A Value Chain Approach to Measuring the U.S. Production Structure*

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Abstract

This paper develops a comprehensive framework to examine the factor composition embedded in U.S. value added across final demand components by integrating value-added data with Integrated Industry-Level Production Account (KLEMS) statistics. This approach quantifies factor-specific value added within U.S. global value chains (GVCs) using the U.S. Bureau of Economic Analysis' (BEA's) domestic requirements tables and the BEA-BLS Integrated Industry-Level Production Account. The decomposition tracks both direct and indirect factor shares across upstream networks, revealing several patterns across final demand categories: exports are most intensive in research and development (R&D) capital, investment relies heavily on non-college labor, government spending has the highest share of college-educated labor, and consumption is least intensive in R&D and information technology (IT) capital. Moreover, exports contain notable embedded indirectly imported content, exceeding 10%. Sectoral comparisons highlight structural asymmetries: chemicals have the highest direct R&D intensity, financial services intensively use college-educated labor, and transportation and textiles primarily rely on non-college labor. These divergences highlight how upstream industries differ significantly from final-stage producers in factor intensity.

Keywords: Trade in Value Added, Global Value Chains, Input–Output Analysis, Factor Decomposition

JEL Codes: F14, D57, D24, E01, O32, C67

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1 Introduction

Understanding how labor and capital inputs are embodied in final demand is central to the analysis of structural change, production networks, and the propagation of macroeconomic shocks. Historically, the U.S. Bureau of Economic Analysis (BEA) and the Integrated Industry-Level Production Account (ILPA) have provided detailed measures of direct factor shares by industry, enabling analysis of sector-specific production technologies. While direct factor shares are well-suited for characterizing industry-level production structures, they are less informative about the factor inputs embodied in upstream supply chains. This paper argues that a more complete understanding of the economy and a more relevant mapping for macroeconomic models and policy analysis require shifting attention from the industries' direct factor use to the indirect linkages embedded in their upstream supply chains.

In this paper, we develop an extensive framework to analyze the factor content of final demand components by tracing their production structures through upstream supply chains. We make three main contributions. First, we introduce a novel methodology that incorporates the full production network by accounting for the factor content of upstream intermediate inputs, showing how measured production structures change once indirect contributions are taken into account. Second, we reorient the analysis from industries to components of final demand, aligning the framework more closely with the structure of macroeconomic models (C + I + G) and with standard approaches to analyze GDP growth. Third, we distinguish between domestically generated and foreign-sourced value added embodied in final demand, extending the trade-in-value-added literature beyond exports to all expenditure categories.

Our primary objective, applicable to both components of final demand and individual industries, is to provide a more complete characterization of production structures by accounting for the production structure of upstream intermediate inputs. Consider agriculture: according to the ILPA, the farm products industry has no research and development (R&D) capital assets and therefore no associated R&D capital services. However, the farm sector is an intensive user of chemical products, and chemical products are relatively intense in R&D capital service. Therefore, ignoring upstream inputs understates the true R&D intensity embodied in agricultural output.

To capture these indirect factor contributions across production networks, we develop a methodology that combines the U.S. Bureau of Economic Analysis' (BEA's) domestic requirements tables and the BEA-BLS Integrated Industry-Level Production Account. This approach yields estimates of factor content embedded in final demand and industry output, enabling analysis of how U.S. production structures evolve over time and differ across industries and demand components.

While our methodology applies to both industries and final demand, our analysis primarily focuses on final demand components that appear on the expenditure side of GDP accounts and serve as the featured measure of U.S. economic activity. Analyses of GDP growth usually start with examining changes to the components of final demand. Moreover, final demand components represent complex bundles of commodities that are linked to industry outputs through BEA's underlying Input-Output Accounts. For this reason, our first objective is to focus on the baskets of final demand when studying production technology.[1]

[1] This has the advantage of being a more applicable mapping for macro models. Macro models often represent the economy as C + I + G, where C denotes personal consumption expenditures, I represents private investment, and G captures government spending; however, these are components of final demand,

Our methodology also allows us to parse out domestically generated versus foreign-sourced value-added embedded in the components of final demand, extending insights from the trade-in-value-added literature. In this literature, U.S. gross exports contain three types of value added: domestic value added from the source industry, domestic value added from upstream producers supplying intermediate inputs, and foreign value added that is imported as an intermediate input either directly or by an upstream producer. Reflecting the growing literature on production networks, BEA now publishes "sources of value" in gross exports, distinguishing between U.S. value added and imported content, which is treated as imported value added.[2] We extend this decomposition beyond exports to all final demand components, identifying how imported value added varies across demand components over time. For the domestic portions, we trace contributions back to primary factors of production throughout the upstream supply chain, revealing not only whether value added is domestic or foreign but also which specific labor and capital inputs generate that domestic value.

Our results show that the decomposition highlights several clear patterns in how capital and labor are distributed across U.S. value added. First, the value-added share of non-college labor has steadily declined in every component of final demand, and its share has been more volatile than other inputs, implying a greater sensitivity to economic cycles and sectoral shifts. By contrast, software and R&D capital have risen gradually, suggesting a slow but steady move toward more innovation-intensive production.[3]

Looking across final demand categories, exports are the most R&D-intensive. Moreover, government spending exhibits the largest value-added share of college-educated labor, while investment has the largest value-added share of non-college labor. Consumption, on the other hand, has the lowest intensity of IT and R&D capital, due to its limited reliance on innovation inputs.

Furthermore, formal statistical analyses imply strong evidence of heterogeneity in production structures across final demand components once upstream production networks are taken into account. Multivariate tests reject equality of factor intensity profiles across consumption, investment, government, and exports, indicating that each demand component embodies a distinct combination of capital and labor inputs. Pairwise comparisons show that innovation-related assets, particularly R&D and creative originals, exhibit significant differences across demand components, while IT capital and non-college labor display greater similarity across several components.

Extending the analysis to individual industries reveals substantial gaps between direct and embedded factor intensities, highlighting that industry-level production structures can differ significantly from the factor content embodied through upstream supply chains. Specifically, direct R&D intensity is the highest in chemicals, college-educated labor is most concentrated in securities and financial services, and non-college labor remains prevalent in transportation and textiles. This contrast underlines the importance of tracking embedded

not industry classifications.

[2] Note that we cannot parse imported value added into value added by country. For example, gross imports of $1 are $1 of imported value added, even though within that $1, $0.50 of value added may be generated in Canada and $0.50 may be generated in Mexico when the gross $1 is recorded as coming from Canada. That is, we don't account for production chains in countries other than the United States and simply account for imported value added regardless of its origin.

