatives* was third for 6086 iterations (60.9 %). A number of occupations in the top 20 are non-production, including sales, engineers, accountants, software developers, material movers, and truck drivers to name a few. A summary of total compensation by broad compensation categories is provided in Table 6A. *Production, management,* and *architecture and engineering occupations* account for the three largest categories. Industry groups often have particular interest in production occupations that contribute to assembly-centric goods; therefore, the top 25 for the base case are listed in Table 6B. Additionally, Table 6C shows the top 25 occupations when including the associated taxes and gross operating surplus. For example, we can see that team assemblers accounts for $27.24 billion, as seen in Table 6B. When including taxes on production and gross operating surplus, team assemblers accounts for $52.96 billion. This is estimated by assuming that the proportion of gross operating surplus and taxes to compensation are constant within an industry; thus, gross operating surplus and taxes are being proportionately associated with labor, as these items correlate with each other. When including the gross operating surplus and taxes, the top 20 account for 39 % of value added compared to the previously discussed 22 %.

*Occupation by Industry*: The largest 20 out of 332 100 occupation industry combinations contributing to assembly-centric products are identified for each iteration of the Monte Carlo analysis. These account for 5 % of the value added in the base case. As seen in Table 7, *sales representatives* from *wholesale trade* was identified as the largest industry/occupation combination for 7423 (74.2 %) of the iterations and accounted for $7.3 billion of the base case value added. *Team assemblers* from the automobile manufacturing industry was identified as the second largest for 7422 of the iterations (74.2 %). These two occupation by industry categories have by far the greatest value added. The next 6 top categories are relatively similar in value added, with baseline value added of 2.3 billion to 3.2 billion. *Truck drivers* for *truck transportation* was identified as the third largest for 4324 of the iterations (43.2 %). A number of non-manufacturing industries and activities were among the top 20. For example, financial managers in the management of companies and enterprises were identified as being the 10$^{th}$ largest in 2789 of the iterations (27.9 %) and industrial engineers in aircraft manufacturing were identified as being the seventeenth largest in 1485 of the iterations (14.9 %). In total, the Monte Carlo analysis has 33 occupation industry combinations appearing in the top 20 with 20 of them being in non-manufacturing industries and 11 being in manufacturing industries.

*Depreciable Assets*: In addition to value added and compensation, the depreciable assets contributing to assembly-centric production was also examined by industry. Two types of assets were examined: buildings and machinery/equipment within the manufacturing industry. Depreciable assets outside of the manufacturing industry are excluded due to data limitations. For each iteration of the Monte Carlo analysis, the 20 industries with the largest value of depreciable building assets were identified as well as the 20 industries with the largest value of depreciable machinery/equipment assets. The results are shown in Table 8 and Table 9. As might be expected, industries that produce large items such as aircraft and automobiles tend to have a higher level of depreciable building assets. *Semiconductor manufacturing* (NAICS 334413), which is known for requiring large levels of investment, was identified as having the largest level of machinery/equipment assets for 9595 iterations (96.0 %). The total depreciable assets, retirements, and capital expenditures for manufacturing buildings and machinery is shown in Table 12. Over the period of one year, new and replaced machinery/equipment represents approximately 5.8 % of the total machinery/equipment assets at the end of the year; therefore, assuming this rate continues unchanged, it would take a little over 17 years to completely replace all the machinery/equipment with its new or improved replacements machinery/equipment.

In addition to considering the depreciable machinery/equipment assets, it is also important to consider the machinery/equipment that was purchased during the study period. Recall that capital purchases are not part of the costs calculated in Table 2 through Table 7, as they include goods and services that are used up in the production process.[2] The results of the Monte Carlo analysis on building capital purchased and machinery capital purchased by industry for assembly-centric products are provided in Table 10 and Table 11. Semiconductor and related device *manufacturing* (NAICS 334413) had the highest building capital cost at $1.97 billion. This cost would be below the top 20 rankings in the industry rankings in Table 2; that is, the $1.97 billion is too small to rank in Table 2. The same sector, NAICS 334413, also had the largest purchase of machinery at $4.29 billion. This value would also be below the top 20 rankings in Table 2. The total capital purchases of buildings for all manufacturing associated with assembly-centric products was $10.14 billion and for machinery it was $41.99 billion. For buildings this would rank around 13th in the industry rankings in Table 2. For machinery, this would rank 3rd.

*Energy*: For electricity, there is an additional $1.26 of value added and $0.39 of imports per dollar of value added of electricity generation and distribution. For natural gas distribution, there is an additional $2.63 of value added and $1.34 of imports per dollar of value added. Table 13 provides the value added of electricity and natural gas that contributes to assembly-centric manufacturing. Also included is the estimate of other industries contributing to electricity and natural gas. The table is broken into the end use of the energy. Process heating constituted $6775 million (calculated as the sum of electricity and natural gas) of the total $27 830 million. Process cooling and refrigeration was $508 million, machine drive was $3443 million. Facility heating and cooling constituted $2637 million and lighting was $658 million. Among value added baseline rankings (Table 2), the total $13 914 in value added energy would rank 12th while the total $27 830 in value added and imports would rank 8th in the value added and imports table (Table 3).

Another source of energy is gasoline and diesel for the transportation of goods. Unfortunately, these fuels cannot be explicitly broken out, as the data categorization does not facilitate it. The NAICS code 324110 for Petroleum refineries is the closest match and accounts for $39.98 billion in value added and imports when including associated industry activity. This estimate would then rank 3rd in the value added with imports table (Table 3). Petroleum refineries, however, make products other than gasoline and diesel, including benzene, jet fuel, asphalt, petroleum waxes, and oils among others. Also, the price of oil fluctuates significantly; therefore, an estimate might change rapidly.

**Summary and Discussion**

Public entities have a significant role in the US innovation system (Block and Keller 2016). One objective of public innovation is to enhance economic security and improve our quality of life (National Institute of Standards and Technology 2017), which is achieved in part by advancing efficiency in which resources are consumed or impacted by production. Without an input-output model or similar analyses, there is limited understanding concerning the use and costs of resources for manufacturing at a national level. This paper examined, in dollar terms, the resources consumed in the production of assembly-centric commodities in the United States. The analysis identified the top 20 industries, occupations, and industry occupation combinations contributing to production. This paper also discussed purchased electricity and natural gas by end use along with depreciable assets associated with assembly-centric commodities. A Monte Carlo sensitivity analysis confirms that the rankings remain relatively stable in the face of significant error; therefore, the results from this analysis can be used with some confidence to prioritize efforts in the US to advance efficiency in assembly-centric manufacturing.

The results show that costs for assembly-centric manufacturing are disproportionally distributed, as illustrated in Figure 4. The Gini coefficient for the industry line (i.e., value added) in this figure is 0.75

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[2] It is important to note that the capital purchases and the goods and services used up in production cannot be added together as it would be double counting some values.

and for the occupations (i.e., compensation) it is 0.86, suggesting very unequal distribution. The Gini coefficient is a measure of statistical dispersion where 0 represents equal distribution (i.e., each cost category represents the same proportion of total cost) and 1 represents total unequal distribution (Klein 2002). The implication of costs being unequally distributed is that reductions in resource consumption in some cost areas can disproportionally reduce total resource consumption. Efforts to develop and disseminate innovative solutions can, therefore, be targeted to these areas, resulting in larger efficiency improvements than might otherwise be achieved. This paper identifies those high resource consumption areas for assembly-centric manufacturing, as discussed below.

Compensation as a whole accounted for 42.1 % of costs with imports, taxes, and gross operating surplus accounting for the remaining portion. Approximately 26.4 % of the cost of compensation for assembly-centric manufacturing was attributed to *production occupations*, the largest category. *Management* was the second largest labor category, accounting for 15.9 % of labor and *architecture and engineering occupations* were the third largest with 11.3 %. *Business and financial operations* (9.1 %)*; office and administrative support* (8.4 %)*; computer and mathematics* (6.3 %)*; sales and related* (6.1 %)*, transportation and material moving operations* (5.3 %); and *installation, maintenance, and repair occupations* (5.1 %) were ranked 4th through 9th. The remaining occupations were each less than 5 %. Moreover, production is a major labor cost, but it accounts for less than a third of the total labor cost. Office work, including engineering, business, administrative, mathematical, sales, and legal related activities, account for a significant portion (42.0 %) of the labor cost. Efficiency efforts that reduce the office burden, such as software interoperability standards or utilizing information technology, has the potential to have a significant impact on labor cost. The management burden, which is the second largest cost, might be reduced by having fewer layers of management and, thus, expanding the average span of manager control (Economist 2008). Public entities can facilitate reduced layers by providing research into the impact of expanding manager control.

The largest industry category (i.e., broad category level) was *Transportation equipment*, accounting for 24.8 % of the value added with imports. *Machinery* and *Computer and electronics* were the second and third largest with 12.5 % and 12.2 % of the value added with imports, respectively. It is not surprising that the assembly-centric industries appear in the top cost categories, as it is common for the industry being examined to have the largest costs rather than its suppliers. The fourth largest, is the refining and forming of metal with 11.7 % of the costs. There may be an opportunity for efficiency improvement in this category, as the USGS estimates that 15 % of steel mill products end up as scrap in the manufacturing process (Fenton 2001). Other sources cite that at least 25 % of liquid steel and 40 % of liquid aluminum does not make it into a finished product due primarily to metal quality (25 % of steel loss and 40 % of aluminum loss), the shape produced[3] (10 % to 15 % of loss), and defects in the manufacturing processes (5 % of loss) (Allwood and Cullen 2012). This means that as much as 1.25 % of the machinery used to produce assembly-centric products, or $6.9 billion in machinery assets, is being used to produce defective products that contain steel. Material losses mean there is the possibility of producing the same goods using less material, which could have rippling effects up and down the supply chain. There would be reductions in the burden of transportation, material handling, machinery, inventory costs, and energy use along with many other activities associated with handling and altering materials.

At the more detailed NAICS code level, *Wholesale trade*, *aircraft manufacturing* (i.e., the final assembly of aircraft), and the *management of companies and enterprises* were the industries with the largest

[3] The steel and aluminum industry often produce standard shapes rather than customized shapes tailored to specific products. This results in needing to cut away some portion of material, which ends up as scrap.

contribution to assembly-centric manufacturing, even when including imports; therefore, public efficiency improvement efforts in these areas are likely to have bigger impact than efficiency improvement efforts in other areas. *Wholesale trade*, for example, is an activity that distributes intermediate goods and services to producers. There may be opportunities for efficiency improvement in connecting intermediate goods with producers through Information technology similar to the impact that it has had on retail trade. The appearance of *management of companies and enterprises*, which is largely company headquarters, in the top three industry rankings reiterates the cost impact of management and other non-manufacturing activities. A number of other non-manufacturing industries were in the top 20 contributing to assembly-centric products with two being in the top five. This suggests that non-manufacturing activities are a significant portion of the value added for these products.

In terms of occupation activities at the detailed level, *team assemblers*, *general and operations managers*, and *sales representatives* were the largest occupations; therefore, efficiency improvements in these areas are likely to have bigger impacts than efficiency improvements in other areas. A number of occupations were non-production activities, further supporting the significant role that non-manufacturing activities play in assembly-centric goods. Among them were *sales representatives*, *supervisors*, *engineers*, *accountants*, *software developers*, *managers*, *material movers*, and *truck drivers*. In terms of industry occupation combinations, *sales representatives* from *wholesale trade* and *team assemblers* from the *automobile manufacturing* industry represented the top two combinations. The appearance of sales in both the top occupation costs and top industry/occupation costs reiterates that a significant amount of resources are consumed in connecting intermediate goods with the producers in the next step of the supply chain.

Energy in the form of electricity and natural gas were discussed separately, but would rank $8^{th}$ in the value added and imports table (Table 3). Process heating, such as the heating that occurs in metal refining and forming, is a significant consumer of electricity and natural gas along with machine drive, making these end use categories an opportunity for efficiency improvement efforts. Petroleum refineries, which includes fuel among other things, would rank $3^{rd}$. Electricity, natural gas, and petroleum refineries together (including all associated industries and imports) would rank $2^{nd}$ in the value added and imports table (Table 3). It is important to note that there are some limitations of this modeling approach in measuring energy consumption during the different stages of the manufacturing process.

