After Redefinition TFP Accounting

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Abstract

When establishments engage in secondary production, measured total factor productivity (TFP) growth at the industry level reflects the joint production process of the primary and secondary products and reallocation between these products within an industry. If secondary products are substantively different from primary products (often with very different price indexes), this confounds the composition of production and TFP and has the potential to obscure analysis of the underlying reasons for changes in aggregate TFP.[1]

We reconsider the basic premise of (Raa & Wolff, 1991) that it is important to distinguish between primary and secondary production in analyzing the sources of aggregate productivity change. To align with BEA's After Redefinition Input-Output tables, we construct a KLEMS production account where outputs and inputs have been moved from their primary to their secondary industry to assess productivity growth for redefined industries. Using unpublished detail from BEA and the BEA-BLS integrated industry level production account, we move nominal and real inputs for two types of workers (those with a college degree and those without) and five types of capital (IT equipment, software, R&D, entertainment originals, and other capital) from primary to secondary industries. Coupled with information on the deflators for secondary outputs, we construct a measure of TFP growth for products that reflects the input structure and costs of the industry in which these products were produced.

Disentangling TFP growth between primary and secondary industries 1) helps shed light on the origins of changes in aggregate TFP, 2) provides useful information in analyzing international competitiveness where trade is driven by product competitiveness, 3) allows for consistent aggregation of TFP growth from commodities to broad components of final demand (e.g. investment and consumption) when primary and secondary industry production span expenditure categories (Basu, Fernald, Fisher, & Kimball, 2013).

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1 Presumably, if production was rebalanced enough toward a secondary product, an establishment's industry classification would change and its primary product would become secondary, so the basic issue would still exist.

1. Introduction

Economic measurement issues related to the computer and electronics sector are a useful lens to examine the overall state of economic statistics because this sector often highlights broader measurement issues that are important for other sectors and for the economy as a whole. The Solow paradox and productive puzzle encouraged important economic research that helped pave the way to official industry-level production accounts that show how innovation in the computer and electronics sector made a significant contribution to economic growth during the information technology (IT) boom of the late 1990s and early 2000s (Jorgenson, Ho, & Stiroh, 2005). The slowdown in measured productivity growth after 2004 led to a reexamination of measurement challenges encountered by growth analysts, again with a focus on IT-related industries. (Byrne, Fernald, & Reinsdorf, 2016) conclude that mis measurement of IT is not a likely source of the measured productivity slowdown.

This paper does not assert that there is mismeasurement problem in the IT sector but does use the computer and electronics sector as another important example of an issue that can complicate analysis of the sources of aggregate productivity growth. We examine the role of secondary production in understanding the sources of growth. In the BEA-BLS integrated industry-level production account, which provides the bottom-up sources of gross domestic product (GDP) and aggregate TFP growth, the economic accounting is done based on the concept of establishments. If an establishment produces more than one output, the total value of all output is typically grouped with other establishments to which this output is primary. For example, according to BEA data, about 6.2 percent of the gross output of the computer and electronics sector in 1987 was research and development and own account software because these activities are conducted within the same establishments that produce computer hardware. This share increased to 21.5 percent in 2019. Obviously, there are good reasons that R&D and own account software are included in the output of the computer and electronic sector because the production of computer and semiconductor hardware is intertwined with the production of R&D and own-account software. But there are also good reasons why analysts would want to separate the activities. The production of R&D and own-account software is very different in nature from the physical production of computers and semiconductor hardware. If the computer and electronics sector devotes an increasing amount of resources to the production of R&D instead of the production of hardware, measured productivity in the combined sector reflects this composition shift. This is potentially important in assessing the sources of aggregate productivity change if productivity change in the production of hardware is different from the productivity change in the production of R&D and own-account software.