[3] At the outset, we note that with the results that we present, we are not able to distinguish between demand-driven and supply-driven structural change. The composition within and across bundles may change for supply-related reasons like prices of factors of production or technological change, or for demand-driven reasons like increasing preference for educational services over air transportation.

inputs throughout the production network to fully understand how different factors are being used.

The rest of the paper is as follows: Section 2 reviews the literature on factor decompositions and value added, Section 3 outlines the analytical framework and data sources, Section 4 presents empirical results on labor and capital input structures, and Section 5 concludes with implications for structural analysis and future research.

2 Literature Review

This paper integrates two emerging strands of research: trade in value added (TIVA) and the KLEMS literature. The TIVA literature has advanced significantly, with key contributions from BEA and the National Center for Science and Engineering Statistics at the National Science Foundation, offering deeper insights into both domestic industry contributions and imported content.[4] Unlike traditional TIVA analyses, which focus primarily on exports, this study takes a broader approach by examining value-added contributions across all components of final demand.

In the United States, the long line of literature has led to BEA and the U.S. Bureau of Labor Statistics (BLS) collaborating to publish official statistics.[5] Building directly on this literature, we adopt the methodology proposed by Samuels [2022], which constructs an industry-level KLEMS production account to reallocate outputs and inputs to their secondary industries to align commodity trade with industry production.

Building on existing literature, our approach aligns closely with Timmer et al. [2014], which assesses the labor and capital content of the manufacturing sector using the World Input-Output Database. We expand this approach by examining the components of final demand rather than concentrating solely on the manufacturing sector. Furthermore, while Timmer et al. [2014] derives capital value added as a residual, we utilize the U.S. KLEMS database to directly measure the value-added shares of labor and disaggregated capital types like R&D and IT capital.

3 Methodology

Our methodology is an extension of standard single-country TIVA decompositions. At its core, we split the value added contributed across all domestic producers into factors of production required to produce each good or service, and then sum these over the value chain. Each producer assembles output using primary factors of production and intermediate inputs, some of which may be imported. Finally, some imports may be direct to personal consumption expenditures, investment, or government spending.

We start with the now-standard decomposition of gross exports to value-added exports. Following the notation in BEA's "Mathematical Derivation of the Domestic Requirements

[4] For a detailed discussion, see Chute et al. [2023]. The research on TIVA has expanded significantly, with contributions from academic scholars and major international institutions. To name a few, Johnson and Noguera [2012] used input–output and bilateral trade data to compute the value-added content of bilateral trade, and Koopman et al. [2014] developed a framework to trace domestic and foreign value-added in gross exports. In addition, the OECD and WTO have jointly developed the TIVA database OECD and WTO [2021], with detailed guidance provided in OECD [2023], while the World Bank has contributed through the edited volume by Mattoo et al. [2013].

[5] For further details, see Garner et al. [2021].

Tables for Input-Output Analysis" BEA [2023], we begin with the following variables that are directly published by BEA:

e_f: an i x 1 vector of final demand commodities
g: an i x 1 vector of industry output
D: an i x i market share matrix
B_D: an i x i domestic requirements table

BEA explains (under standard input-output modeling assumptions) how the industry-level domestic output required to satisfy a given bundle of final demand can be derived using the domestic requirements table and the market share matrix in the following expression:

$$g = D(I - B_D D)^{-1} e_f$$

That is, given a bundle of items in final demand e_f, the vector g represents the output by each domestic industry required to produce that bundle. This derivation is conditional on the industry input-output relationships, including the fact that some industries produce multiple commodities. It is important to emphasize here that B_D is the domestic requirements table. It accounts for *domestic* production by recognizing that some intermediate inputs may be imported. If intermediate inputs are imported, these are accounted for in the import-use table. But for the purposes of this paper, we focus exclusively on identifying the domestic production associated with each bundle of final demand. The remainder is the imported value added.

BEA identifies value added embedded in gross exports via the following equation:

$$VA_X = \widehat{V} D(I - B_D D)^{-1} e_X \tag{1}$$

This decomposition works as follows. The term $D(I - B_D D)^{-1} e_X$ is the measure of industry gross output required to produce the export bundle. e_X comes straight from the published BEA use table.[6] Premultiplying this output vector by a diagonal matrix of value-added shares $\widehat{V}$ (a jxj matrix with the nominal value-added share of industry output in each industry) yields the associated value added by each industry for the export bundle. Because this is a single-country model and data, it does not account for multiple rounds of production across international borders. For example, there is no way to measure the U.S. content that may be embedded in imports if a U.S. part was exported to produce a final good that is then imported into the United States.

Our extension to the basic method recognizes that value added encompasses payments to factors of production. Under the assumptions of the BEA-BLS Integrated Industry-Level Production Account, value added reflects payments to capital and labor, that is, zero net pure economic profit.[7] In the published ILPA account, five types of capital and two components of labor are published, even though the account itself is built up from a finer level of detail. In the equations, we refer to each type of labor or capital as type k, where

[6] There are some nuisance cases where a commodity within a bundle is of opposite sign. These happen for technical reasons discussed in BEA's documentation. For ease, we set these to zero.

[7] In the latest update to the ILPA, net taxes on product are removed from value added. For this version of the paper, we use a version of the ILPA that implicitly assigns all taxes as a payment to capital input. A next step is to update the calculations here to reflect the new ILPA data.

$k = 7$. The two types of labor include workers with and without a bachelor's degree (which we call college and non-college workers). The five types of capital include IT, R&D capital, software, entertainment original, and "other capital." Other capital includes instruments, structures, land, inventories, transportation equipment, and "other equipment."

We augment Equation 1 by imposing the accounting identity that $\widehat{V} = \sum_k \widehat{V_k}$. That is, the value-added share for each industry is simply the sum of the value-added share of the components of capital and labor services. The intuition for this is simple: labor compensation can be divided into payments to workers with a college degree or above and to workers without a college degree. Obviously, these two shares must sum to the total labor compensation share in value added. This allows us to write for each primary input k:

$$VA_X = \sum_k \widehat{V_k} D (I - B_D D)^{-1} e_X$$
$$VA_{X_k} \equiv \widehat{V_k} D (I - B_D D)^{-1} e_X \tag{2}$$

The first equation substitutes the sum of the k matrices, each representing the value-added share associated with a distinct primary input. The second equation defines the value-added contribution for input k as the product of its share in gross output and the domestic industry output required to produce the export bundle e_X. Since the k matrices sum to the original $\widehat{V}$ matrix, the primary input contributions add up to the total U.S. value added embedded in gross exports. It is important to note that this approach decomposes only the U.S. value-added contributions. For a bundle like PCE, a portion of the total gross value includes both direct imports of consumption goods and indirect imports of foreign value added via intermediate inputs. In the results below, we provide evidence on how each of these components has evolved.