*Truck transportation* was within the top 20 industries contributing to assembly-centric products and appeared in the top 20 industry occupation categories. *Laborers and material movers* along with *truck drivers* was among the top 20 occupation components and both appeared in the list of industry occupation combination categories. The appearance of these suggests that the movement of goods is a significant cost and these estimates don’t even include the energy for onsite transportation or fuel for trucks. The total of the transportation industries, their associated costs (e.g., fuel and repairs), *laborers and material movers* in other industries, and associated costs (i.e., gross operating surplus and taxes) accounts for \$70.2 billion or 5.9 % of the value added with imports, which would rank second in the value added with imports seen in Table 3. There might be opportunities for efficiency improvement in truck transportation, as approximately 20 % of truck miles are driven with no product being transported (Bureau of Transportation Statistics 2015). Reducing these empty miles would decrease labor, capital expenditures, and traffic. Several methods are being considered across the global economy to reduce these excess miles. In Germany, a new auction platform aims to improve truck space utilization (Science Daily 2011). Other efforts to co-load or ride-share have also received some attention. Efforts to develop and disseminate Innovative solutions like these might reduce the resources consumed in the transport of goods.

*Sales representatives* and, as previously mentioned, *wholesale trade* appear as top costs, suggesting that the logistics of storing and distributing intermediate goods consumes significant resources. Advancing the dissemination of information on intermediate products might reduce the sales burden needed for distributing intermediate parts and components to producers. In addition to sales activity, wholesalers function as a warehouse to store inventory. Note that additional warehousing costs are categorized as "warehousing and storage" (NAICS 493000). Warehousing is needed to buffer for unpredictable fluctuations in demand. Thus, improved forecasting in demand might lessen the need for inventory/warehousing and in turn reduce wholesale trade costs.

Multiple types of engineers are included in both the occupation and industry occupation combination lists. Reducing redundancy such as data re-entry might reduce the amount of engineering needed for production. Accountants and lawyers appear among the top 20 occupations as well.

Public entities have a significant role in the US innovation system, including developing, disseminating, and nurturing numerous innovations and industries. One implicit objective of public innovation is to improve the efficiency in which resources are consumed or impacted by production. Public entities and other change agents might use this model and results to identify efficiency improvement efforts that will make the biggest impact on industry per dollar of expenditure.

**Conclusion**

The results of this analysis show that costs for assembly-centric manufacturing are disproportionally distributed, suggesting that reductions in resource consumption in some cost areas can disproportionally reduce total resource consumption. Efforts to develop and disseminate innovative solutions can, therefore, be targeted to these areas, resulting in larger efficiency improvements than might otherwise be achieved. A number of supply chain cost areas were identified, including *wholesale trade,* energy*, truck transportation,* and the *management of companies and enterprises.* Additionally, *team assemblers, general operations managers,* and *sales representatives (wholesale and manufacturing, except technical and scientific products)* were identified as top labor costs. A sensitivity analysis varying the top 30 industry costs confirms that the rankings of the supply chain categories and labor costs is fairly robust. Future research might investigate the consumption of non-monetary resources such as environmental impacts and natural resources.

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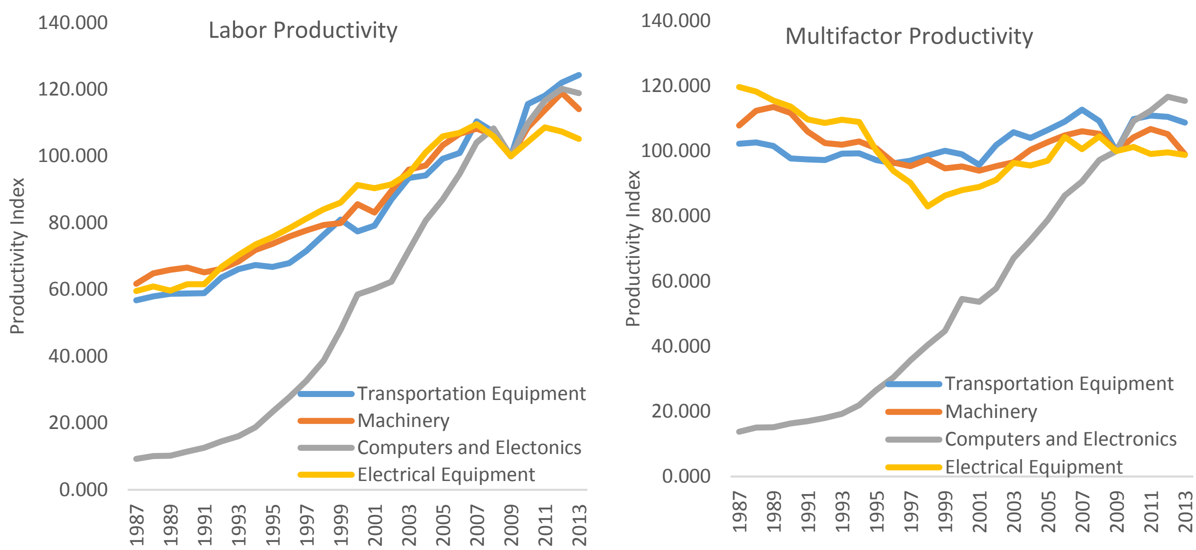
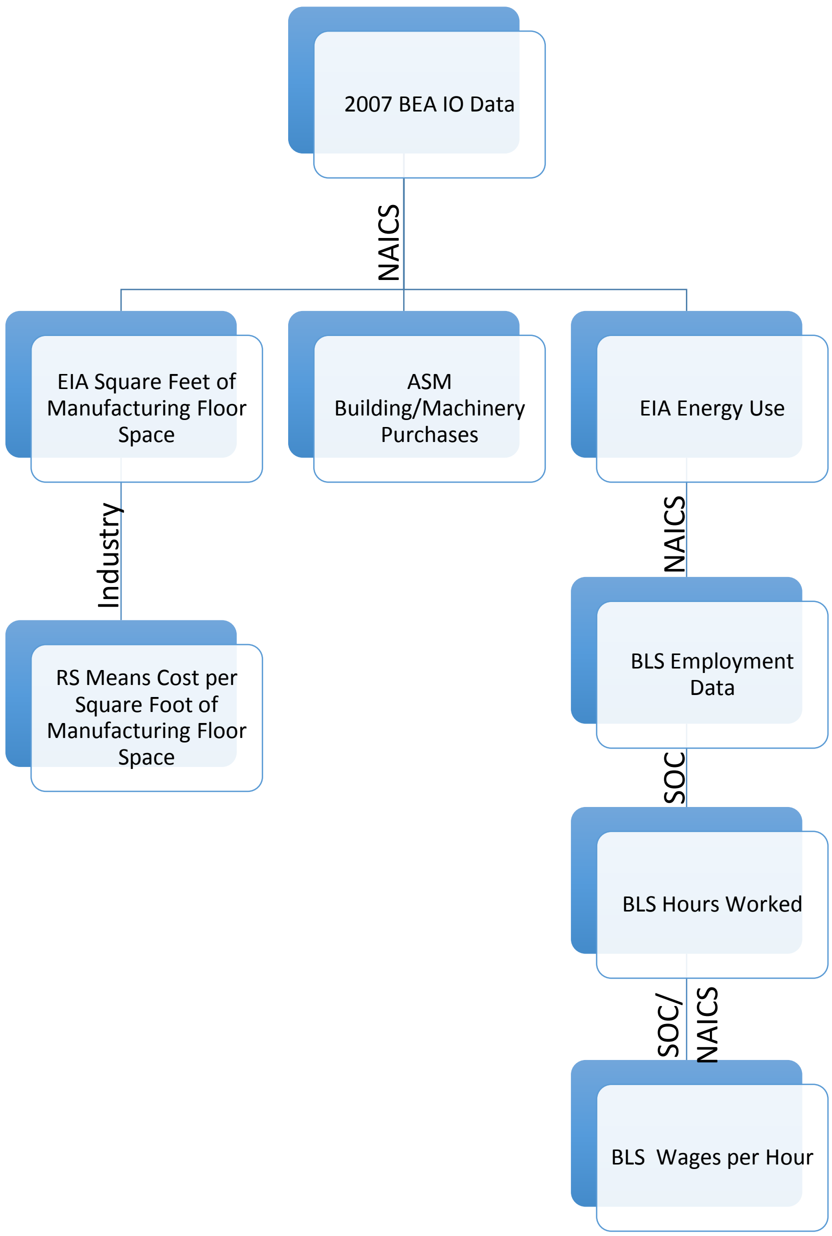
Figure 1: Productivity in Assembly-Centric Manufacturing



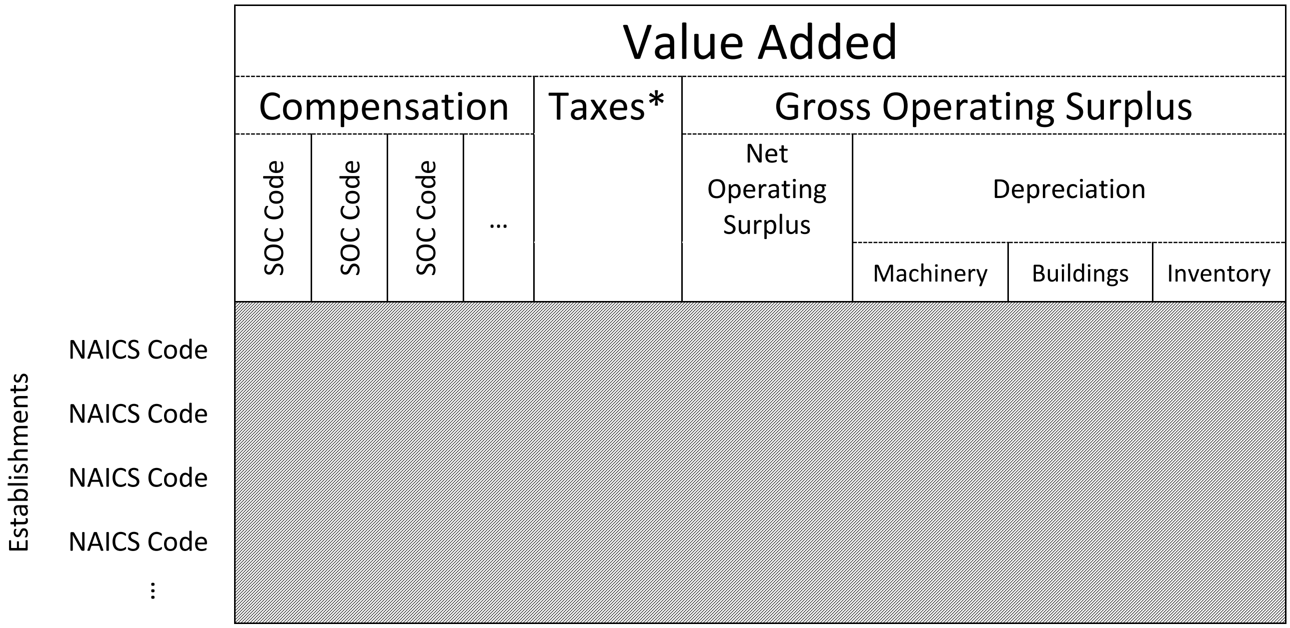

Source: Bureau of Labor Statistics. BLS Productivity Statistics. https://www.bls.gov/bls/productivity.htm

Figure 2A: Map of Data Connections




Note: NAICS and SOC are used in the figure to indicate the classification system to link data sets. NAICS is the North American Industry Classification System and SOC is the Standard Occupation Classification system.