The purpose of this paper is to present a new industry-level productivity account that reorganizes secondary production to align with the BEA's After Redefinition Tables and uses this account to measure the sources of U.S. economic growth. BEA's After Redefinition Input-output tables reorganize outputs and inputs when the production process of the secondary output significantly differs from an industry's primary product. For example, all construction activity is moved to the Construction sector in the After Redefinition tables. An advantage of this new organization is that this allows for a bottom-up analysis of the contribution of productivity growth that avoids confounding compositional change between primary and secondary products with changes in measured TFP growth for industries that embed secondary output. It is important to note that there are other ways to approach handling of secondary production in industry accounting. For example, it may be of interest to move all secondary production to the industry in which it is primary. This would result in an account that approaches the concept of commodities instead of industries, but the objective of this paper is to construct an account that aligns with BEA's After Redefinition tables.

In addition to providing a potentially cleaner view of the sources of productivity growth, the realignment of the productivity accounts has two other major benefits from an analytical perspective. The first is related to measuring international competitiveness at the industry level. (Jorgenson, Nomura, & Samuels, 2016) shows how to measure industry price and productivity gaps at the industry level to assess competitiveness on international markets. But, the constructs in that paper may suffer from the same basic issue: price and productivity gaps may reflect the composition of secondary production and thus obscure the true economic competitiveness of certain products. For example, (Jorgenson, Nomura, & Samuels, 2018) finds that the chemicals sector in Japan surpassed the chemicals sector in the U.S. in its productivity level. Suppose that chemicals sector in the United States does significantly more R&D than the same sector in Japan. If this were true, then the measured productivity gap could reflect the composition of R&D and not the gap in actual production of chemical products. In assessing competitiveness on international markets, it is the latter concept that is of primary interest. This basic issue is also relevant in efforts to reconceptualize from national to global economic accounting, such as the proposal in (Samuels & Strassner, 2019) for the same reason: establishment-based price and productivity gap measures embed composition differences due to secondary production.

Another major benefit of productivity accounts that are more closely aligned to products is the analysis of global value chains (GVCs) and measuring trade in value added (TiVA). TiVA measures are based on answering the following question using input-output tables: for a given export, how much of the value of the export is composed of domestic value added (including from all upstream industries that contribute to that export) and how much of the value of that gross export is embedded value from foreign producers. Because of this, TiVA estimates are (ideally) based on narrow products instead of broad industries to avoid including (mostly) irrelevant value. For example, using the before redefinition industry concept to construct TiVA estimates would impose that every time the U.S. exported a computer more R&D had to be done to support that export. To avoid that, using after redefinition input-output tables are preferable, and BEA uses this approach in its recent TiVA work.[2] But, suppose one wanted to take it one step further and estimate the worker skill composition embedded in TiVA. Without a corresponding production account that is matched to the relevant input-output tables, it is not possible to consistently estimate this value. This paper presents such an account.

The importance of distinguishing between products and industries has a long history in input-output accounting and has been addressed in the context of productivity accounting as well. (Raa & Wolff, 1991) find that the distinction between commodities and industries matters for certain sectors, but not for the overall economy under a certain set of assumptions and the data available at the time. While the premise of this paper is basically the same, it is worth revisiting. First, the BEA now produces official after redefinition input-output tables that address this basic issue that

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[2] Recent discussion: Single Country TiVA (bea.gov)

are data driven and avoid some of the stronger assumptions of (Raa & Wolff, 1991). Second, the national accounts have since recognized research and development and own-account software as a capital asset, which necessitates including this in gross industry output in the establishment-based industry accounts. Third, KLEMS (Capital, Labor, Energy, Materials, Services) productivity accounts have advanced so that there is now price data for detailed inputs. This allows for a cleaner mapping between inputs used in primary and secondary production.

At the outset, it is important to note that the new production account presented in this paper does involve assumptions to translate measured data into estimates of output and input that can be assigned between primary and secondary industries and there are certainly other ways to implement such an account.[3] The sections below will enumerate those assumptions, but how far these assumptions are from economic reality in comparison to the many other assumptions used to measure industry growth and (total factor) productivity is not obvious, nor is it the focus of this paper. Therefore, the estimates presented in this paper should be considered in the context of the other broad sets of assumptions that are used to assemble economic estimates of TFP growth.