In addition to this extension, we also apply the same basic approach to analyze the other components of final demand:

e_C: an i x 1 vector of personal consumption expenditures

e_I: an i x 1 vector of gross investment

e_G: an i x 1 vector of government expenditures

e_X: an i x 1 vector of gross exports

e_M: an i x 1 vector of gross imports

For the consumption bundle e_C, we define the domestic value-added contribution of primary input k as: $VA_{C_k} \equiv \widehat{V_k} D (I - B_D D)^{-1} e_C$. This expression captures the domestic contribution of factor k to the gross consumption basket. However, not all components of e_C are produced domestically—some imports enter directly into final demand. To isolate the domestic production component, we define $e_{C,D}$ as the domestic production of the personal consumption basket and construct it as $e_{C,D} = e_C - e_{M,C}$, where $e_{M,C}$ is the import bundle that goes directly to personal consumption expenditures. Accordingly, the decomposition of domestic value added becomes: $VA_{C_k,D} \equiv \widehat{V_k} D (I - B_D D)^{-1} e_{C,D}$. The import vector $e_{M,C}$ is from BEA's import-use matrix, which provides the imports used by each industry by commodity and the imports directly to final demand by commodity. This decomposition is performed analogously for investment (I) and government consumption (G).

A note on e_M: this is imports by commodity. e_M is not domestic production; it is imported goods or services that are purchased by consumers or businesses. When analyzing

e_M, we are posing a counterfactual question: *What would the U.S. production structure need to look like to domestically produce a bundle that is currently imported?* We speculate that tracking this over time may offer insight into how the economy would need to evolve to internalize production of currently imported final demand components.

Finally, we compare production structures for commodities by distinguishing between direct and upstream (indirect) contributions to the production structure of the industry for which that commodity is the final stage of production. For example, the final producer of motor vehicles, bodies, trailers, and parts is the motor vehicles, bodies, trailers, and parts industry. The share of primary input k directly contributing to the value added of industry j is referred to as the direct input share, denoted: $VASHR_{k,j}$. This measure captures the proportion of value added attributed to input k within industry j, relative to the total nominal value added of that industry. It is directly tabulated from the ILPA. We compare this to the structure of production that takes into account the upstream producers for all the intermediate inputs that flow into the motor vehicles, bodies, and trailers, and parts sector, and the entire value chain embedded in the intermediate inputs of the intermediate producers, etc. We define the indirect value-added share for j as $VASHR_{k,j} = \frac{VA_{X_k,j}}{VA_{X,j}}$. This is the value of an embedded primary input k across all upstream industries contributing to the production of commodity j ($VA_{X_k,j}$) over the total value added across the entire production chain for a given j ($VA_{X,j}$). This formulation weights the primary input value-added shares across all contributors according to each industry's share of contribution in the production of final output j. This produces the same result as tabulating the direct and upstream structure for \$1 worth of each commodity j.

4 Results

4.1 Analyses of Demand Components

Table 1 presents the summary statistics for the share of value added created by each type of capital and labor, as well as the share of imports and the imported intermediate inputs for each component of final demand. Moreover, in the final section of the table, we document the hypothetical value-added shares for imported goods, constructed under the assumption that these goods were to be produced domestically in the United States using the U.S. domestic requirements matrix.

Considering the C, I, G, and X components of final demand, on average, college and non-college labor and other capital consistently account for the largest shares of value added among the factors of production. Furthermore, when analyzing volatility, these three components show the highest volatility, with non-college labor showing the most pronounced fluctuations. This suggests that non-college labor is more impacted by economic volatility.

Exports have the largest share of value added from R&D compared to other components of final demand, reflecting their greater reliance on R&D capital in the production process over the entire value chain. Furthermore, under the counterfactual scenario in which imported goods are produced domestically using U.S. production methods, the value-added share of R&D capital inputs would be slightly higher than in the case of exports. The slightly higher R&D share under the counterfactual reflects the fact that many imported commodities originate from industries that are relatively R&D-intensive in the U.S. input-output structure, revealing latent R&D demand embedded in global supply chains.

Moreover, exports have the highest share of value added from imported intermediate in-

puts. This indicates that exports rely more heavily on foreign-sourced components throughout the production process relative to other final-demand categories. Additionally, under the counterfactual scenario in which imported goods are produced domestically using U.S. production methods, the value-added share of imported intermediate inputs would be slightly higher than in the case of exports.

Table 1: Summary Statistics of Value-Added Shares

Variable by Component	Mean (%)	StdDev (%)	Min (%)	Max (%)
Government Spending (G)				
IT Capital	1.6	0.1	1.4	1.9
R&D Capital	5.6	0.3	5.0	6.2
Software Capital	2.1	0.3	1.6	2.7
Creative Originals	0.4	0.0	0.3	0.4
Other Capital	26.6	2.4	21.5	30.5
College-Educated Labor	32.9	1.2	30.1	35.9
Non-College Labor	22.8	3.4	17.6	29.2
Imported Intermediate Inputs	6.7	0.9	5.5	8.7
Direct Imports	1.3	0.3	0.9	1.8
Personal Consumption (C)				
IT Capital	2.1	0.3	1.6	2.8
R&D Capital	2.0	0.2	1.8	2.7
Software Capital	2.2	0.5	1.3	2.8
Creative Originals	0.6	0.1	0.4	0.7
Other Capital	34.3	1.2	32.2	35.9
College-Educated Labor	24.5	1.9	22.1	28.8
Non-College Labor	23.5	2.9	19.8	29.0
Imported Intermediate Inputs	5.6	0.8	4.5	7.3
Direct Imports	5.3	0.4	4.3	6.0
Exports (X)				
IT Capital	2.2	0.5	1.4	3.0
R&D Capital	6.4	0.8	4.8	8.0
Software Capital	2.7	0.4	1.7	3.3
Creative Originals	0.8	0.2	0.5	1.0
Other Capital	26.4	2.5	21.5	29.4
College-Educated Labor	25.1	2.3	21.7	31.3
Non-College Labor	23.4	4.5	17.9	31.1
Imported Intermediate Inputs	13.1	1.5	10.5	16.5
Direct Imports	0.0	0.0	0.0	0.0
Investment (I)				
IT Capital	2.0	0.3	1.5	2.4
R&D Capital	3.5	0.5	2.7	4.5
Software Capital	2.3	0.4	1.4	2.7
Creative Originals	0.9	0.2	0.6	1.3
Other Capital	20.4	1.2	17.2	21.8
College-Educated Labor	25.0	2.6	21.3	30.4
Non-College Labor	27.7	4.2	23.6	35.0
Imported Intermediate Inputs	7.7	0.6	6.7	8.9
Direct Imports	10.4	1.4	8.4	12.6
Import Counterfactual (M)				
IT Capital	1.4	0.4	0.9	2.1
R&D Capital	7.5	2.0	5.2	11.5
Software Capital	2.2	0.3	1.6	2.7
Creative Originals	0.3	0.0	0.2	0.3
Other Capital	26.3	2.7	22.5	31.9
College-Educated Labor	22.2	2.5	18.6	28.2
Non-College Labor	23.5	4.1	19.2	31.7
Imported Intermediate Inputs	16.5	1.4	14.3	19.6
Direct Imports	0.0	0.0	0.0	0.0