Figure 2B: Illustration of Data Categorization




* Taxes on production

Table 1: Assumptions for Monte Carlo Analysis

| NAICS | Description | Distribution | |
|---|---|---|---|
| 420000 | Wholesale trade | +/- 25 % | Triangular Distribution |
| 336411 | Aircraft manufacturing | +/- 25 % | Triangular Distribution |
| 550000 | Management of companies and enterprises | +/- 25 % | Triangular Distribution |
| 336112 | Light truck and utility vehicle manufacturing | +/- 25 % | Triangular Distribution |
| 336111 | Automobile manufacturing | +/- 25 % | Triangular Distribution |
| 334413 | Semiconductor and related device manufacturing | +/- 25 % | Triangular Distribution |
| 211000 | Oil and gas extraction | +/- 25 % | Triangular Distribution |
| 334511 | Search, detection, and navigation instruments manufacturing | +/- 25 % | Triangular Distribution |
| 336412 | Aircraft engine and engine parts manufacturing | +/- 25 % | Triangular Distribution |
| 334510 | Electromedical and electrotherapeutic apparatus manufacturing | +/- 25 % | Triangular Distribution |
| 336413 | Other aircraft parts and auxiliary equipment manufacturing | +/- 25 % | Triangular Distribution |
| 331110 | Iron and steel mills and ferroalloy manufacturing | +/- 25 % | Triangular Distribution |
| 336370 | Motor vehicle metal stamping | +/- 25 % | Triangular Distribution |
| 333111 | Farm machinery and equipment manufacturing | +/- 25 % | Triangular Distribution |
| 334220 | Broadcast and wireless communications equipment | +/- 25 % | Triangular Distribution |
| 336611 | Ship building and repairing | +/- 25 % | Triangular Distribution |
| 333130 | Mining and oil and gas field machinery manufacturing | +/- 25 % | Triangular Distribution |
| 333120 | Construction machinery manufacturing | +/- 25 % | Triangular Distribution |
| 336390 | Other motor vehicle parts manufacturing | +/- 25 % | Triangular Distribution |
| 484000 | Truck transportation | +/- 25 % | Triangular Distribution |
| 541100 | Legal services | +/- 25 % | Triangular Distribution |
| 52A000 | Monetary authorities and depository credit intermediation | +/- 25 % | Triangular Distribution |
| 333920 | Material handling equipment manufacturing | +/- 25 % | Triangular Distribution |
| 336350 | Motor vehicle transmission and power train parts manufacturing | +/- 25 % | Triangular Distribution |
| 561300 | Employment services | +/- 25 % | Triangular Distribution |
| 33391A | Pump and pumping equipment manufacturing | +/- 25 % | Triangular Distribution |
| 33399A | Other general purpose machinery manufacturing | +/- 25 % | Triangular Distribution |
| 533000 | Lessors of nonfinancial intangible assets | +/- 25 % | Triangular Distribution |
| 531ORE | Other real estate | +/- 25 % | Triangular Distribution |
| 332720 | Turned product and screw, nut, and bolt manufacturing | +/- 25 % | Triangular Distribution |
| | All other industries | +/- 10 %* | Triangular Distribution |

* Calculated as a multiplier for all industries

Figure 3: Dollar Flow for Selected Commodities (private sector)

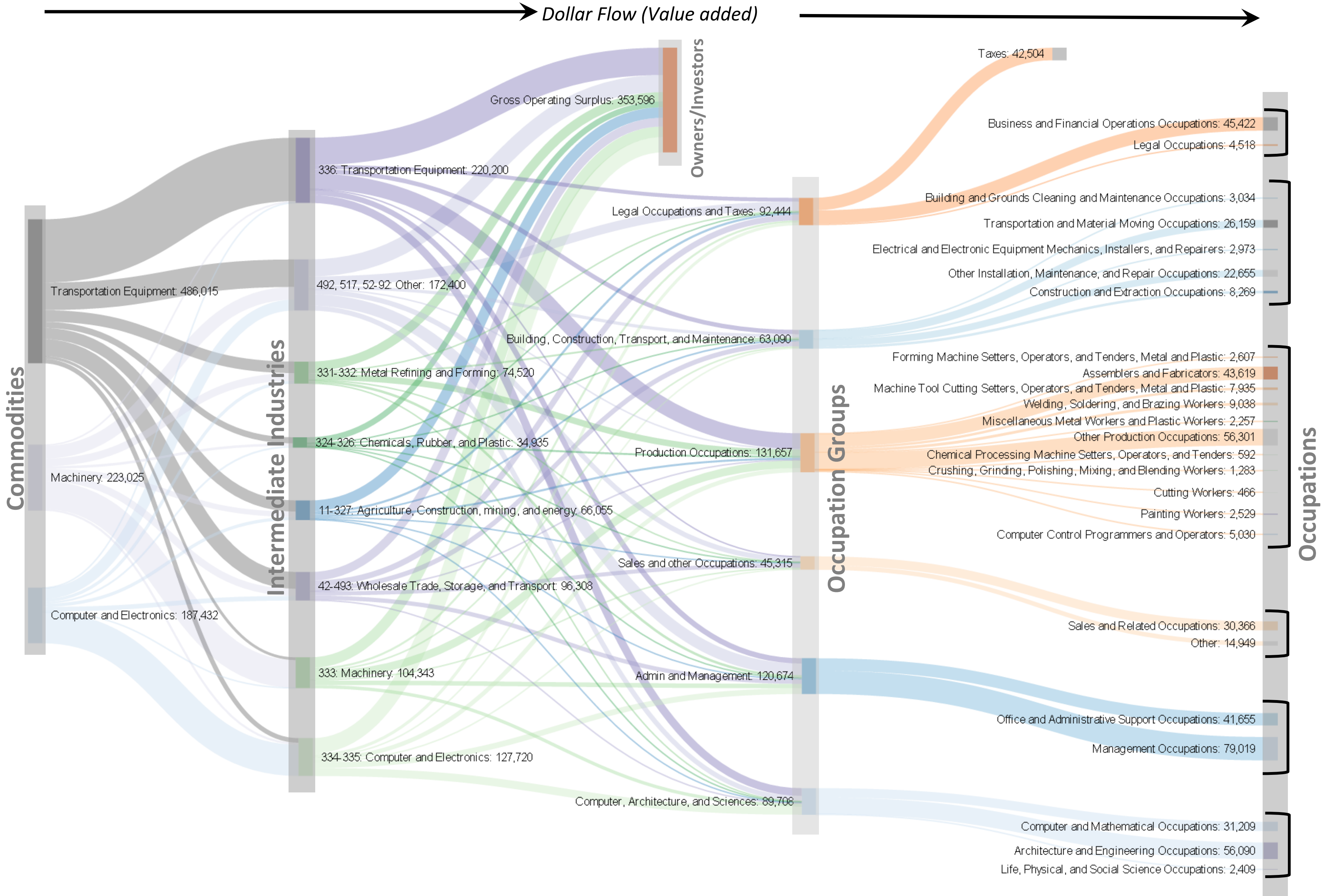


Table 2: Percent of Monte Carlo Iterations by Industry by Rank, Top 20 Value Added Components of Assembly-Centric manufacturing (ordered by base case rank)

| | | Rank - Top 20 | | | | | | | | | | | | | | | | | | | | Baseline |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NAICS | Description | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | ($Billion) |
| 420000 | Wholesale trade | 99.9 | 0.2 | | | | | | | | | | | | | | | | | | | 73.45 |
| 336411 | Aircraft manufacturing | 0.2 | 88.3 | 11.5 | 0.1 | | | | | | | | | | | | | | | | | 49.24 |
| 550000 | Management of companies and enterprises | | 11.5 | 80.9 | 7.6 | | | | | | | | | | | | | | | | | 41.24 |
| 336112 | Light truck and utility vehicle manufacturing | | 0.0 | 7.7 | 90.9 | 1.4 | | | | | | | | | | | | | | | | 33.44 |
| 336111 | Automobile manufacturing | | | | 1.4 | 77.2 | 15.4 | 4.9 | 1.1 | 0.0 | 0.0 | | | | | | | | | | | 24.35 |
| 334413 | Semiconductor and related device manufacturing | | | | | 15.2 | 46.6 | 23.1 | 11.3 | 3.2 | 0.5 | 0.0 | | | | | | | | | | 21.16 |
| 211000 | Oil and gas extraction | | | | | 4.5 | 24.4 | 35.4 | 23.7 | 8.8 | 2.6 | 0.6 | 0.0 | | | | | | | | | 19.71 |
| 334511 | Search, detection, and navigation instruments manufacturing | | | | | 1.7 | 12.5 | 28.1 | 34.1 | 14.4 | 7.1 | 1.9 | 0.2 | 0.0 | | | | | | | | 18.80 |
| 336412 | Aircraft engine and engine parts manufacturing | | | | | 0.0 | 0.7 | 4.7 | 14.9 | 31.8 | 27.8 | 14.1 | 5.8 | 0.2 | | | | | | | | 16.32 |
| 334510 | Electromedical and electrotherapeutic apparatus manufacturing | | | | | | 0.4 | 3.7 | 13.3 | 30.5 | 29.2 | 15.5 | 7.1 | 0.3 | | | | | | | | 16.13 |
| 336413 | Other aircraft parts and auxiliary equipment manufacturing | | | | | | | 0.1 | 1.3 | 7.3 | 19.1 | 34.6 | 34.0 | 3.4 | 0.1 | | | | | | | 14.28 |
| 331110 | Iron and steel mills and ferroalloy manufacturing | | | | | | | 0.0 | 0.4 | 3.9 | 13.1 | 30.9 | 45.6 | 5.6 | 0.5 | 0.1 | | | | | | 13.79 |
| 336370 | Motor vehicle metal stamping | | | | | | | | | | | 0.1 | 0.8 | 22.7 | 21.1 | 15.7 | 11.9 | 8.7 | 6.6 | 5.3 | 3.3 | 9.83 |
| 333111 | Farm machinery and equipment manufacturing | | | | | | | | | | | 0.0 | 0.4 | 17.4 | 19.3 | 15.6 | 13.4 | 10.7 | 7.6 | 5.5 | 4.3 | 9.63 |
| 334220 | Broadcast and wireless communications equipment | | | | | | | | | | | 0.0 | 0.4 | 15.7 | 18.6 | 16.5 | 13.0 | 10.1 | 8.1 | 6.6 | 4.5 | 9.59 |
| 336611 | Ship building and repairing | | | | | | | | | | | | 0.1 | 7.7 | 13.0 | 14.0 | 13.4 | 13.1 | 10.9 | 8.2 | 6.6 | 9.19 |
| 333130 | Mining and oil and gas field machinery manufacturing | | | | | | | | | 0.1 | 0.5 | 2.3 | 5.6 | 19.3 | 7.2 | 6.1 | 5.1 | 4.5 | 4.2 | 4.0 | 3.8 | 8.95 |
| 333120 | Construction machinery manufacturing | | | | | | | | | | | | | 3.1 | 7.2 | 9.9 | 12.0 | 12.6 | 12.1 | 11.2 | 9.7 | 8.76 |
| 336390 | Other motor vehicle parts manufacturing | | | | | | | | | | | | | 2.2 | 5.4 | 8.7 | 10.5 | 12.5 | 13.2 | 11.9 | 9.5 | 8.67 |
| 484000 | Truck transportation | | | | | | | | | | | | | 1.6 | 4.3 | 6.9 | 9.5 | 11.7 | 12.3 | 12.1 | 11.3 | 8.54 |
| 541100 | Legal services | | | | | | | | | | | | | 0.7 | 3.3 | 5.9 | 8.4 | 10.0 | 11.7 | 12.6 | 11.3 | 8.39 |
| 52A000 | Monetary authorities and depository credit intermediation | | | | | | | | | | | | | 0.0 | 0.1 | 0.3 | 1.1 | 2.2 | 4.4 | 6.5 | 8.7 | 7.51 |
| 333920 | Material handling equipment manufacturing | | | | | | | | | | | | | 0.0 | 0.1 | 0.3 | 1.2 | 2.1 | 4.2 | 6.3 | 8.6 | 7.50 |
| 336350 | Motor vehicle transmission and power train parts manufacturing | | | | | | | | | | | | | | 0.0 | 0.1 | 0.4 | 1.2 | 2.9 | 4.3 | 6.9 | 7.33 |
| 561300 | Employment services | | | | | | | | | | | | | | | 0.0 | 0.1 | 0.4 | 1.1 | 2.4 | 4.2 | 7.06 |
| 33391A | Pump and pumping equipment manufacturing | | | | | | | | | | | | | | | | 0.0 | 0.0 | 0.3 | 0.9 | 2.0 | 6.80 |
| 33399A | Other general purpose machinery manufacturing | | | | | | | | | | | | | | | | | 0.1 | 0.2 | 0.8 | 1.8 | 6.77 |
| 533000 | Lessors of nonfinancial intangible assets | | | | | | | | | | | | | | | | | 0.0 | 0.1 | 0.8 | 1.8 | 6.76 |
| 531ORE | Other real estate | | | | | | | | | | | | | | | | | 0.0 | 0.1 | 0.4 | 1.1 | 6.62 |
| 332720 | Turned product and screw, nut, and bolt manufacturing | | | | | | | | | | | | | | | | | 0.0 | 0.0 | 0.2 | 0.6 | 6.51 |