We find that distinguishing between primary and secondary production is important for measuring TFP growth, but only for a small subset of industries for the sample period for which data is available to make the adjustment between primary and secondary production. The major impacts are in the computer and electronic products and data processing, internet publishing, and other information services sectors. Another noteworthy finding is that the manufacturing sector has a smaller share in GDP when non-manufacturing secondary production is moved out of the sector.

The paper proceeds by first describing the construction of an industry level production account that adjusts for secondary production, first by focusing on the nominal production account including industry outputs and inputs in sections 2.1 and 2.2.. The second component of this is linking prices to these output and inputs to construct a real account for measuring industry TFP and this is described in section 2.3. Section 3 presents the sources of economic growth when secondary production is moved out of its primary industry. Section 4 concludes.

2. Constructing After Redefinition KLEMS Accounts

This section discusses the steps and economic assumptions employed to construct the production account that adjusts for secondary production. The nomenclature used to refer to this new account is "after redefinitions" to follow the terminology used by BEA in constructing its input-output tables. The point of comparison for this account is the BEA-BLS Integrated Industry-level production account, which is built with the "before redefinition" input-output tables. For brevity, and because there is a large accompanying literature, the methods and economic assumptions of BEA-BLS integrated industry-level production account are not covered in this paper.[4]

[3] See the appendix for additional discussion.
[4] See (Garner, Harper, Russell, & Samuels, 2020) for a more recent discussion of the BEA-BLS data and (Jorgenson, Ho, & Stiroh, 2005) for a comprehensive description of the general concepts and methods.

2.1. After redefinition output and input in current dollars

Assembling after redefinition KLEMS (capital, labor, energy, materials, services) accounts requires constructing industry output, intermediate input, capital and labor services in current and constant dollars. The basic approach is to distinguish primary and secondary production where secondary production is defined as production of goods and services that use a substantially different input pattern. Because it is often difficult to analyze input patterns systematically based on available source data, choosing what to redefine likely involves analyst judgement based on product line information like that from the economic census. The starting point for after redefinition KLEMS in this paper is the official data produced by BEA on after redefinition input-output tables as this provides a consistent measure of output and intermediate input (EMS) in current dollars that sums to the official GDP. The basic method for translating the before redefinition tables to after redefinition is given in (Horowitz & Planting, 2006) so this paper provides only a broad overview to convey the important ideas. In the extreme case, every industry produces only one commodity (so that the make table is diagonal) but this is not the approach in the official after redefinition tables produced by BEA. The after redefinition KLEMS productivity account presented in this paper follows the official BEA data on redefinitions, though alternatives with other assumptions around reclassification may be worth considering.[5] [6]

The basic motivation for after redefinition input-output tables is that grouping disparate outputs within the same industry complicates input-output analysis. Consider a stylized case where an accommodations (hotel) establishment also produces restaurant meals that are served to both hotel and non-hotel guests. A typical input-output approach to figuring out how many more inputs would be required to expand the number of rooms offered by the hotel (while keeping the number of restaurant meals to outsiders held constant) wouldn't be possible when meal sales are included in the input and output measures of the industry. At the same time, if one wanted to answer a question about how many more inputs would be required to produce both more hotel rooms and more meals to outsiders, having the output grouped together is useful.

The first step BEA takes in constructing the after redefinition input-output tables is to decide which industries have secondary production to be redefined. In these cases, the value of output of the secondary product is moved to the industry in which it is primary. For example, construction activities performed in any industry are moved to the construction sector in the after redefinition tables.

The second step is to reallocate the accompanying intermediate inputs from the primary to the secondary industry. For example, when margin sales on shampoo in a salon are redefined to the retail trade industry, the corresponding intermediate inputs need to be moved as well. The basic

[5] A simpler approach that could be implemented with publicly available summary level data is to use the published Make table. Some notes on this approach and its caveats are discussed in the Appendix.