Next, we compare factors of production with respect to each component of final demand. Specifically, for each final demand component, we first group the demand for domestically produced and imported goods. Next, we disentangle the total value added with respect to the upstream contribution of each domestic factor of production, as well as the imported intermediate goods. This grouping implies that the shares of contribution for domestic factors of production, imported intermediate goods, and imports add up to 1 for each demand component.

Figure 1: Value-Added Share of IT Capital

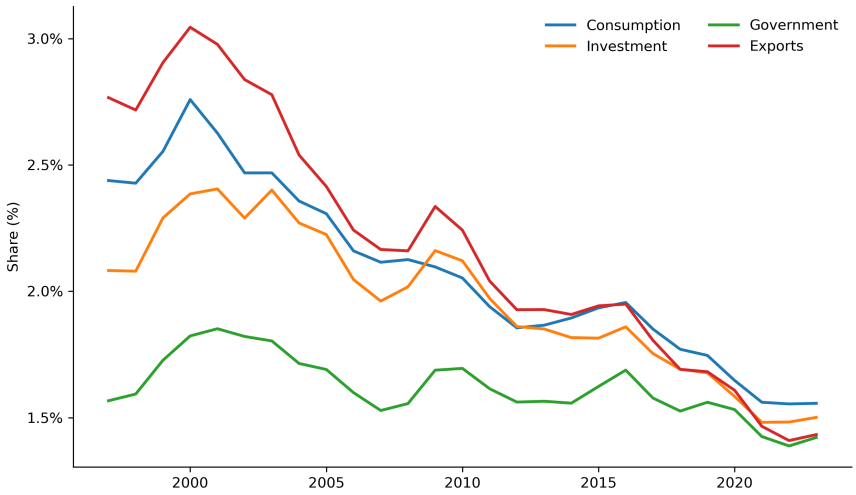


Figure 1 shows the distribution of total IT capital value added, incorporating both direct and upstream contributions, over the period from 1997 to 2023. The IT value-added share ranged between 1% and 3%, varying across different components of final demand. In the late 1990s, exports held the highest share of IT value-added. However, by the late 2010s, this share had declined and converged with those of consumption and investment. For government expenditures, the IT value-added share remained consistently around 1.5% throughout the entire period. This may be due to the diminishing marginal impact of IT capital on aggregate productivity growth. Specifically, more recent studies, such as Cardarelli and Lusinyan [2015], argue that the productivity gains from the IT revolution of the 1990s have largely plateaued, and that the slowdown in total factor productivity is not due to reduced IT investment, but to the diminishing marginal returns of IT capital on aggregate productivity.

Figure 2: Value-Added Share of Software Capital

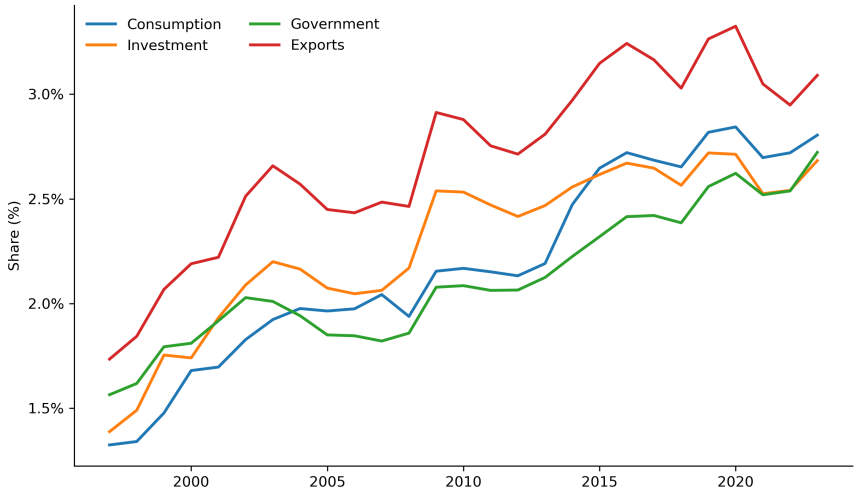


Figure 2 shows an upward trend in the value-added shares of software capital across all components, with exports exhibiting the most pronounced increase. Additionally, during the 2008 Great Recession, the software value-added share rose across all components. This pattern is in line with the findings of Corrado et al. [2009], who argue that software capital—alongside other intangible assets—has become an increasingly important contributor to U.S. economic growth as national accounts have started to treat it as a capital investment rather than an intermediate input.

Figure 3: Value-Added Share of R&D Capital

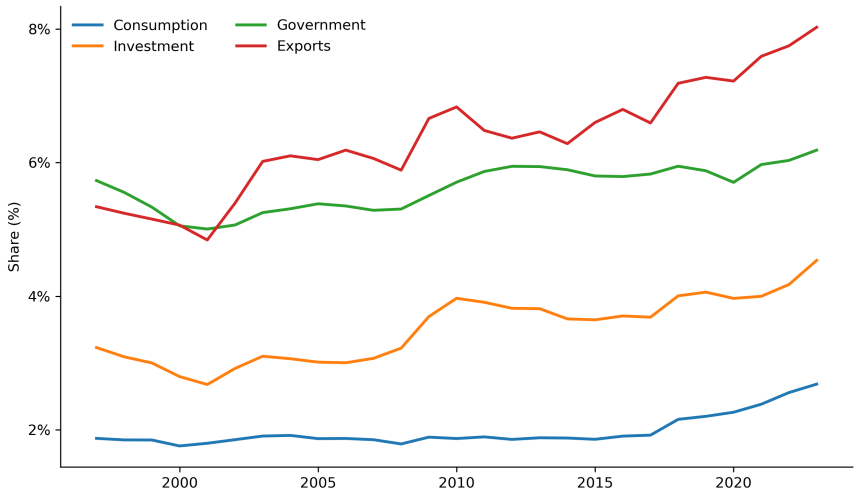


Figure 3 presents the share of upstream R&D value added. In the early years of the sample, exports and government spending had the highest share of R&D value added. However, while the R&D share declined over time for government, this share increased for exports. The R&D value-added share in investment spending followed a similar pattern to exports, rising steadily over the past two decades.