Table 3: Percent of Monte Carlo Iterations by Industry by Rank, Top 20 Value Added (with Imports) Components for Assembly-Centric manufacturing (ordered by base case rank)

| | | Rank - Top 20 | | | | | | | | | | | | | | | | | | | | Baseline |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NAICS | Description | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | ($Billion) |
| 420000 | Wholesale trade | 99.9 | 0.2 | | | | | | | | | | | | | | | | | | | 73.45 |
| 336411 | Aircraft manufacturing | 0.2 | 87.1 | 11.1 | 1.6 | 0.1 | | | | | | | | | | | | | | | | 49.24 |
| 550000 | Management of companies and enterprises | | 11.1 | 60.7 | 21.3 | 5.6 | 1.1 | 0.2 | 0.0 | | | | | | | | | | | | | 41.24 |
| 211000 | Oil and gas extraction | | 1.7 | 23.5 | 47.8 | 17.3 | 6.8 | 2.4 | 0.5 | 0.1 | | | | | | | | | | | | 37.25 |
| 336112 | Light truck and utility vehicle manufacturing | | 0.0 | 3.7 | 19.1 | 38.3 | 21.2 | 10.6 | 5.1 | 1.7 | 0.2 | | | | | | | | | | | 33.44 |
| 331110 | Iron and steel mills and ferroalloy manufacturing | | | 0.9 | 7.9 | 23.3 | 31.3 | 19.3 | 11.1 | 4.9 | 1.3 | 0.0 | | | | | | | | | | 31.33 |
| 334413 | Semiconductor and related device manufacturing | | | 0.1 | 1.8 | 10.4 | 21.9 | 28.4 | 19.8 | 12.3 | 4.7 | 0.6 | 0.0 | | | | | | | | | 29.25 |
| 336412 | Aircraft engine and engine parts manufacturing | | | | 0.5 | 4.2 | 12.0 | 22.4 | 28.3 | 19.8 | 10.6 | 2.1 | 0.2 | | | | | | | | | 27.78 |
| 336390 | Other motor vehicle parts manufacturing | | | | 0.0 | 0.8 | 4.6 | 12.0 | 22.6 | 31.4 | 21.0 | 6.3 | 1.2 | 0.1 | 0.0 | | | | | | | 26.07 |
| 336111 | Automobile manufacturing | | | | | 0.0 | 1.1 | 4.6 | 11.9 | 24.7 | 38.8 | 13.7 | 4.2 | 0.9 | 0.1 | | | | | | | 24.35 |
| 336413 | Other aircraft parts and auxiliary equipment manufacturing | | | | | | | 0.1 | 0.7 | 4.4 | 17.4 | 42.7 | 19.8 | 8.6 | 3.7 | 1.7 | 0.6 | 0.2 | 0.1 | | | 21.29 |
| 334511 | Search, detection, and navigation instruments manufacturing | | | | | | | | 0.0 | 0.7 | 4.5 | 20.8 | 32.6 | 17.8 | 9.5 | 5.4 | 4.2 | 2.7 | 1.5 | 0.4 | 0.0 | 19.47 |
| 334220 | Broadcast and wireless communications equipment | | | | | | | | | 0.1 | 1.4 | 8.8 | 21.0 | 24.4 | 15.3 | 9.1 | 7.3 | 5.9 | 4.7 | 1.8 | 0.2 | 18.31 |
| 336350 | Motor vehicle transmission and power train parts manufacturing | | | | | | | | | | 0.2 | 3.8 | 13.1 | 19.1 | 18.0 | 13.2 | 10.4 | 9.0 | 8.0 | 4.4 | 0.7 | 17.50 |
| 336310 | Motor vehicle gasoline engine and engine parts manufacturing | | | | | | | | | | | 0.3 | 4.2 | 18.6 | 33.4 | 31.5 | 11.2 | 0.7 | 0.0 | | | 17.38 |
| 331419 | Primary smelting and refining of nonferrous metal (except copper and aluminum) | | | | | | | | | | | | 0.0 | 0.6 | 5.7 | 21.8 | 39.0 | 28.3 | 4.4 | 0.2 | | 16.39 |
| 334510 | Electromedical and electrotherapeutic apparatus manufacturing | | | | | | | | | | | 0.9 | 3.8 | 9.4 | 12.7 | 13.4 | 13.2 | 14.0 | 16.4 | 12.1 | 3.7 | 16.27 |
| 333618 | Other engine equipment manufacturing | | | | | | | | | | | | | | 0.1 | 0.9 | 7.6 | 28.7 | 44.8 | 16.2 | 1.7 | 15.45 |
| 333120 | Construction machinery manufacturing | | | | | | | | | | | | | 0.3 | 1.0 | 2.5 | 5.2 | 8.2 | 14.4 | 39.6 | 21.9 | 14.16 |
| 333111 | Farm machinery and equipment manufacturing | | | | | | | | | | | | | | | 0.0 | 0.2 | 0.7 | 3.1 | 17.7 | 48.4 | 12.66 |
| 336370 | Motor vehicle metal stamping | | | | | | | | | | | | | | | | | | | 0.6 | 5.6 | 10.45 |
| 336360 | Motor vehicle seating and interior trim manufacturing | | | | | | | | | | | | | | | | | | | | 1.0 | 10.38 |
| 333130 | Mining and oil and gas field machinery manufacturing | | | | | | | | | | | | 0.0 | 0.0 | 0.3 | 0.6 | 1.1 | 1.7 | 2.6 | 6.8 | 11.7 | 10.30 |
| 333920 | Material handling equipment manufacturing | | | | | | | | | | | | | | | | | | 0.0 | 0.3 | 3.7 | 10.22 |
| 33399A | Other general purpose machinery manufacturing | | | | | | | | | | | | | | | | | | | 0.0 | 1.2 | 9.67 |
| 336611 | Ship building and repairing | | | | | | | | | | | | | | | | | | | | 0.2 | 9.20 |
| 484000 | Truck transportation | | | | | | | | | | | | | | | | | | | | 0.0 | 8.73 |
| 332720 | Turned product and screw, nut, and bolt manufacturing | | | | | | | | | | | | | | | | | | | | 0.0 | 8.64 |

Table 4: Value Added Statistics from Monte Carlo Analysis on US Assembly Centric Manufacturing ($millions 2014)

| | Value Added | | | | | Value Added + Imports | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| NAICS Codes and Description | Base Case | Base Case % | Median | Minimum | Maximum | Base Case | Base Case % | Median | Minimum | Maximum |
| 11: Agriculture | 2 546 | 0.3% | 2 546 | 2 292 | 2 795 | 3 289 | 0.3% | 3 289 | 2 961 | 3 610 |
| 21A: Energy - Processes | 4 848 | 0.5% | 4 847 | 4 364 | 5 321 | 4 898 | 0.4% | 4 897 | 4 409 | 5 376 |
| 21B: Energy - Facilities | 1 038 | 0.1% | 1 038 | 935 | 1 140 | 1 044 | 0.1% | 1 044 | 939 | 1 146 |
| 21C: Energy - Other/Undesignated Onsite | 2 990 | 0.3% | 2 990 | 2 692 | 3 282 | 3 013 | 0.3% | 3 012 | 2 712 | 3 307 |
| 21D: Oil and Gas Extraction | 19 709 | 2.2% | 19 768 | 14 903 | 24 570 | 37 246 | 3.1% | 37 357 | 28 164 | 46 432 |
| 21E: Mining | 10 721 | 1.2% | 10 719 | 9 650 | 11 768 | 11 794 | 1.0% | 11 792 | 10 616 | 12 945 |
| 2213: Other Utilities | 166 | 0.0% | 166 | 149 | 182 | 166 | 0.0% | 166 | 149 | 182 |
| 331-332: Metal Refining and Forming | 74 520 | 8.3% | 74 545 | 66 218 | 83 277 | 137 940 | 11.7% | 138 008 | 121 949 | 154 902 |
| 333: Machinery | 104 339 | 11.6% | 104 314 | 90 533 | 118 621 | 147 794 | 12.5% | 147 821 | 129 484 | 167 025 |
| 334: Computer and Electronics | 108 809 | 12.1% | 108 846 | 95 878 | 121 731 | 144 045 | 12.2% | 144 081 | 127 306 | 161 167 |
| 335: Electrical Equipment | 18 910 | 2.1% | 18 907 | 17 022 | 20 757 | 30 024 | 2.5% | 30 019 | 27 026 | 32 955 |
| 336: Transportation Equipment | 220 198 | 24.4% | 220 098 | 195 819 | 246 705 | 293 418 | 24.8% | 293 274 | 263 174 | 325 720 |
| 324-326: Chemicals, Rubber, and Plastic | 34 935 | 3.9% | 34 929 | 31 446 | 38 345 | 53 930 | 4.6% | 53 921 | 48 544 | 59 195 |
| 23-327: Construction and Other Materials | 24 035 | 2.7% | 24 031 | 21 635 | 26 381 | 35 612 | 3.0% | 35 607 | 32 056 | 39 089 |
| 42: Wholesale Trade | 73 448 | 8.1% | 73 245 | 55 268 | 91 694 | 73 448 | 6.2% | 73 245 | 55 268 | 91 694 |
| 44-45: Retail Trade | 4 033 | 0.4% | 4 033 | 3 631 | 4 427 | 4 033 | 0.3% | 4 033 | 3 631 | 4 427 |
| 48-49: Transportation | 16 290 | 1.8% | 16 302 | 13 590 | 18 972 | 16 800 | 1.4% | 16 813 | 14 027 | 19 554 |
| 493: Warehousing and Storage | 2 537 | 0.3% | 2 537 | 2 284 | 2 785 | 2 537 | 0.2% | 2 537 | 2 284 | 2 785 |
| 492, 517: Communications | 10 627 | 1.2% | 10 626 | 9 566 | 11 665 | 10 643 | 0.9% | 10 641 | 9 580 | 11 682 |
| 52: Finance, Insurance, and Real estate | 27 370 | 3.0% | 27 407 | 23 730 | 31 560 | 28 013 | 2.4% | 28 049 | 24 318 | 32 252 |
| 53: Equipment Rental | 10 063 | 1.1% | 10 072 | 8 219 | 11 885 | 10 063 | 0.9% | 10 072 | 8 219 | 11 885 |
| 54: Legal and Professional Services | 27 384 | 3.0% | 27 390 | 23 883 | 30 869 | 28 237 | 2.4% | 28 247 | 24 654 | 31 802 |
| 541: Engineering, Consulting, and Research | 13 801 | 1.5% | 13 799 | 12 423 | 15 148 | 15 484 | 1.3% | 15 481 | 13 938 | 16 996 |
| 55: Management of Companies | 41 242 | 4.6% | 41 208 | 31 042 | 51 354 | 41 242 | 3.5% | 41 208 | 31 042 | 51 354 |
| 56: Admin and Support | 21 855 | 2.4% | 21 856 | 19 001 | 24 901 | 21 928 | 1.9% | 21 930 | 19 061 | 24 988 |
| 485, 511-515, 61-92: Other | 25 681 | 2.8% | 25 677 | 23 116 | 28 188 | 25 786 | 2.2% | 25 782 | 23 211 | 28 303 |
| All Industries | 902 098 | 100.0% | 902 005 | 839 451 | 973 031 | 1 182 427 | 100.0% | 1 182 431 | 1 103 662 | 1 269 776 |

Figure 4: Line Graph of the Cumulative Percent of cost by Percentile of Industry/Occupation Cost (Assembly-Centric Products)