[6] It is worth noting that this paper follows BEA's approach for reallocating output that is for own use in addition to output that is for sale. While it would be of interest to construct an alternative account that redefines only output that is sold on the market, this would require a new time series of input-output tables and would not match BEA's published after redefinition tables.

assumption employed BEA's after redefinition tables is to impose that the intermediate input composition (across detailed commodities) for the output being redefined corresponds to the intermediate input composition of the secondary industry. Therefore, if output is being moved from beauty salons to retail trade, the basic assumption is that the accompanying intermediate inputs that are moved have the same composition as those in the retail trade sector. The proportion of output that is not reallocated to intermediate input is reallocated to value added. The starting point for the estimates presented in this paper is these official after redefinition use tables that are published by BEA.

2.2. After redefinition capital and labor services in current dollars

The after redefinition production account requires estimates of nominal capital and labor services for the redefined industries. BEA's published after redefinition input-output tables include information on employee compensation, gross operating surplus (GOS), and taxes on production and imports, but the gross operating surplus includes mixed income for self-employed so this cannot be directly mapped to capital and labor services in the redefined industries. Furthermore, it is imperative to capture heterogeneity within the capital and labor inputs (think differences in information technology and structures capital input and highly educated experienced workers and less educated inexperienced workers) in the after redefinition accounts to match the categories used in the before redefinitions BEA-BLS integrated industry level production account.

The primary reason for recognizing this heterogeneity is that it is necessary to distinguish between changes in input composition from changes in total factor productivity growth. Measures that fail to account for this heterogeneity will confound shifts to higher quality inputs and growth in TFP (Jorgenson & Griliches, 1967) . Unfortunately, there is not reliable source data on which detailed capital and labor inputs are used to produce which outputs within establishments. For example, the beauty salon that sells beauty products is likely to employ the same worker to undertake both tasks, but the skill mix and capital composition of running the production line in pharmaceutical manufacturing may be very different from the skill mix and capital composition in producing R&D on pharmaceuticals.

The nominal capital and labor estimates presented in this paper are constructed using the following method. Total employee labor compensation is reallocated using the same assumption and data that is used in the official after redefinition tables; the value of labor compensation that is moved into an industry reflects the share of employee labor compensation in value added in the secondary industry. For example, if meat processing value added is reallocated from the wholesale sector to the manufacturing sector, the portion of this that is attributed to employee labor compensation is determined by the share of employee labor compensation in value added in the manufacturing sector. This reproduces the official after redefinition estimate of employee compensation.

Gross operating surplus is reallocated in a similar fashion, but an adjustment is made to split mixed income into labor and capital income. Specifically, for all reallocations of gross operating surplus, unpublished BEA data is used to link the reallocation of gross operating surplus to its industry of origin. The industry of origin is used to split the reallocated GOS into self-employed labor compensation and a remainder that gets allocated to capital income based on this same share in the BEA-BLS integrated industry level production account. For example, if meat processing value added is reallocated from the wholesale sector to the manufacturing sector, the portion of this that is attributed to GOS is determined by the share of GOS in value added in the manufacturing sector. But the share of GOS that is allocated to self-employed labor compensation is determined by the share of self-employed workers in GOS in the wholesale sector. The reason why the allocation between self-employed labor and GOS is not based on the share in the manufacturing sector will be discussed below.

Finally, taxes on production and imports are reallocated to secondary industries using the same approach as employee compensation but are assigned to capital income. Including taxes on production and imports in capital income is also the approach the BEA-BLS integrated industry-level production account, though work is underway at BEA to revisit this.