During the 2001 and 2008 recessions, the R&D value-added share declined for both exports and investments but rebounded during periods of economic recovery. Consistent with

existing literature on R&D cyclicality,[8] Figure 3 suggests that this fluctuation is primarily driven by the export and investment components of final demand, whereas consumption and government spending exhibit minimal variation in their R&D share. Finally, consumption expenditures maintain the lowest R&D value-added share, remaining relatively stable throughout the sample period.

Figure 4: Value-Added Share of College Degree Labor

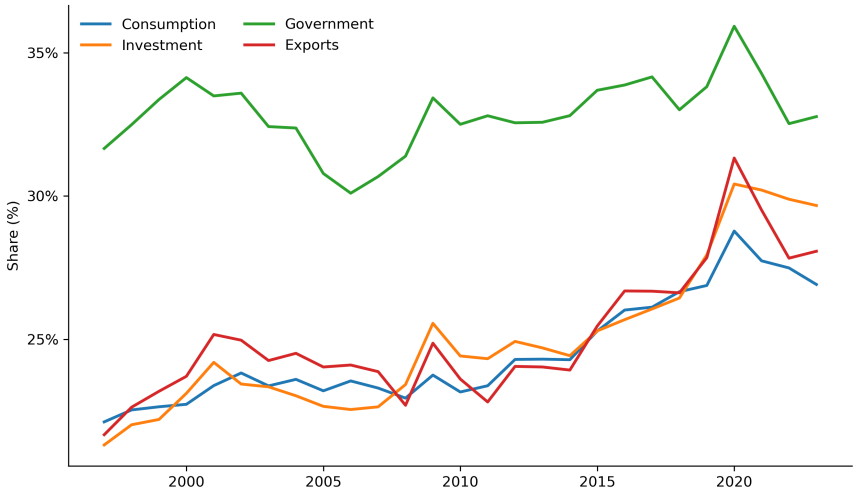


Figure 4 presents the share of upstream labor value added attributable to workers with a college degree. Throughout the sample period, government spending exhibited the highest share of college-educated labor value added, while the other components maintained similar levels. Additionally, following the 2008 financial crisis, the share of college degree labor value added increased for government spending, investment, and exports.

Figure 5: Value-Added Share of Non-College Degree Labor

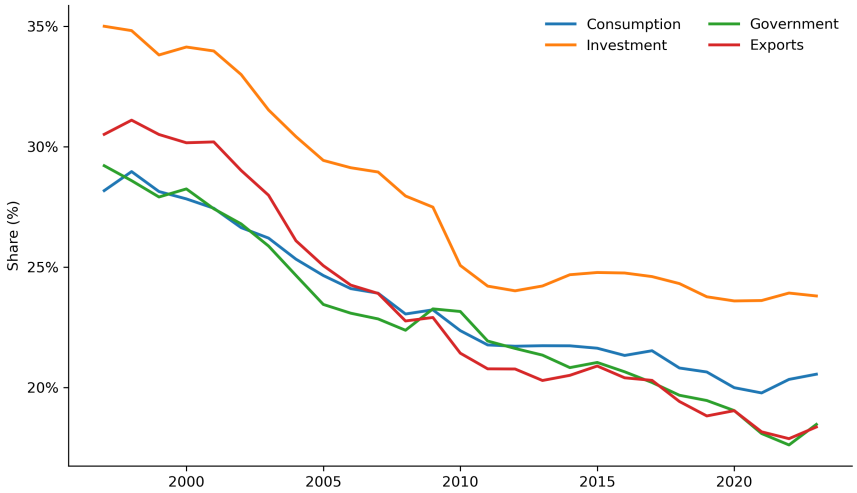


Figure 5 presents the share of upstream labor value added for workers without a col-

[8] See Barlevy [2007] on the cyclicality of R&D.

lege degree. In the early years of the sample period, non-college labor held the highest share across all components of final demand except within government spending. However, throughout the 2010s, this share steadily declined across all components, as the college-educated labor share increased.

Investment exhibited the highest share of non-college labor value added among all components, but following the 2008 recession, its decline became more pronounced before leveling off in subsequent years. Along with this downward trend, the value-added share of non-college labor in government and consumption spending was less volatile, indicating less sensitivity to economic downturns.

Figure 6: Value-Added Share of Imported Intermediate Inputs

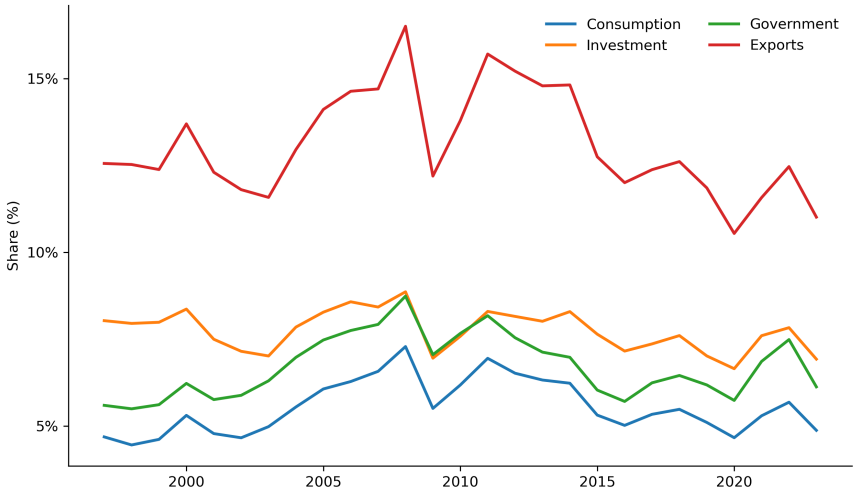


Figure 6 presents the share of upstream value added from imported intermediate inputs. This analysis helps assess the degree of import dependence embedded in domestic production. Notably, exported goods consistently hold the highest share of imported intermediate inputs throughout the sample period. Moreover, the value-added share of imported intermediate inputs remains stable over time.