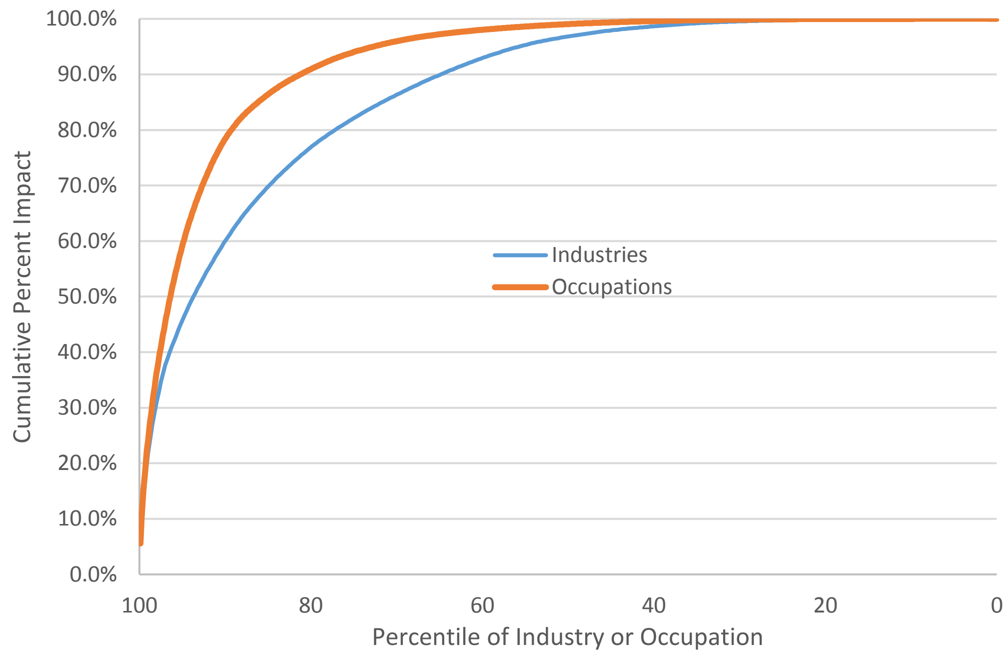



Figure 5: Cumulative Probability for Value Added from Monte Carlo Analysis

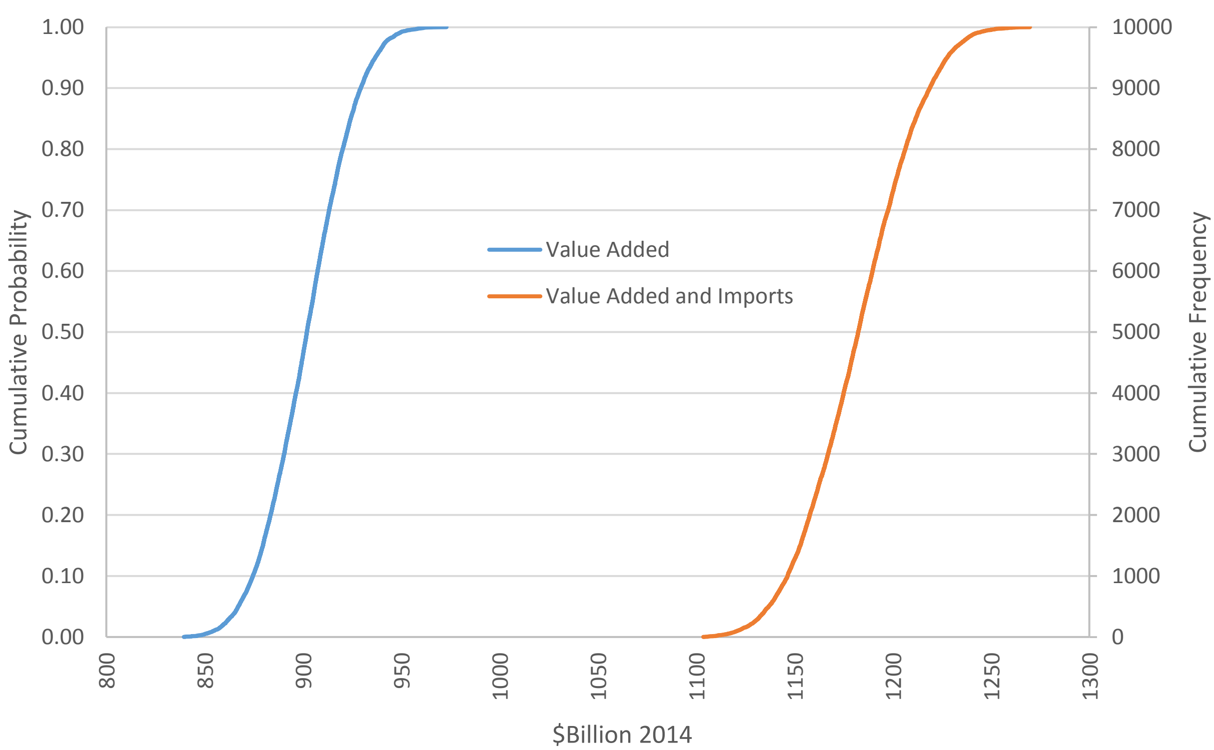


Table 5: Percent of Monte Carlo Iterations by Occupation by Rank, Top 20 Occupation Components for Assembly-Centric manufacturing (ordered by base case rank)

| | | Rank - Top 20 | | | | | | | | | | | | | | | | | | | | Baseline |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NAICS | Description | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | ($Billion) |
| 512092 | Team Assemblers | 100.0 | | | | | | | | | | | | | | | | | | | | 27.24 |
| 111021 | General and Operations Managers | | 100.0 | | | | | | | | | | | | | | | | | | | 23.23 |
| 414012 | Sales Representatives, Wholesale and Manufacturing, Except Technical and Scientific Products | | | 60.9 | 39.1 | 0.0 | | | | | | | | | | | | | | | | 13.26 |
| 511011 | First-Line Supervisors of Production and Operating Workers | | | 39.1 | 60.9 | | | | | | | | | | | | | | | | | 13.01 |
| 172112 | Industrial Engineers | | | | 0.0 | 93.4 | 6.6 | | | | | | | | | | | | | | | 11.07 |
| 514041 | Machinists | | | | | 6.6 | 93.4 | 0.1 | | | | | | | | | | | | | | 10.87 |
| 172141 | Mechanical Engineers | | | | | | 0.1 | 99.9 | | | | | | | | | | | | | | 10.61 |
| 132011 | Accountants and Auditors | | | | | | | | 51.7 | 47.0 | 1.3 | | | | | | | | | | | 8.40 |
| 119041 | Architectural and Engineering Managers | | | | | | | | 48.3 | 51.7 | | | | | | | | | | | | 8.39 |
| 519061 | Inspectors, Testers, Sorters, Samplers, and Weighers | | | | | | | | | 1.3 | 98.6 | 0.1 | | | | | | | | | | 8.02 |
| 113051 | Industrial Production Managers | | | | | | | | | | | 28.0 | 63.4 | 8.6 | | | | | | | | 7.59 |
| 151133 | Software Developers, Systems Software | | | | | | | | | | | 38.2 | 22.5 | 39.3 | 0.0 | | | | | | | 7.57 |
| 514121 | Welders, Cutters, Solderers, and Brazers | | | | | | | | | | 0.1 | 33.7 | 14.2 | 51.3 | 0.8 | | | | | | | 7.53 |
| 113031 | Financial Managers | | | | | | | | | | | | | 0.8 | 76.7 | 20.7 | 1.8 | 0.0 | | | | 6.92 |
| 151132 | Software Developers, Applications | | | | | | | | | | | | | | 21.9 | 76.6 | 1.5 | 0.0 | | | | 6.80 |
| 537062 | Laborers and Freight, Stock, and Material Movers, Hand | | | | | | | | | | | | | | 0.6 | 2.7 | 96.4 | 0.3 | | | | 6.48 |
| 112022 | Sales Managers | | | | | | | | | | | | | | | | | 75.0 | 24.9 | 0.0 | | 6.00 |
| 533032 | Heavy and Tractor-Trailer Truck Drivers | | | | | | | | | | | | | | | 0.0 | 0.4 | 24.6 | 33.2 | 16.2 | 9.4 | 5.76 |
| 434051 | Customer Service Representatives | | | | | | | | | | | | | | | | | | 36.2 | 56.4 | 6.8 | 5.68 |
| 172071 | Electrical Engineers | | | | | | | | | | | | | | | | | 0.0 | 5.7 | 26.4 | 64.5 | 5.52 |
| 131023 | Purchasing Agents, Except Wholesale, Retail, and Farm Products | | | | | | | | | | | | | | | | | | 0.0 | 0.9 | 18.5 | 5.40 |
| 499041 | Industrial Machinery Mechanics | | | | | | | | | | | | | | | | | | | 0.1 | 0.6 | 5.23 |
| 499071 | Maintenance and Repair Workers, General | | | | | | | | | | | | | | | | | | | | 0.1 | 5.23 |
| 131199 | Business Operations Specialists, All Other | | | | | | | | | | | | | | | | | | | | 0.0 | 5.16 |

Table 6A: Total Compensation by Occupation for Assembly-Centric Products – Base Case

| SOC | Description | $millions | Percent of Labor | Percent of Value Added w/Imports |
|---|---|---|---|---|
| 510000 | Production Occupations | 131 655.8 | 26.4% | 11.1% |
| 110000 | Management Occupations | 79 018.7 | 15.9% | 6.7% |
| 170000 | Architecture and Engineering Occupations | 56 090.0 | 11.3% | 4.7% |
| 130000 | Business and Financial Operations Occupations | 45 421.8 | 9.1% | 3.8% |
| 430000 | Office and Administrative Support Occupations | 41 655.0 | 8.4% | 3.5% |
| 150000 | Computer and Mathematical Occupations | 31 208.5 | 6.3% | 2.6% |
| 410000 | Sales and Related Occupations | 30 365.9 | 6.1% | 2.6% |
| 530000 | Transportation and Material Moving Occupations | 26 159.2 | 5.3% | 2.2% |
| 490000 | Installation, Maintenance, and Repair Occupations | 25 627.9 | 5.1% | 2.2% |
| 470000 | Construction and Extraction Occupations | 8 268.8 | 1.7% | 0.7% |
| 230000 | Legal Occupations | 4 518.0 | 0.9% | 0.4% |
| 270000 | Arts, Design, Entertainment, Sports, and Media Occupations | 4 489.5 | 0.9% | 0.4% |
| 370000 | Building and Grounds Cleaning and Maintenance Occupations | 3 034.0 | 0.6% | 0.3% |
| 190000 | Life, Physical, and Social Science Occupations | 2 409.4 | 0.5% | 0.2% |
| 290000 | Healthcare Practitioners and Technical Occupations | 2 137.7 | 0.4% | 0.2% |
| 350000 | Food Preparation and Serving Related Occupations | 2 062.5 | 0.4% | 0.2% |
| 330000 | Protective Service Occupations | 1 840.0 | 0.4% | 0.2% |
| 450000 | Farming, Fishing, and Forestry Occupations | 701.6 | 0.1% | 0.1% |
| 390000 | Personal Care and Service Occupations | 500.1 | 0.1% | 0.0% |
| 310000 | Healthcare Support Occupations | 248.0 | 0.0% | 0.0% |
| 250000 | Education, Training, and Library Occupations | 236.0 | 0.0% | 0.0% |
| 210000 | Community and Social Service Occupations | 212.5 | 0.0% | 0.0% |
| | | 497 860.8 | 100.0% | 42.1% |

Table 6B: Top 25 Occupations within Production Occupations from Table 6A, by Contribution to Value Added ($billions) – Base Case

| SOC | Description | Compensation $billions |
|---|---|---|
| 512092 | Team Assemblers | 27.24 |
| 511011 | First-Line Supervisors of Production and Operating Workers | 13.01 |
| 514041 | Machinists | 10.87 |
| 519061 | Inspectors, Testers, Sorters, Samplers, and Weighers | 8.02 |
| 514121 | Welders, Cutters, Solderers, and Brazers | 7.53 |
| 512022 | Electrical and Electronic Equipment Assemblers | 4.50 |
| 514011 | Computer-Controlled Machine Tool Operators, Metal and Plastic | 4.16 |
| 514111 | Tool and Die Makers | 3.71 |
| 514031 | Cutting, Punching, and Press Machine Setters, Operators, and Tenders, Metal and Plastic | 3.36 |
| 512099 | Assemblers and Fabricators, All Other | 3.30 |
| 512011 | Aircraft Structure, Surfaces, Rigging, and Systems Assemblers | 2.74 |
| 519198 | Helpers--Production Workers | 2.68 |
| 514081 | Multiple Machine Tool Setters, Operators, and Tenders, Metal and Plastic | 2.52 |
| 519199 | Production Workers, All Other | 2.18 |
| 514072 | Molding, Coremaking, and Casting Machine Setters, Operators, and Tenders, Metal and Plastic | 1.95 |
| 512031 | Engine and Other Machine Assemblers | 1.75 |
| 514033 | Grinding/Lapping/Polishing/Buffing Machine Tool Setters, Operators, and Tenders, Metal and Pla | 1.74 |
| 514122 | Welding, Soldering, and Brazing Machine Setters, Operators, and Tenders | 1.61 |
| 512041 | Structural Metal Fabricators and Fitters | 1.56 |
| 512023 | Electromechanical Equipment Assemblers | 1.37 |
| 519121 | Coating, Painting, and Spraying Machine Setters, Operators, and Tenders | 1.34 |
| 514034 | Lathe and Turning Machine Tool Setters, Operators, and Tenders, Metal and Plastic | 1.21 |
| 514021 | Extruding and Drawing Machine Setters, Operators, and Tenders, Metal and Plastic | 1.20 |
| 519122 | Painters, Transportation Equipment | 1.02 |
| 519111 | Packaging and Filling Machine Operators and Tenders | 0.89 |

Table 6C: Top 25 Occupations for Assembly-Centric Products when Including Associated Taxes and Gross Operating Surplus, by Contribution to Value Added ($billions) – Base Case

| NAICS | Description | Baseline ($Billion) |
|---|---|---|
| 512092 | Team Assemblers | 52.96 |
| 111021 | General and Operations Managers | 40.97 |
| 414012 | Sales Representatives, Wholesale and Manufacturing, Except Technical and Scientific Products | 24.53 |
| 511011 | First-Line Supervisors of Production and Operating Workers | 23.38 |
| 172112 | Industrial Engineers | 20.02 |
| 172141 | Mechanical Engineers | 17.82 |
| 514041 | Machinists | 17.51 |
| 119041 | Architectural and Engineering Managers | 15.08 |
| 132011 | Accountants and Auditors | 14.40 |
| 519061 | Inspectors, Testers, Sorters, Samplers, and Weighers | 13.98 |
| 113051 | Industrial Production Managers | 13.53 |
| 151133 | Software Developers, Systems Software | 12.77 |
| 514121 | Welders, Cutters, Solderers, and Brazers | 11.95 |
| 113031 | Financial Managers | 11.67 |
| 537062 | Laborers and Freight, Stock, and Material Movers, Hand | 11.29 |
| 151132 | Software Developers, Applications | 11.22 |
| 499041 | Industrial Machinery Mechanics | 10.52 |
| 112022 | Sales Managers | 10.45 |
| 533032 | Heavy and Tractor-Trailer Truck Drivers | 10.25 |
| 499071 | Maintenance and Repair Workers, General | 10.07 |
| 434051 | Customer Service Representatives | 9.90 |
| 172071 | Electrical Engineers | 9.68 |
| 131199 | Business Operations Specialists, All Other | 9.50 |
| 131023 | Purchasing Agents, Except Wholesale, Retail, and Farm Products | 9.23 |
| 414011 | Sales Representatives, Wholesale and Manufacturing, Technical and Scientific Products | 8.80 |