The above describes the estimates of total nominal capital and labor services by industry, but additional steps are needed to determine the composition of capital and labor. There is no information on this in the official after redefinition tables. As noted above, this prototype account considers two categories of labor: workers with a BA degree and above and other workers (those with less education), and five types of capital assets (IT equipment, software, R&D, entertainment originals, and other capital). The assumption used to determine this allocation is that the composition of capital and labor being reallocated reflects the *primary* industry from which it is being reallocated. Thus, if employee labor compensation from the meat processing industry is reallocated from the wholesale sector to the manufacturing sector, then the share of this labor compensation that is attributed to workers with a BA degree in the redefined manufacturing sector reflects the share of labor compensation paid to workers with a BA degree in the wholesale meat processing industry. This approach is employed for two basic reasons. The first reason is based on the idea that much of what is being reallocated is produced under a joint production technology. For example, if the process of wholesaling meat is fundamentally inseparable from the process of meat processing within an establishment (e.g. due to feedback loops in the process), then the composition of inputs used in meat processing must be the same as the composition of inputs used in meat wholesaling. Another example is that it may be the case that conducting R&D (and returns from R&D) in medical sector is fundamentally inseparable from the provision of medical care. In the case of only two input types, this assumption can be represented with a generalized production function of the form $F(Y_1, Y_2) = G(L_C, L_N)$ where Y_1 and Y_2 are meat wholesaling and meat processing and L_C and L_N are workers with a BA or higher degree and others. This specification can be compared to separable production functions of the form $Y_1 = G(L_{C1}, L_{N1})$ and $Y_2 = G(L_{C2}, L_{N2})$ where inputs can be separated and allocated across meat processing and meat wholesaling. It is important to reemphasize that the source data is establishment based so that splitting inputs between meat wholesaling and meat processing and imposing separate production functions, which may be more intuitive, likely involves stronger economic assumptions than the assumption employed in this paper that the two outputs are produced jointly.

The second reason that the composition of the inputs is assumed to match that of the primary industry is practical. If the composition of inputs is assumed to be the same as the destination industry, when inputs are reallocated, the reallocation may result in negative inputs in the primary industry. For example, if college labor compensation is to be moved between the chemicals sector and the professional, scientific and technical services industry sector and the professional, scientific and technical services industry is much more intensive in college labor than the chemicals sector, then so much college labor could be taken out of the chemicals sector that negative labor compensation for college workers in this sector is left as a residual. This causes obvious problems in the chemicals sector. Furthermore, any attempt to address this would likely have to include an entire rebalancing of the input-output tables.

The same basic approach is used to allocate capital across the five types of capital. The GOS being reallocated (after adjusting for self-employed workers) is allocated to the five types of capital based on shares in the primary industry. Similarly, the taxes on production and imports that are reallocated to capital are assumed to have the same capital composition as capital in the primary industry. Importantly, all the redefinitions and reallocations result in no changes to nominal GDP.

2.3. Prices for after redefinition capital and labor services

Each component of nominal output, intermediate input, capital, and labor that is reallocated needs to be associated with a price index to construct KLEMS quantity indexes and measure TFP growth. Due to the way that BEA constructs its industry accounts, associating each component of output and intermediate input with a price index is straightforward. BEA constructs its industry accounts at an unpublished level of detail called the item level. When these items are moved in the redefinition of output and reallocation of intermediate input, the accompanying price index can easily be attached to each new component of output and intermediate input. For the account presented in this paper, these items are then aggregated up to a new after redefinition estimate of the price and quantity of industry output and intermediate input.

Constructing after redefinition capital and labor prices is significantly more complicated due to the underlying assumptions discussed above that allow for jointly produced secondary production.
Joint production implies that the composition of the capital and labor services being reallocated matches the composition of the primary industry and therefore necessitates tracking all the flows across industries, not just the final allocation of capital and labor. The intuition behind this method is that capital and labor prices reflect production conditions in the primary industry because returns to capital and labor are inextricably linked to the primary production process. For example, the price of R&D capital in the computer and electronics sector reflects the rate of return in that sector and this is the price that is relevant for measuring the input and output of R&D. Unpublished details on the flows of labor compensation and gross operating surplus allow for tracing gross flows of capital and labor inputs for each industry. To construct a price index for each primary input for each industry, each component of capital and labor is linked to a price index from its industry of origin and weighted by the value contributed by each industry of origin. For example, the miscellaneous professional, scientific, and technical services sector after redefinition industry has labor compensation added to it that originates from both the chemicals sector and the computer and electronic products sector. The price index for college-educated labor in the redefined miscellaneous professional, scientific, and technical services sector is

constructed as the weighted price change of the college labor prices in these two sectors where the weights capture the relative importance of these in comparison to the college educated labor that was measured in the Miscellaneous professional, scientific, and technical services sector before redefinitions. Of course, because labor compensation may move out of the miscellaneous professional, scientific, and technical services sector, the weights reflect these net flows.