We now examine in detail how each type of capital and labor contributes to value added across the different components of final demand.

Figure 7: Value-Added Share of Final Demand Components

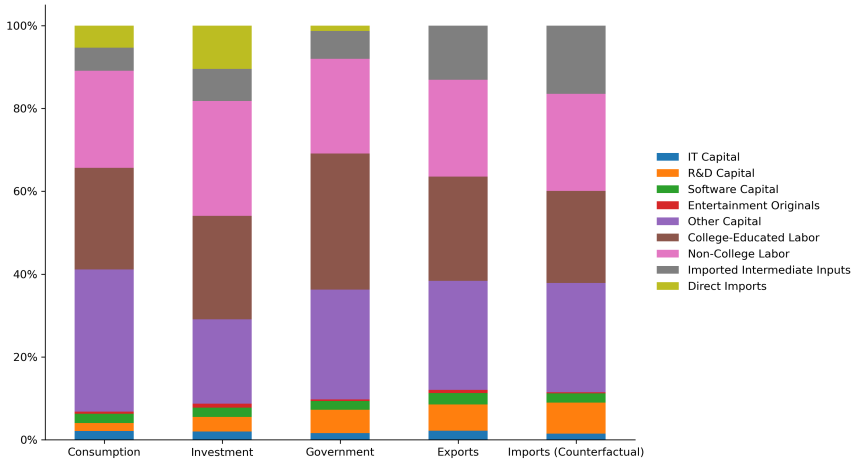


Figure 7 presents the average factor composition of each final demand component over the 1997–2023 period. By aggregating across time, the figure allows a direct comparison of the relative importance of capital, labor, and imported intermediate inputs across components.[9]

Government spending has the highest share of college-educated labor, accounting for roughly one-third of total value added, consistent with the public sector's concentration in education, defense, and administrative services. By contrast, investment exhibits the largest share of non-college labor, possibly reflecting its close association with the production of physical capital.

Exports and the imports (counterfactual) have larger shares of R&D capital, suggesting that traded goods are more R&D-intensive along the value chain. Consumption, in contrast, displays the lowest capital intensity overall, with particularly small R&D and IT capital shares, due to its concentration in retail trade, food services, and healthcare that rely less heavily on knowledge-intensive inputs.

Across all components, other capital, together with the two labor categories, accounts for the majority of domestic value added. At the same time, imported intermediate inputs are most prominent in exports and in the imports (counterfactual). Direct imports appear primarily in consumption and investment. Although these comparisons are based on period averages, they suggest substantial structural heterogeneity discussed in Section 4.1.1.

4.1.1 Production Structures of Demand Components

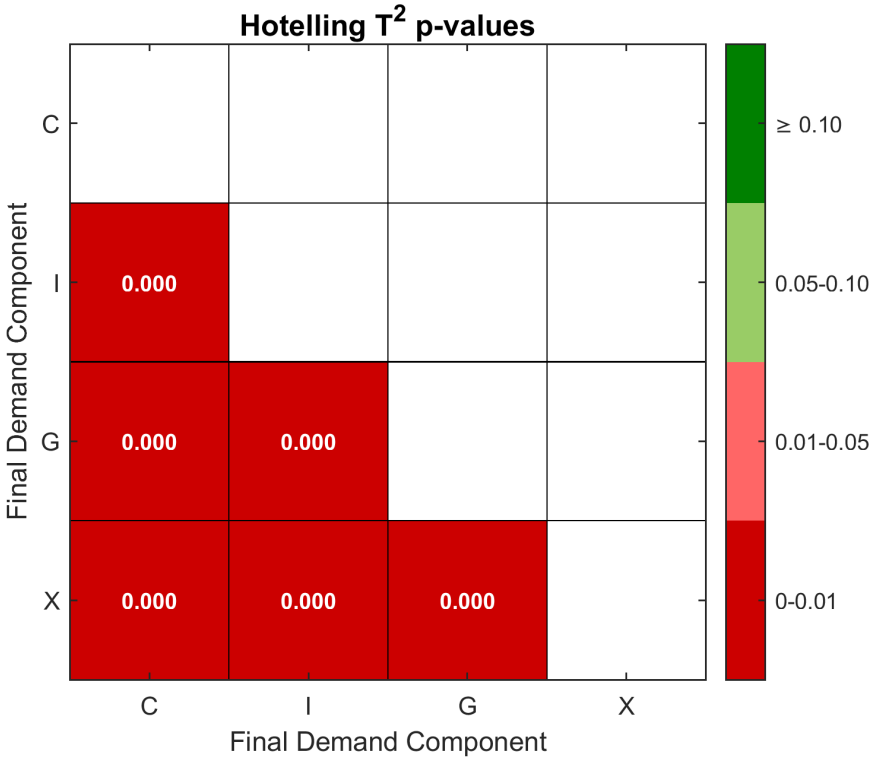
Following the visual comparison of value-added factor shares across demand components, this section formally evaluates whether the production structure of final demand components differs in terms of value-added factor intensities. We proceed in two steps: First, we test whether the overall production structures differ across demand components using a multivariate framework that captures joint differences in factor shares. Next, we examine pairwise differences in individual factor intensities across demand components.

[9]More detailed time-series profiles of these shares for each component, illustrating the evolution of production structures over time, can be found in Appendix A.

Global Differences in Production Structures: Hotelling's T^2 test Results

We begin with the application of Hotelling's T^2 test to evaluate if the mean factor intensity vectors differ significantly across demand components. Under the null hypothesis, any two demand components—Consumption (C), Investment (I), Government (G), or Exports (X)—would exhibit statistically identical patterns of input use across all seven factors. Unlike univariate tests that consider each factor separately, this multivariate test assesses whether the overall input-use profile differs jointly across demand components. As shown in the Hotelling's T^2 p-value heatmap in Figure 8, all pairwise comparisons between the four demand components show p-values below 0.01, as indicated by the dark red cells in the lower triangular matrix. This implies consistent rejection of the hypothesis across all comparisons, providing evidence that the combined factor composition of inputs required for Consumption, Investment, Government, and Exports are distinctly different.

Figure 8: Hotelling's T^2 Test



Pairwise Factor Asymmetry: Welch t-test Results

Building on the overall structural differences identified by Hotelling's T^2 tests, we next decompose these variations and examine which individual production factors drive these differences by conducting pairwise Welch t-tests for each of the seven factors. This approach tests the null hypothesis that, for a given factor, the average intensity does not differ significantly between two demand components, helping us identify which demand components show statistically similar factor intensities and where these intensities differ. Figure 9 summarizes the p-values from the Welch t-test for pairwise comparisons of factors across demand components.