Table 7: Percent of Monte Carlo Iterations by Industry/Occupation Combination and by Rank, Top 20 Industry/Occupation Combinations for Assembly-Centric Manufacturing (ordered by base case rank)

| Industry NAICS | Description | Occupation SOC | Description | Rank - Top 20: 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Baseline ($billion) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 420000 | Wholesale trade | 414012 | Sales Representatives, Wholesale and Manufacturing, Except Technical and Scientific Products | 74.2 | 25.8 | | | | | | | | | 7.25 |
| 336111 | Automobile manufacturing | 512092 | Team Assemblers | 25.8 | 74.2 | 0.0 | | | | | | | | 6.34 |
| 484000 | Truck transportation | 533032 | Heavy and Tractor-Trailer Truck Drivers | | 0.0 | 43.2 | 25.1 | 14.8 | 9.8 | 4.3 | 2.2 | 0.6 | 0.1 | 3.15 |
| 336112 | Light truck and utility vehicle manufacturing | 512092 | Team Assemblers | | | 23.6 | 24.4 | 21.5 | 15.2 | 8.7 | 4.8 | 1.5 | 0.3 | 2.94 |
| 420000 | Wholesale trade | 111021 | General and Operations Managers | | | 20.6 | 23.9 | 22.2 | 16.6 | 10.7 | 5.1 | 0.8 | 0.2 | 2.91 |
| 550000 | Management of companies and enterprises | 111021 | General and Operations Managers | | | 9.4 | 17.1 | 20.3 | 22.3 | 17.1 | 9.3 | 4.0 | 0.5 | 2.71 |
| 541100 | Legal services | 231011 | Lawyers | | | 2.6 | 7.0 | 13.4 | 18.9 | 23.6 | 18.6 | 10.3 | 3.7 | 2.46 |
| 336411 | Aircraft manufacturing | 172011 | Aerospace Engineers | | | 0.5 | 2.3 | 6.2 | 11.6 | 19.4 | 25.5 | 19.8 | 9.3 | 2.26 |
| 420000 | Wholesale trade | 414011 | Sales Representatives, Wholesale and Manufacturing, Technical and Scientific Products | | | 0.0 | 0.3 | 1.5 | 4.9 | 12.5 | 21.6 | 28.0 | 16.2 | 2.08 |
| 550000 | Management of companies and enterprises | 113031 | Financial Managers | | | | | 0.1 | 0.8 | 3.6 | 10.6 | 21.7 | 27.9 | 1.88 |
| 541200 | Accounting, tax preparation, bookkeeping, and payroll services | 132011 | Accountants and Auditors | | | | | | | 0.1 | 1.4 | 6.6 | 17.7 | 1.67 |
| 336120 | Heavy duty truck manufacturing | 512092 | Team Assemblers | | | | | | | 0.0 | 0.5 | 3.1 | 10.0 | 1.60 |
| 336411 | Aircraft manufacturing | 512011 | Aircraft Structure, Surfaces, Rigging, and Syst | | | | | | | 0.0 | 0.3 | 2.6 | 8.1 | 1.53 |
| 550000 | Management of companies and enterprises | 132011 | Accountants and Auditors | | | | | | | 0.0 | 0.1 | 0.7 | 3.3 | 1.47 |
| 332710 | Machine shops | 514041 | Machinists | | | | | | | | | 0.1 | 1.0 | 1.43 |
| 523A00 | Securities and commodity contracts intermediation and brokerage | 413031 | Securities, Commodities, and Financial Servic | | | | | | | | 0.0 | 0.1 | 0.9 | 1.41 |
| 420000 | Wholesale trade | 537062 | Laborers and Freight, Stock, and Material Mov | | | | | | | | | 0.1 | 0.8 | 1.33 |
| 336411 | Aircraft manufacturing | 172112 | Industrial Engineers | | | | | | | | | 0.0 | 0.2 | 1.27 |
| 420000 | Wholesale trade | 112022 | Sales Managers | | | | | | | | | | 0.0 | 1.20 |
| 550000 | Management of companies and enterprises | 131199 | Business Operations Specialists, All Other | | | | | | | | | | | 1.11 |
| 550000 | Management of companies and enterprises | 119199 | Managers, All Other | | | | | | | | | | | 1.05 |
| 336411 | Aircraft manufacturing | 172141 | Mechanical Engineers | | | | | | | | | | | 1.04 |
| 550000 | Management of companies and enterprises | 111011 | Chief Executives | | | | | | | | | | | 1.03 |
| 336390 | Other motor vehicle parts manufacturing | 512092 | Team Assemblers | | | | | | | | | | | 1.03 |
| 420000 | Wholesale trade | 533032 | Heavy and Tractor-Trailer Truck Drivers | | | | | | | | | | | 1.03 |
| 336411 | Aircraft manufacturing | 151133 | Software Developers, Systems Software | | | | | | | | | | | 1.01 |
| 550000 | Management of companies and enterprises | 113021 | Computer and Information Systems Managers | | | | | | | | | | | 0.97 |
| 336370 | Motor vehicle metal stamping | 512092 | Team Assemblers | | | | | | | | | | | 0.95 |
| 550000 | Management of companies and enterprises | 112021 | Marketing Managers | | | | | | | | | | | 0.92 |
| 561600 | Investigation and security services | 339032 | Security Guards | | | | | | | | | | | 0.87 |
| 420000 | Wholesale trade | 411012 | First-Line Supervisors of Non-Retail Sales Wo | | | | | | | | | | | 0.85 |
| 336411 | Aircraft manufacturing | 119041 | Architectural and Engineering Managers | | | | | | | | | | | 0.84 |
| 336350 | Motor vehicle transmission and power train parts manufacturing | 512092 | Team Assemblers | | | | | | | | | | | 0.79 |

| Industry NAICS | Description | Occupation SOC | Description | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | Baseline ($billion) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 420000 | Wholesale trade | 414012 | Sales Representatives, Wholesale and Manufacturing, Except Technical and Scientific Products | | | | | | | | | | | 7.25 |
| 336111 | Automobile manufacturing | 512092 | Team Assemblers | | | | | | | | | | | 6.34 |
| 484000 | Truck transportation | 533032 | Heavy and Tractor-Trailer Truck Drivers | | | | | | | | | | | 3.15 |
| 336112 | Light truck and utility vehicle manufacturing | 512092 | Team Assemblers | 0.1 | | | | | | | | | | 2.94 |
| 420000 | Wholesale trade | 111021 | General and Operations Managers | 0.0 | | | | | | | | | | 2.91 |
| 550000 | Management of companies and enterprises | 111021 | General and Operations Managers | 0.1 | 0.0 | | | | | | | | | 2.71 |
| 541100 | Legal services | 231011 | Lawyers | 1.2 | 0.4 | 0.1 | 0.0 | 0.0 | | | | | | 2.46 |
| 336411 | Aircraft manufacturing | 172011 | Aerospace Engineers | 3.2 | 1.3 | 0.6 | 0.3 | 0.1 | 0.0 | | | | | 2.26 |
| 420000 | Wholesale trade | 414011 | Sales Representatives, Wholesale and Manufacturing, Technical and Scientific Products | 7.4 | 3.6 | 2.2 | 1.1 | 0.6 | 0.3 | 0.0 | 0.0 | | | 2.08 |
| 550000 | Management of companies and enterprises | 113031 | Financial Managers | 13.6 | 8.4 | 5.7 | 3.5 | 2.1 | 1.1 | 0.5 | 0.3 | 0.1 | 0.0 | 1.88 |
| 541200 | Accounting, tax preparation, bookkeeping, and payroll services | 132011 | Accountants and Auditors | 22.3 | 18.8 | 12.9 | 8.5 | 5.9 | 3.4 | 1.6 | 0.6 | 0.2 | 0.1 | 1.67 |
| 336120 | Heavy duty truck manufacturing | 512092 | Team Assemblers | 17.8 | 19.4 | 16.6 | 12.0 | 8.8 | 5.9 | 3.4 | 1.6 | 0.6 | 0.1 | 1.60 |
| 336411 | Aircraft manufacturing | 512011 | Aircraft Structure, Surfaces, Rigging, and Systems Assemblers | 13.0 | 13.6 | 13.3 | 12.2 | 10.8 | 10.3 | 7.0 | 4.4 | 1.9 | 1.0 | 1.53 |
| 550000 | Management of companies and enterprises | 132011 | Accountants and Auditors | 9.7 | 11.4 | 12.2 | 13.1 | 12.6 | 11.3 | 9.7 | 7.7 | 4.2 | 1.9 | 1.47 |
| 332710 | Machine shops | 514041 | Machinists | 4.6 | 8.1 | 12.2 | 15.3 | 16.7 | 15.0 | 11.6 | 7.5 | 3.7 | 1.8 | 1.43 |
| 523A00 | Securities and commodity contracts intermediation and brokerage | 413031 | Securities, Commodities, and Financial Services Sales Agents | 3.0 | 6.9 | 11.3 | 14.9 | 16.1 | 15.5 | 12.9 | 8.7 | 4.8 | 2.1 | 1.41 |
| 420000 | Wholesale trade | 537062 | Laborers and Freight, Stock, and Material Movers, Hand | 2.7 | 4.8 | 6.9 | 8.9 | 10.8 | 13.1 | 14.4 | 13.2 | 7.9 | 4.2 | 1.33 |
| 336411 | Aircraft manufacturing | 172112 | Industrial Engineers | 1.1 | 2.4 | 4.1 | 6.0 | 8.9 | 11.4 | 14.9 | 14.2 | 11.2 | 7.1 | 1.27 |
| 420000 | Wholesale trade | 112022 | Sales Managers | 0.4 | 0.8 | 1.6 | 3.2 | 4.1 | 7.6 | 11.7 | 14.2 | 14.3 | 9.2 | 1.20 |
| 550000 | Management of companies and enterprises | 131199 | Business Operations Specialists, All Other | 0.0 | 0.1 | 0.3 | 1.0 | 2.2 | 4.1 | 6.9 | 10.5 | 11.6 | 11.0 | 1.11 |
| 550000 | Management of companies and enterprises | 119199 | Managers, All Other | | | | | 0.1 | 0.3 | 1.7 | 4.3 | 9.1 | 12.1 | 1.05 |
| 336411 | Aircraft manufacturing | 172141 | Mechanical Engineers | | | | | 0.0 | 0.2 | 1.1 | 4.4 | 9.3 | 11.7 | 1.04 |
| 550000 | Management of companies and enterprises | 111011 | Chief Executives | | | | | | 0.0 | 0.1 | 0.9 | 3.2 | 7.2 | 1.03 |
| 336390 | Other motor vehicle parts manufacturing | 512092 | Team Assemblers | | | | 0.0 | 0.1 | 0.5 | 1.9 | 4.5 | 7.3 | 9.3 | 1.03 |
| 420000 | Wholesale trade | 533032 | Heavy and Tractor-Trailer Truck Drivers | | | | | | 0.0 | 0.5 | 1.8 | 6.4 | 11.4 | 1.03 |
| 336411 | Aircraft manufacturing | 151133 | Software Developers, Systems Software | | | | | | | 0.1 | 0.5 | 2.2 | 5.9 | 1.01 |
| 550000 | Management of companies and enterprises | 113021 | Computer and Information Systems Managers | | | | | | | | | 0.1 | 0.7 | 0.97 |
| 336370 | Motor vehicle metal stamping | 512092 | Team Assemblers | | | | | | 0.0 | 0.1 | 0.9 | 1.9 | 3.3 | 0.95 |
| 550000 | Management of companies and enterprises | 112021 | Marketing Managers | | | | | | | | | | 0.0 | 0.92 |
| 561600 | Investigation and security services | 339032 | Security Guards | | | | | | | | | | 0.0 | 0.87 |
| 420000 | Wholesale trade | 411012 | First-Line Supervisors of Non-Retail Sales Wo | | | | | | | | | | 0.0 | 0.85 |
| 336411 | Aircraft manufacturing | 119041 | Architectural and Engineering Managers | | | | | | | | | | 0.0 | 0.84 |
| 336350 | Motor vehicle transmission and power train parts manufacturing | 512092 | Team Assemblers | | | | | | | | | 0.0 | 0.1 | 0.79 |