3. The Sources of Economic Growth After Redefinitions

This section presents a bottom-up accounting of the sources of economic growth using the after redefinitions industry-level production account. The results are divided into two basic sections, the first provides the sources of growth at the industry level after redefinitions in comparison to before redefinitions, and a second section compares the aggregate sources of growth using the two concepts.

3.1. Industry sources of growth adjusting for secondary production

The results show that the broad industry trends are similar between the after and before redefinitions production account but there are some noteworthy differences. Tables 1-3 show the industry sources of growth after redefinition, before redefinition, and the differences between the two. As expected, based on the motivation for this paper presented above, the computer and electronic products sector has faster measured TFP growth after secondary production has been moved. Table 3 indicates that this is mostly driven by faster value added growth in the redefined sector (faster output growth and a smaller contribution of intermediate input). Underlying detail (not published) shows that the output difference mostly is driven by the movement of research and development and own account software output from the computer and electronic products sector. Because the research and development and own account software is associated with a price index that grows faster than the computer and electronic product equipment price, moving this output from the sector results in faster real output growth. Table 3 also demonstrates the importance of the complete production account in understanding the differences in measured TFP growth. While the redefinitions did not have a significant impact on the measured contributions of capital and labor in this sector, the redefinitions had a large impact on the measured contribution of intermediate input. After redefinitions, the contribution of intermediate was lower than the contribution before redefinition and this reflects the intermediate product mix used in producing research and development and own account software differs from the product mixing in producing computer and electronic equipment. It is important to note that neither of these measures is necessarily preferred over the other. If one is interested in understanding the narrower concept of productivity in the production of computer hardware, for example in comparison to other countries, then the after redefinition concept is likely more useful. If one is interested in the entire production process for computers and electronic components including all the R&D and own account software, then the before redefinition concept may be more appropriate. It is important to emphasize the even after redefinitions, the computer and electronics sector uses some R&D and own account software as a capital input, but no longer produces it as an output.

Interestingly, the miscellaneous professional, scientific, and technical services industry (the industry that produces R&D for sale) has significantly higher TFP growth after redefinitions; its measured productivity growth was slightly negative before redefinitions and slightly positive after redefinitions. Table 3 shows how this works out from an accounting perspective; this was mostly driven by differences in the labor contribution which was significantly lower after redefinitions. In practice what happens is that over the entire period about 20 percent more output is added to the sector each in each year. But the underlying data indicates that the industries that produce this output became more intensive in intermediate inputs over time relative to the labor and capital inputs that were also being reallocated to this sector. Once the linked prices are applied to this new composition of inputs, the resulting TFP growth is higher in the after redefinition industry. Regardless of the accounting explanation of the result, the basic premise is that the after redefinition estimate reflects something fundamentally different than the estimate before redefinition. The after redefinition estimate more closely captures the commodity concept of R&D while the before redefinition concept is aimed at measuring R&D production that is primarily for sale on the market. Of course, the differences in the TFP growth estimates reflect both these different concepts and the economic assumption that were used to translate between the two concepts.

Other industries where TFP growth was noticeably higher using the after redefinitions production account were the data processing, internet publishing, and other information services industry; rental and leasing services and lessors of intangible assets; and amusements, gambling, and recreation industries. Industries where TFP growth was noticeably lower using the after redefinitions production account include the pipeline transportation industry; performing arts, spectator sports, museums, and related activities; accommodation; and the food services and drinking places sector. Figure 1 shows that the TFP growth measured before and after redefinitions did not change the basic trends for most industries. Figure 2 shows how translating between the before redefinition production account and the after redefinition production account impacts TFP measures for each sector. The takeaway is that only for a few sectors did the long term trend in TFP get impacted by the translation. Yet, for certain industries, the difference may be large enough to affect our understanding of industry trends.