The results show that R&D and Entertainment Originals exhibit the most pronounced

structural differences across demand components. For both factors, every pairwise comparison across Consumption (C), Investment (I), Government (G), and Exports (X) yields a p-value less than 0.01. This indicates that innovation and creative asset requirements differ systematically across final demand categories.

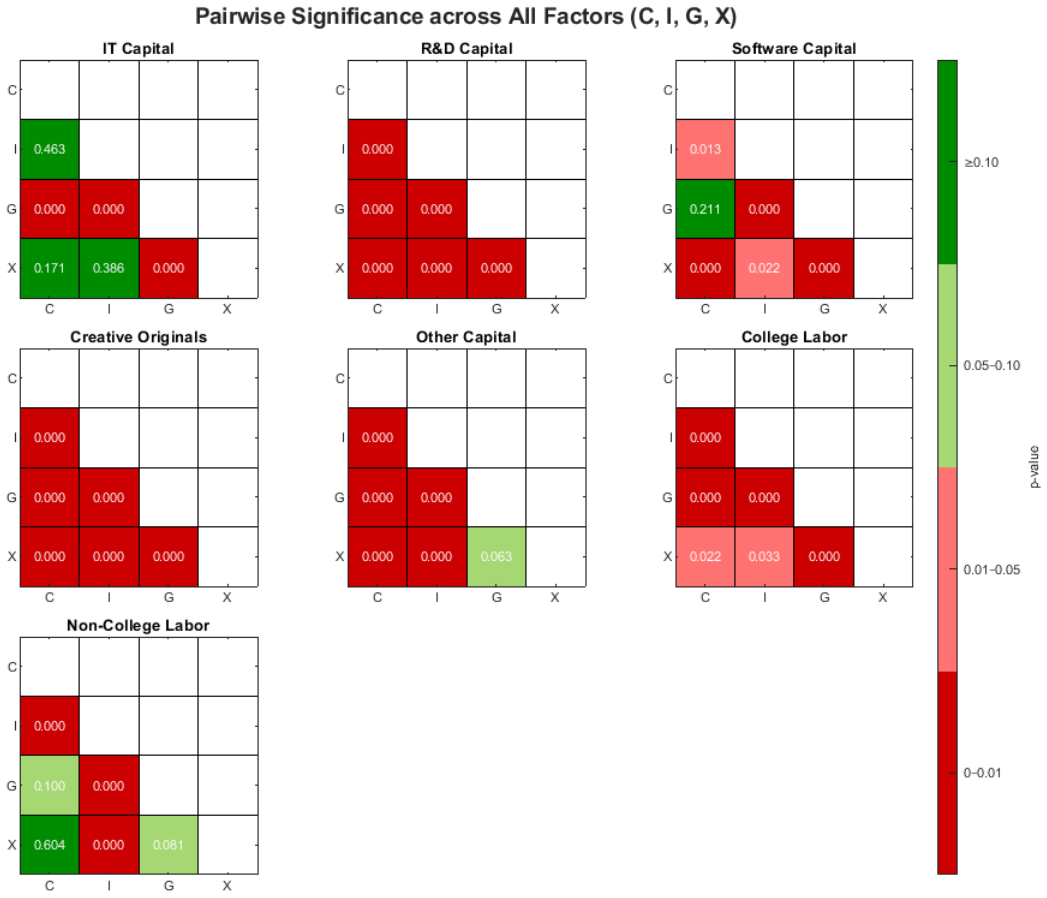
In contrast, the results for IT and software capital show structural similarity across some of the demand components. Specifically, the IT Capital results show that the intensities for Investment and Consumption (p=0.463), Exports and Consumption (p=0.171), and Exports and Investment (p=0.386) are not statistically different. This suggests a common structure for IT asset usage across these sectors, while the Government component is an exception with significant differences across all its pairings (p=0.000). Similarly, Software Capital shows no significant difference between Consumption and Government (p=0.211), though most other sector pairs remain statistically significant.

Considering the comparison of labor requirements, college-educated labor shows significant differences across all demand components, with all p-values falling below the 0.05 threshold. This suggests that the college-educated labor required for production depends heavily on the type of final demand. In contrast, the usage of non-college labor shows significant structural similarity across demand components. No statistically significant differences were found in the non-college labor requirements between Exports and Consumption (p=0.604), Government and Consumption (p=0.100), or Exports and Government (p=0.081). In this case, Investment remains an exception with significant differences across all its pairings (p=0.000).

Lastly, physical capital requirements, captured in the "Other Capital" category, are mostly different. Most pairwise tests result in p-values of 0.000, indicating unique machinery and structural needs. The only exception is the comparison between Exports and Government, which yields a p-value of 0.063, indicating these two components share more similar intensities of other capital than other demand component pairs.

These results reveal significant structural heterogeneity in factor intensities across demand components. With the exceptions of IT and non-college labor, each type of final demand relies on a distinct combination of factor inputs. This heterogeneity implies that macroeconomic policies or shocks are likely to have asymmetric effects depending on which demand component they primarily affect.

Figure 9: Welch t-test



4.2 Production Structures of Commodities

This section shifts the analysis from final demand components to individual commodities, linking each commodity to its primary producing industry as identified in ILPA. For each commodity, we calculate the value-added shares of production factors required to generate \$1 of that commodity, accounting for the entire production chain, including both direct production and indirect contributions from intermediate inputs. We then compare these upstream (indirect) factor shares with the corresponding direct value-added shares of the primary producing industry from the ILPA. If a factor's indirect share exceeds its direct share, this indicates that upstream industries rely on that factor more heavily than the primary industry. Conversely, if the indirect share is lower than the direct share, the primary industry utilizes that factor more extensively than the upstream industries. All shares are expressed relative to total domestically produced value added and therefore exclude imported value added and direct imports.

Figure 10: Industry-level difference between indirect and direct R&D Capital shares, averaged over 1997–2023.