## Table 8: Percent of Monte Carlo Iterations by Industry by Rank, Depreciable Building Assets for Assembly-Centric Products, Top 20 Industries

| | | Rank - Top 20 | | | | | | | | | | | | | | | | | | | | Baseline |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NAICS | Description | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | ($Billions) |
| 336411 | Aircraft manufacturing | 54.4 | 45.6 | | | | | | | | | | | | | | | | | | | 11.68 |
| 336112 | Light truck and utility vehicle manufacturing | 45.6 | 54.4 | | | | | | | | | | | | | | | | | | | 11.48 |
| 336111 | Automobile manufacturing | | | 77.6 | 15.0 | 5.5 | 1.5 | 0.3 | 0.0 | 0.0 | | | | | | | | | | | | 4.82 |
| 336413 | Other aircraft parts and auxiliary equipment manufacturing | | | 10.4 | 35.4 | 26.9 | 14.5 | 7.3 | 3.4 | 1.4 | 0.6 | 0.2 | 0.0 | | | | | | | | | 4.10 |
| 336412 | Aircraft engine and engine parts manufacturing | | | 10.0 | 32.8 | 27.7 | 15.5 | 7.9 | 3.5 | 1.7 | 0.7 | 0.3 | 0.0 | | | | | | | | | 4.07 |
| 333120 | Construction machinery manufacturing | | | 1.4 | 11.4 | 21.1 | 26.2 | 16.2 | 9.6 | 5.8 | 4.0 | 2.6 | 1.2 | 0.4 | 0.1 | | | | | | | 3.71 |
| 331110 | Iron and steel mills and ferroalloy manufacturing | | | 0.3 | 3.8 | 11.3 | 20.0 | 22.2 | 14.5 | 10.0 | 7.0 | 5.1 | 3.2 | 2.0 | 0.7 | 0.1 | 0.0 | | | | | 3.50 |
| 332720 | Turned product and screw, nut, and bolt manufacturing | | | 0.0 | 0.4 | 3.2 | 8.0 | 14.8 | 16.4 | 14.5 | 12.7 | 10.3 | 8.6 | 6.2 | 3.5 | 1.1 | 0.3 | 0.1 | 0.0 | | | 3.24 |
| 332710 | Machine shops | | | | | 0.1 | 1.3 | 7.1 | 19.5 | 27.9 | 25.5 | 13.9 | 4.4 | 0.5 | | | | | | | | 3.20 |
| 333920 | Material handling equipment manufacturing | | | | 0.3 | 1.5 | 6.1 | 11.9 | 14.6 | 14.6 | 13.8 | 12.9 | 9.6 | 8.1 | 4.3 | 1.6 | 0.5 | 0.2 | 0.1 | 0.0 | | 3.18 |
| 336370 | Motor vehicle metal stamping | | | | 0.0 | 0.5 | 2.6 | 6.4 | 10.4 | 12.4 | 13.7 | 15.5 | 13.5 | 11.5 | 7.5 | 3.4 | 1.4 | 0.7 | 0.5 | 0.2 | 0.0 | 3.04 |
| 326190 | Other plastics product manufacturing | | | | | | | | 0.2 | 1.4 | 8.0 | 20.2 | 31.9 | 26.4 | 10.6 | 1.3 | 0.1 | | | | | 2.88 |
| 333111 | Farm machinery and equipment manufacturing | | | | | | 0.3 | 1.5 | 3.5 | 6.4 | 9.1 | 12.5 | 16.1 | 19.0 | 13.6 | 6.9 | 3.6 | 2.9 | 2.5 | 1.6 | 0.4 | 2.83 |
| 333130 | Mining and oil and gas field machinery manufacturing | | | 0.1 | 1.0 | 2.4 | 4.0 | 4.7 | 4.7 | 3.9 | 4.4 | 4.5 | 5.1 | 6.2 | 8.3 | 4.9 | 3.0 | 3.0 | 3.9 | 5.5 | 4.0 | 2.54 |
| 33291A | Valve and fittings other than plumbing | | | | | | | | | | | 0.0 | 0.5 | 5.0 | 21.1 | 35.0 | 27.7 | 9.6 | 1.1 | 0.1 | | 2.48 |
| 336350 | Motor vehicle transmission and power train parts manufacturing | | | | | | | | | 0.1 | 0.5 | 1.8 | 4.2 | 9.4 | 16.1 | 16.2 | 10.2 | 8.4 | 10.3 | 11.7 | 6.7 | 2.46 |
| 33329A | Other industrial machinery manufacturing | | | | | | | | | | | | | 0.1 | 1.6 | 11.7 | 29.3 | 34.0 | 19.2 | 3.9 | 0.3 | 2.38 |
| 336390 | Other motor vehicle parts manufacturing | | | | | | | | | 0.0 | 0.1 | 0.3 | 1.6 | 5.1 | 11.2 | 13.6 | 10.4 | 9.6 | 12.6 | 15.6 | 10.4 | 2.36 |
| 331510 | Ferrous metal foundries | | | | | | | | | | | | | | 0.1 | 0.8 | 8.0 | 24.5 | 35.7 | 23.7 | 6.4 | 2.34 |
| 33399A | Other general purpose machinery manufacturing | | | | | | | | | | | | 0.0 | 0.2 | 1.5 | 3.0 | 4.7 | 5.4 | 9.0 | 17.1 | 22.4 | 2.11 |
| 333618 | Other engine equipment manufacturing | | | | | | | | | | | | | | | | | 0.0 | 0.8 | 7.0 | 23.7 | 2.00 |
| 336611 | Ship building and repairing | | | | | | | | | | | | | 0.0 | 0.0 | 0.3 | 0.7 | 1.5 | 3.1 | 8.8 | 15.5 | 1.95 |
| 33391A | Pump and pumping equipment manufacturing | | | | | | | | | | | | | | | 0.0 | 0.1 | 0.3 | 1.3 | 4.9 | 10.0 | 1.86 |
| 333295 | Semiconductor machinery manufacturing | | | | | | | | | | | | | | | | | | | | 0.2 | 1.77 |

Table 9: Percent of Monte Carlo Iterations by Industry by Rank, Depreciable Machinery/Equipment Assets for Assembly-Centric Products, Top 20 Industries

| | | Rank - Top 20 | | | | | | | | | | | | | | | | | | | | Baseline |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NAICS | Description | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | ($Billions) |
| 334413 | Semiconductor and related device manufacturing | 96.0 | 4.1 | | | | | | | | | | | | | | | | | | | 47.69 |
| 336111 | Automobile manufacturing | 4.1 | 87.4 | 8.6 | 0.0 | | | | | | | | | | | | | | | | | 37.05 |
| 331110 | Iron and steel mills and ferroalloy manufacturing | | 8.6 | 85.1 | 6.3 | | | | | | | | | | | | | | | | | 30.31 |
| 336112 | Light truck and utility vehicle manufacturing | | 0.0 | 6.4 | 93.2 | 0.5 | | | | | | | | | | | | | | | | 24.29 |
| 336370 | Motor vehicle metal stamping | | | | 0.4 | 70.7 | 23.8 | 3.9 | 1.0 | 0.1 | | | | | | | | | | | | 16.83 |
| 336350 | Motor vehicle transmission and power train parts manufacturing | | | | 0.0 | 27.4 | 53.0 | 12.3 | 5.5 | 1.6 | 0.2 | 0.0 | | | | | | | | | | 15.46 |
| 336310 | Motor vehicle gasoline engine and engine parts manufacturing | | | | | 1.0 | 16.9 | 60.7 | 18.2 | 2.9 | 0.2 | | | | | | | | | | | 13.82 |
| 334510 | Electromedical and electrotherapeutic apparatus manufacturing | | | | | 0.3 | 3.9 | 12.8 | 31.2 | 25.2 | 13.5 | 8.0 | 5.0 | 0.2 | | | | | | | | 12.35 |
| 334511 | Search, detection, and navigation instruments manufacturing | | | | | 0.1 | 2.2 | 8.3 | 26.4 | 28.4 | 16.2 | 10.2 | 7.7 | 0.5 | 0.0 | | | | | | | 12.05 |
| 336411 | Aircraft manufacturing | | | | | 0.0 | 0.2 | 1.8 | 12.2 | 21.8 | 24.8 | 18.7 | 16.9 | 3.1 | 0.6 | 0.0 | | | | | | 11.26 |
| 325190 | Other basic organic chemical manufacturing | | | | | | | | 0.9 | 7.0 | 24.7 | 41.0 | 26.2 | 0.2 | | | | | | | | 10.72 |
| 336390 | Other motor vehicle parts manufacturing | | | | | | 0.0 | 0.2 | 4.7 | 13.0 | 20.3 | 21.3 | 31.0 | 7.2 | 2.3 | 0.2 | | | | | | 10.66 |
| 325211 | Plastics material and resin manufacturing | | | | | | | | | | 0.0 | 0.3 | 8.4 | 67.7 | 23.4 | 0.2 | | | | | | 8.98 |
| 336412 | Aircraft engine and engine parts manufacturing | | | | | | | | | 0.0 | 0.0 | 0.6 | 4.8 | 20.6 | 36.7 | 23.2 | 7.9 | 2.6 | 1.2 | 0.9 | 0.7 | 8.32 |
| 333618 | Other engine equipment manufacturing | | | | | | | | | | | | | 0.2 | 33.3 | 58.9 | 6.9 | 0.6 | 0.1 | | | 7.98 |
| 33329A | Other industrial machinery manufacturing | | | | | | | | | | | | | | | 2.3 | 27.6 | 35.3 | 23.2 | 9.1 | 2.2 | 6.84 |
| 336611 | Ship building and repairing | | | | | | | | | | | | | | 1.0 | 5.0 | 19.1 | 12.9 | 8.0 | 5.6 | 6.8 | 6.59 |
| 324110 | Petroleum refineries | | | | | | | | | | | | | | | | 0.7 | 15.5 | 30.0 | 29.5 | 17.5 | 6.59 |
| 336360 | Motor vehicle seating and interior trim manufacturing | | | | | | | | | | | | | | | | | 0.7 | 15.1 | 29.7 | 29.6 | 6.58 |
| 336413 | Other aircraft parts and auxiliary equipment manufacturing | | | | | | | | | | | | | | 0.5 | 3.8 | 16.4 | 12.7 | 7.9 | 5.6 | 6.6 | 6.51 |
| 331200 | Steel product manufacturing from purchased steel | | | | | | | | | | | | | | | | | | 0.2 | 7.8 | 21.5 | 6.38 |
| 332720 | Turned product and screw, nut, and bolt manufacturing | | | | | | | | | | | | | | 0.1 | 2.2 | 12.0 | 11.5 | 7.0 | 5.5 | 6.2 | 6.35 |
| 333611 | Turbine and turbine generator set units manufacturing | | | | | | | | | | | | | | | | | | | 0.0 | 1.5 | 6.03 |
| 333120 | Construction machinery manufacturing | | | | | | | | | | | | | | | 0.2 | 1.7 | 3.4 | 3.7 | 3.5 | 3.9 | 5.81 |
| 334220 | Broadcast and wireless communications equipment | | | | | | | | | | | | | | | | 0.2 | 0.6 | 1.1 | 1.3 | 1.8 | 5.50 |
| 333130 | Mining and oil and gas field machinery manufacturing | | | | | | | | | | | | | 0.4 | 2.2 | 4.1 | 7.4 | 4.4 | 2.6 | 1.7 | 1.7 | 5.30 |