Finally, the results show that there is not a major difference in the productivity slowdown in computer and electronic products sector using after redefinition concept even though R&D and own account software became a large share of industry output over the period. After redefinitions, TFP grew by about 8.8 percent per year from 1997 to 2007 and by about 3.5 percent per year from 2009 to 2019. This deceleration of about 4.8 percent per year is very similar to the TFP deceleration in measured TFP growth before redefinitions of 5.0 percent per year over the same periods. Results for the other sectors are given in table 4.

3.2. Aggregate sources of growth adjusting for secondary production

This section compares the aggregate sources of growth using the after redefinition concept to the existing measures that are based on the before redefinition concept. Table 5 shows that within major sectors the most noticeable difference is the shift in the contribution and share of other services in growth, though even this is relatively small. The share of nominal GDP that is attributed to other services is somewhat higher after redefinitions. The bottom portion of the table also shows that both manufacturing and trade are smaller after redefinitions while construction is larger.

Table 6 shows that aggregate TFP growth is measured to be slightly higher over the 1997-2019 period using the after redefinition production account. Since aggregate nominal GDP, capital, and labor are unchanged between the two concepts, this result reflects the prices applied to the detailed components of capital and labor that are linked to their primary industries and the composition of intermediate inputs after redefinition.[7] The largest contributor to the aggregate TFP difference is the other services industry which likely reflects its higher nominal weight in the after redefinitions production account. Overall, the contributions of both capital and labor to aggregate value- added growth are slightly smaller in the after- redefinitions production account, but these differences are not large enough to change the basic story on the sources of economic growth.

4. Conclusions

There are some noteworthy differences in measured TFP growth across industries when the production account is adjusted to reallocate secondary production. Measured TFP growth of computers and electronic products and data processing, internet publishing, and other information services is significantly higher once secondary production is moved out of these industries. Because these industries are of particular focus in understanding the role of the information economy, it is worth considering these differences when analyzing the sources of economic growth. It is also noteworthy that in aggregate, the manufacturing share of GDP is somewhat smaller once non-manufacturing output produced by the manufacturing sector are moved out of manufacturing.

On the other hand, the approach to accounting for secondary production that is considered in this paper does not change major trends in estimated TFP growth over the 1997–2019 period. Therefore, it is unlikely that this adjustment would matter much for understanding the sources of economic growth or international economic competitiveness. Nevertheless, it cannot be ruled out that a longer time series of after redefinition TFP measures using the method considered in this paper may have a more noteworthy impact on measured TFP growth, or that the application of different assumptions that refine the translation of outputs and inputs between industries may yield different estimates and a different conclusion.

[7] The concept of aggregate productivity in this paper is based on the direct (Domar-weighted) aggregation of TFP growth across industries.

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Appendix A.

This section briefly considers using the Make table to construct a commodity-level production account using publicly available (from BEA) summary level data.[8] Summary-level data includes information at the two or three digit level and the common denominator between the input-output data and TFP data at this level of detail is the set of industries included in the BEA-BLS integrated industry level production account (63 total industries). The basic idea is that the Make table includes information on commodities produced by each industry. Therefore, one can use this information to back out commodity level TFP growth given observations on industry level TFP growth. This section lays out the basics and argues that while these estimates are potentially useful and easy to assemble, the underlying assumptions are stronger than those employed in this paper and may yield misleading results.

[8] This alternative was considered in John Fernald's discussion of this paper at the March 2022 Conference on Research in Income and Wealth.

The basic approach of using the Make table to define a commodity-level production account can be summarized as:

$$\begin{bmatrix} \Delta \ln TFP_{I1} \\ \Delta \ln TFP_{I2} \\ \vdots \\ \Delta \ln TFP_{IN} \end{bmatrix} = \begin{pmatrix} m_{11} & \cdots & m_{1N} \\ m_{21} & \cdots & m_{2N} \\ \vdots & & \\ m_{N1} & \cdots & m_{NN} \end{pmatrix} \begin{bmatrix} \Delta \ln TFP_{C1} \\ \Delta \ln TFP_{C2} \\ \vdots \\ \Delta \ln TFP_{CN} \end{bmatrix}$$