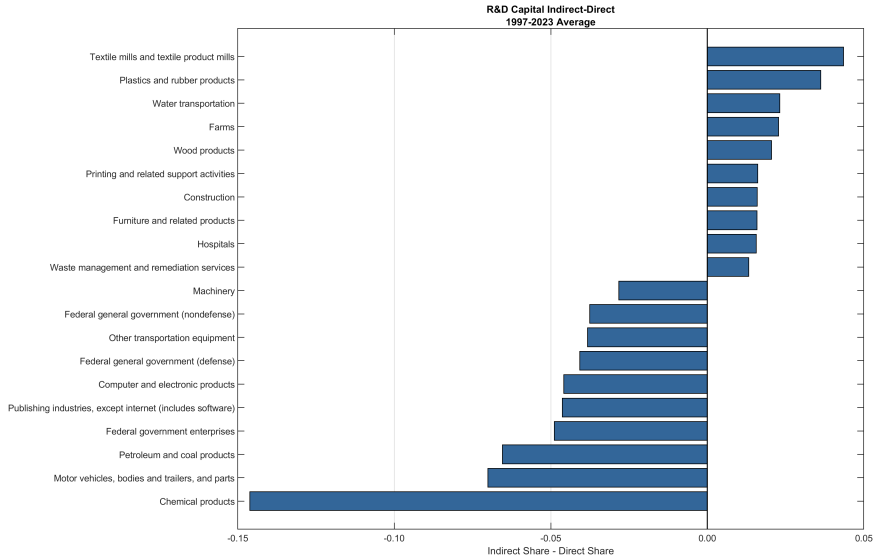


Figure 10 reports industry-level averages of the difference between indirect and direct factor shares for R&D capital over the period 1997–2023. Positive values indicate that a factor is used more intensively in upstream production networks compared to its direct use by the industry itself, while negative values suggest a greater direct use relative to indirect exposure. Industries are ordered within each figure by the magnitude of the indirect–direct difference. For ease of presentation, the figure displays the top 10 and bottom 10 industries based on this magnitude.

The distribution of the indirect–direct difference is highly uneven across industries. Chemical products and motor vehicles exhibit strongly negative differences in R&D, indicating a greater concentration of direct R&D use, while industries such as textile mills and plastics show positive differences, reflecting reliance on R&D embedded in materials and components sourced from upstream producers.

Figure 16–Figure 21 in the Appendix extend this comparison to the remaining capital and labor categories. Across all factors, indirect–direct differences exhibit substantial heterogeneity across industries, indicating that factor intensities measured at the point of production can differ significantly from those embedded through upstream production networks. For IT capital, the broadcasting and telecommunications and data processing sectors exhibit the largest negative values, suggesting that IT capital is used more intensively as a direct input within these industries than through upstream production networks. In contrast, funds, trusts, and other financial vehicles exhibit large positive differences, indicating greater reliance on IT capital embodied in upstream inputs rather than direct use.

Software capital follows a similar pattern. Data processing and internet publishing concentrate on software use in-house, as reflected in their strongly negative values. Meanwhile, other real estate and financial sectors show positive differences for software capital, suggesting these industries access software primarily through the intermediate services they purchase from upstream suppliers.

For art and entertainment originals, the motion picture and sound recording industries, along with the publishing industries, exhibit a negative differential, suggesting a heavier reliance on art and entertainment originals capital. Conversely, data processing, internet

publishing, and other information services, and the miscellaneous professional, scientific, and technical services industry demonstrate greater usage of art and entertainment originals capital in upstream industries compared to their primary industry.

For other capital, funds and trusts, other real estate, and oil and gas extraction exhibit large negative differences, reflecting a greater concentration of direct capital use relative to indirect exposure. By contrast, securities and commodity contracts show positive differences for other capital, indicating that these industries primarily access capital services indirectly through upstream providers instead of utilizing physical assets directly.

Regarding labor shares, college-educated labor displays large negative differences in the securities, commodity contracts, and investments and educational services sectors, indicating relatively greater direct use of skilled labor compared to its utilization through upstream production networks. In contrast, sectors such as funds and trusts and other real estate display positive differences for college-educated labor, reflecting reliance on skilled labor used in upstream production networks rather than direct employment. Conversely, non-college labor shows strongly negative differences in manual-intensive industries such as textile mills, apparel, and truck transportation, consistent with these sectors' heavier reliance on direct labor inputs relative to indirect exposure.

Overall, financial and real estate sectors consistently function as downstream collectors of value added. Specifically, across many factors, from IT and software capital to both college and non-college labor, these sectors exhibit among the largest positive indirect–direct differences, indicating a systematic reliance on factors embodied in upstream production networks rather than on direct factor use.

5 Conclusion

If a primary input is important in an upstream industry but not in the final stage of production, looking only at the final stage may provide a misleading picture of the resources needed in production. In this paper, our main goal is to address this issue and propose a detailed framework to analyze the factor content embodied in final demand by tracing production structures through upstream supply chains. To do this, we link domestic requirement tables with ILPA data that include information on the use of primary factors of production by industry.

Based on our analysis, we find common trends in the long-term trajectories of some input shares. For example, non-college labor shares have steadily declined across all final-demand bundles and exhibit greater volatility than other inputs. In contrast, software and R&D capital have risen modestly over time, signaling a gradual shift toward knowledge-intensive production. Among bundles, exports remain the most R&D-intensive. Government spending shows the highest value-added share of college-educated labor, while investment has the highest value-added share of non-college labor despite its overall downward trend. The consumption bundle exhibits the lowest intensity in IT and R&D capital, likely reflecting that the consumption bundle includes many consumer staples.[10] In addition, exports contain notable embedded indirectly imported content, exceeding 10%.

Following the visual examination, we formally evaluate whether the production structure of final demand components differs in terms of value-added factor intensities. Across final

[10] Personal consumption expenditures are concentrated in sectors such as retail trade, food services, and transportation, which fall into the lowest R&D intensity categories according to the OECD taxonomy of economic activities Galindo-Rueda and Verger [2016].

demand components, multivariate and pairwise tests reveal pronounced structural heterogeneity in factor intensities, with R&D, creative assets, college-educated labor, and physical capital varying systematically across Consumption, Investment, Government, and Exports. In contrast, IT capital and non-college labor display more uniform patterns across several demand components, suggesting common baseline requirements in these dimensions.

Finally, we find that looking only at the final stage of production may yield a misleading view of the entire production structure for specific industries. At the industry level, comparisons between indirect and direct factor shares show wide dispersion, indicating that factor intensities observed at the point of production often differ substantially from those embedded through upstream supply chains. Financial and real estate–related industries, in particular, emerge as downstream collectors of value added, relying heavily on factors embodied in intermediates rather than direct input use. These findings highlight the importance of moving beyond direct production structures to understand how factor demands, policy shocks, and structural change propagate through production networks. Consequently, this paper serves as a proof of concept that, when analyzing the production structure of components of final demand and individual industries, it is important to account for the production structure of intermediate inputs across the entire U.S. value chain.

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