Table 10: Percent of Monte Carlo Iterations by Industry by Rank, Purchased Building Capital for Assembly-Centric Products, Top 20 Industries

| | | Rank - Top 20 | | | | | | | | | | | | | | | | | | | | Baseline |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NAICS | Description | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | ($Billions) |
| 334413 | Semiconductor and related device manufacturing | 100.0 | | | | | | | | | | | | | | | | | | | | 1.97 |
| 336111 | Automobile manufacturing | | 100.0 | | | | | | | | | | | | | | | | | | | 1.20 |
| 334510 | Electromedical and electrotherapeutic apparatus manufacturing | | | 91.8 | 8.2 | | | | | | | | | | | | | | | | | 0.59 |
| 336112 | Light truck and utility vehicle manufacturing | | | 8.2 | 90.4 | 1.4 | 0.1 | | | | | | | | | | | | | | | 0.48 |
| 336411 | Aircraft manufacturing | | | | 0.9 | 45.5 | 36.2 | 17.5 | | | | | | | | | | | | | | 0.34 |
| 334220 | Broadcast and wireless communications equipment | | | | 0.6 | 42.4 | 37.2 | 19.8 | | | | | | | | | | | | | | 0.34 |
| 331110 | Iron and steel mills and ferroalloy manufacturing | | | | 0.0 | 10.7 | 26.6 | 62.6 | 0.1 | | | | | | | | | | | | | 0.31 |
| 333120 | Construction machinery manufacturing | | | | | | | 0.0 | 54.3 | 26.3 | 12.0 | 5.0 | 2.0 | 0.4 | 0.1 | | | | | | | 0.20 |
| 334511 | Search, detection, and navigation instruments manufacturing | | | | | | | | 24.6 | 35.6 | 19.9 | 10.8 | 6.3 | 2.4 | 0.3 | 0.1 | | | | | | 0.19 |
| 336370 | Motor vehicle metal stamping | | | | | | | | 6.4 | 19.1 | 25.9 | 20.6 | 16.0 | 8.6 | 2.6 | 0.6 | 0.2 | 0.0 | | | | 0.17 |
| 336414 | Guided missile and space vehicle manufacturing | | | | | | | | 0.5 | 5.2 | 23.4 | 38.0 | 26.3 | 6.4 | 0.2 | | | | | | | 0.17 |
| 336611 | Ship building and repairing | | | | | | | | 0.8 | 4.0 | 10.2 | 16.3 | 26.6 | 23.4 | 9.7 | 4.9 | 3.0 | 0.9 | 0.2 | | | 0.16 |
| 333130 | Mining and oil and gas field machinery manufacturing | | | | | | | 0.1 | 13.2 | 9.8 | 8.5 | 7.4 | 9.0 | 9.8 | 5.8 | 4.7 | 4.4 | 6.0 | 6.5 | 3.9 | 0.7 | 0.15 |
| 336310 | Motor vehicle gasoline engine and engine parts manufacturing | | | | | | | | | | | 0.1 | 2.6 | 16.9 | 34.8 | 32.5 | 12.5 | 0.6 | | | | 0.14 |
| 336350 | Motor vehicle transmission and power train parts manufacturing | | | | | | | | | 0.0 | 0.2 | 1.1 | 6.1 | 17.1 | 22.0 | 16.9 | 16.0 | 13.6 | 6.1 | 0.9 | | 0.13 |
| 333111 | Farm machinery and equipment manufacturing | | | | | | | | | 0.0 | 0.1 | 0.7 | 5.2 | 14.6 | 19.7 | 17.9 | 17.6 | 15.8 | 7.3 | 1.2 | | 0.13 |
| 324110 | Petroleum refineries | | | | | | | | | | | | | 0.2 | 3.7 | 18.2 | 36.2 | 34.8 | 6.8 | 0.2 | | 0.12 |
| 336413 | Other aircraft parts and auxiliary equipment manufacturing | | | | | | | | | | | | 0.0 | 0.2 | 1.3 | 4.2 | 9.0 | 21.8 | 43.3 | 16.0 | 1.8 | 0.11 |
| 336390 | Other motor vehicle parts manufacturing | | | | | | | | | | | | | | 0.0 | 0.1 | 1.2 | 6.2 | 25.3 | 44.9 | 5.5 | 0.10 |
| 33451A | Watch, clock, and other measuring and controlling device manufacturing | | | | | | | | | | | | | | | | | 0.0 | 2.7 | 21.7 | 53.7 | 0.09 |
| 333618 | Other engine equipment manufacturing | | | | | | | | | | | | | | | | | | 0.0 | 2.2 | 19.1 | 0.09 |
| 33399A | Other general purpose machinery manufacturing | | | | | | | | | | | | | | | | | 0.1 | 1.7 | 8.1 | 14.7 | 0.08 |
| 331510 | Ferrous metal foundries | | | | | | | | | | | | | | | | | | | | 0.0 | 0.08 |
| 332720 | Turned product and screw, nut, and bolt manufacturing | | | | | | | | | | | | | | | | | | 0.1 | 0.7 | 2.9 | 0.08 |
| 336412 | Aircraft engine and engine parts manufacturing | | | | | | | | | | | | | | | | | | 0.0 | 0.4 | 1.7 | 0.07 |
| 332710 | Machine shops | | | | | | | | | | | | | | | | | | | | | 0.07 |
| 336360 | Motor vehicle seating and interior trim manufacturing | | | | | | | | | | | | | | | | | | | | | 0.06 |
| 326190 | Other plastics product manufacturing | | | | | | | | | | | | | | | | | | | | | 0.06 |

## Table 11: Percent of Monte Carlo Iterations by Industry by Rank, Purchased Machinery Capital for Assembly-Centric Products, Top 20 Industries

| | | Rank - Top 20 | | | | | | | | | | | | | | | | | | | | Baseline |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NAICS | Description | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | ($Billions) |
| 334413 | Semiconductor and related device manufacturing | 82.6 | 14.7 | 2.7 | | | | | | | | | | | | | | | | | | 4.29 |
| 336111 | Automobile manufacturing | 14.7 | 58.5 | 26.8 | | | | | | | | | | | | | | | | | | 3.68 |
| 336112 | Light truck and utility vehicle manufacturing | 2.6 | 26.8 | 70.6 | | | | | | | | | | | | | | | | | | 3.37 |
| 334510 | Electromedical and electrotherapeutic apparatus manufacturing | | | | 91.0 | 8.4 | 0.5 | | | | | | | | | | | | | | | 1.95 |
| 336370 | Motor vehicle metal stamping | | | | 8.4 | 72.3 | 17.2 | 2.2 | | | | | | | | | | | | | | 1.60 |
| 331110 | Iron and steel mills and ferroalloy manufacturing | | | | 0.6 | 18.5 | 59.3 | 20.8 | 0.7 | | | | | | | | | | | | | 1.40 |
| 336310 | Motor vehicle gasoline engine and engine parts manufacturing | | | | | 0.8 | 22.9 | 76.1 | 0.2 | | | | | | | | | | | | | 1.28 |
| 336350 | Motor vehicle transmission and power train parts manufacturing | | | | | | 0.0 | 0.9 | 82.1 | 14.2 | 2.4 | 0.4 | 0.0 | | | | | | | | | 0.99 |
| 336390 | Other motor vehicle parts manufacturing | | | | | | | | 14.6 | 57.1 | 17.5 | 7.1 | 3.0 | 0.7 | 0.1 | | | | | | | 0.85 |
| 336411 | Aircraft manufacturing | | | | | | | | 1.8 | 16.3 | 36.5 | 22.2 | 12.3 | 6.6 | 3.1 | 1.0 | 0.2 | 0.0 | | | | 0.76 |
| 333120 | Construction machinery manufacturing | | | | | | | | 0.4 | 8.3 | 23.9 | 27.8 | 18.6 | 11.5 | 6.6 | 2.5 | 0.5 | | | | | 0.72 |
| 333130 | Mining and oil and gas field machinery manufacturing | | | | | | | | 0.2 | 2.4 | 5.6 | 6.2 | 6.3 | 6.9 | 7.7 | 8.4 | 7.4 | 3.8 | 2.7 | 4.6 | 5.3 | 0.53 |
| 336413 | Other aircraft parts and auxiliary equipment manufacturing | | | | | | | | 0.0 | 0.9 | 5.5 | 14.5 | 22.3 | 22.6 | 17.7 | 9.7 | 4.1 | 1.5 | 0.7 | 0.5 | 0.1 | 0.65 |
| 332720 | Turned product and screw, nut, and bolt manufacturing | | | | | | | | 0.0 | 0.9 | 7.6 | 16.4 | 22.2 | 22.3 | 15.5 | 9.2 | 4.0 | 1.1 | 0.5 | 0.3 | 0.1 | 0.66 |
| 333111 | Farm machinery and equipment manufacturing | | | | | | | | | 0.0 | 1.0 | 4.6 | 11.7 | 19.0 | 25.4 | 18.8 | 8.9 | 3.7 | 2.7 | 2.4 | 1.4 | 0.60 |
| 334511 | Search, detection, and navigation instruments manufacturing | | | | | | | | | | 0.1 | 0.8 | 3.5 | 9.5 | 17.9 | 24.9 | 17.0 | 7.0 | 5.6 | 6.8 | 4.4 | 0.56 |
| 336412 | Aircraft engine and engine parts manufacturing | | | | | | | | | | | 0.0 | 0.1 | 0.4 | 2.6 | 7.2 | 11.4 | 11.2 | 8.8 | 14.2 | 18.1 | 0.49 |
| 333618 | Other engine equipment manufacturing | | | | | | | | | | | | 0.0 | 0.4 | 3.4 | 17.3 | 36.9 | 33.3 | 8.7 | | | 0.53 |
| 332710 | Machine shops | | | | | | | | | | | | | | 0.1 | 1.1 | 9.1 | 31.6 | 41.3 | 16.9 | 0.0 | 0.51 |
| 324110 | Petroleum refineries | | | | | | | | | | | | | | | 0.0 | 0.5 | 6.7 | 28.5 | 43.3 | 20.9 | 0.50 |
| 334220 | Broadcast and wireless communications equipment | | | | | | | | | | | | | | | | | 0.0 | 0.1 | 0.4 | 2.8 | 0.38 |
| 326190 | Other plastics product manufacturing | | | | | | | | | | | | | | | | | | 0.5 | 10.3 | 39.8 | 0.45 |
| 331510 | Ferrous metal foundries | | | | | | | | | | | | | | | | | | | 0.2 | 7.0 | 0.44 |
| 336360 | Motor vehicle seating and interior trim manufacturing | | | | | | | | | | | | | | | | | | | | 0.0 | 0.42 |

Table 12: Depreciable Assets and the Rate of Change, 2012 ($million 2012)

| | Buildings | Machinery and Equipment | Total |
|---|---|---|---|
| Gross value of depreciable assets (acquisition costs), end of year | 545 316 | 2 290 718 | 2 836 034 |
| Retirements | 9 224 | 39 466 | 48 690 |
| Capital Expenditures | 30 859 | 132 031 | 162 890 |
| Capital Expenditures less Retirements | 21 635 | 92 565 | 114 200 |
| Percent of Depreciable Assets that are Replaced | 1.69% | 1.72% | 1.72% |
| Percent of Depreciable Assets that are New | 3.97% | 4.04% | 4.03% |
| Percent of Depreciable Assets that are New or Replaced | 5.66% | 5.76% | 5.74% |

Table 13: Electricity and Natural Gas Use (Including Industries that Contribute to Electricity and Natural Gas) for Assembly-Centric Production, Value Added and Imports ($million)

| NAICS and Description | | Value Added | Contributing Industry Value Added | Associated Imports | Total |
|---|---|---|---|---|---|
| **Electric power generation, transmission, and distribution** | | **5 923** | **7 488** | **2 294** | **15 704** |
| 221100 | Undesignated and non-manufacturing | 2 172 | 2 746 | 841 | 5 760 |
| 221100-A | Indirect Uses-Boiler Fuel | 254 | 321 | 98 | 674 |
| 221100-B | Process Heating | 573 | 725 | 222 | 1 521 |
| 221100-C | Process Cooling and Refrigeration | 171 | 217 | 66 | 455 |
| 221100-D | Machine Drive | 1 238 | 1 565 | 479 | 3 282 |
| 221100-E | Electro-Chemical Processes | 292 | 369 | 113 | 774 |
| 221100-F | Other Process Use | 97 | 122 | 37 | 257 |
| 221100-G | Facility HVAC | 373 | 471 | 144 | 988 |
| 221100-H | Facility Lighting | 248 | 314 | 96 | 658 |
| 221100-I | Other Facility Support | 78 | 98 | 30 | 206 |
| 221100-J | Onsite Transportation | 110 | 139 | 43 | 291 |
| 221100-K | Other Nonprocess Use | 26 | 32 | 10 | 68 |
| 221100-L | End Use Not Reported | 291 | 368 | 113 | 771 |
| **Natural gas distribution** | | **2 439** | **6 426** | **3 260** | **12 125** |
| 221200 | Undesignated and non-manufacturing | 344 | 905 | 459 | 1 708 |
| 221200-A | Indirect Uses-Boiler Fuel | 622 | 1 639 | 831 | 3 092 |
| 221200-B | Process Heating | 1 057 | 2 785 | 1 413 | 5 254 |
| 221200-C | Process Cooling and Refrigeration | 11 | 28 | 14 | 54 |
| 221200-D | Machine Drive | 32 | 85 | 43 | 160 |
| 221200-F | Other Process Use | 30 | 78 | 40 | 147 |
| 221200-G | Facility HVAC | 332 | 874 | 443 | 1 649 |
| 221200-I | Other Facility Support | 8 | 20 | 10 | 39 |
| 221200-K | Conventional Electricity Generation | 2 | 5 | 2 | 9 |
| 221200-L | Other Nonprocess Use | 3 | 7 | 3 | 13 |
| TOTAL | | 8 361 | 13 914 | 5 554 | 27 830 |