Where the first vector on the left hand side is an Nx1 matrix of measured industry-level TFP growth rates. The right hand side is made up of an NxN matrix of shares of commodities produced be each industry (industry on rows and shares of each commodity in its industry output in each column) multiplied by an Nx1 vector of commodity-level TFP growth rates. This says that observed industry TFP growth is a linear combination of TFP growth rates of the various commodity it produces. Premultiplying both sides by the inverse of the Make share matrix yields an estimate of commodity-level growth TFP rates. To consider how this would work in practice, consider the following stylized example with a Computer hardware sector (Comp) and a Miscellaneous professional, scientific, and technical services sector (Misc). In the BEA-BLS industry production account, the Misc sector holds the establishments primarily engaged in R&D and other establishments that are in the same NAICS group. Suppose that the Make table and industry level TFP growth rates observed were:

$$\begin{bmatrix} 5.8\%_{I\_Comp} \\ 0\%_{I\_Misc} \end{bmatrix} = \begin{pmatrix} 0.85 & 0.15 \\ 0 & 1 \end{pmatrix} \begin{bmatrix} \Delta \ln TFP_{C\_Comp} \\ \Delta \ln TFP_{C\_Misc} \end{bmatrix}$$

Applying the matrix inverse to both sides imposes yield the following estimates for commodity-level TFP growth.

$$\begin{bmatrix} \Delta \ln TFP_{C\_Comp} \\ \Delta \ln TFP_{C\_Misc} \end{bmatrix} = \begin{bmatrix} 6.9\% \\ 0\% \end{bmatrix}$$

This is not unreasonable, but it is worth comparing this to the approach taken in this paper and how it misses underlying data. First, the Make table approach based on the level of detail in this example would impose that the measured TFP growth in the Misc sector corresponds exactly to the TFP growth of the Misc commodity because the Misc sector produces no Computer hardware output. Remember that the Misc sector in the actual data includes industries and commodities other than R&D, including Accounting, Architecture, Management consulting, Advertising, Photography, and Veterinary services. The summary-level Make table approach imposes that measured TFP growth in the Misc commodity produced by the Computer sector (which is R&D) has the same TFP growth rate as all of the industries included in the Misc. sector. That is, this method imposes that TFP growth of the R&D produced by the Comp sector is zero. Furthermore, if one wanted to apply this same approach to decomposing the sources of growth by replacing measured TFP growth with the sources of industry level growth and the sources of commodity level growth we get the equation:

$$\begin{bmatrix} \Delta \ln Y_{I\_Comp} - w_{IK}\Delta \ln K_{I\_Comp} - w_{IL}\Delta \ln K_{I\_Comp} - w_{IX}\Delta \ln X_{I\_Comp} \\ \Delta \ln Y_{I\_Misc} - w_{IK}\Delta \ln K_{I\_Misc} - w_{IL}\Delta \ln K_{I\_Misc} - w_{IX}\Delta \ln X_{I\_Misc} \end{bmatrix} =$$

$$\begin{pmatrix} 0.85 & 0.15 \\ 0 & 1 \end{pmatrix} \begin{bmatrix} \Delta \ln Y_{C\_Comp} - w_{CK}\Delta \ln K_{C\_Comp} - w_{CL}\Delta \ln K_{C\_Comp} - w_{CX}\Delta \ln X_{C\_Comp} \\ \Delta \ln Y_{C\_Misc} - w_{CK}\Delta \ln K_{C\_Misc} - w_{CL}\Delta \ln K_{C\_Misc} - w_{CX}\Delta \ln X_{C\_Misc} \end{bmatrix}$$

If we associate each term in the industry growth equation with the corresponding term in the commodity equation, for example equating the output terms:

$$\begin{bmatrix} \Delta \ln Y_{I\_Comp} \\ \Delta \ln Y_{I\_Misc} \end{bmatrix} = \begin{pmatrix} 0.85 & 0.15 \\ 0 & 1 \end{pmatrix} \begin{bmatrix} \Delta \ln Y_{C\_Comp} \\ \Delta \ln Y_{C\_Misc} \end{bmatrix}$$

we see that we get the result that this method would tell us that output growth in the Misc commodity including Computer R&D would be equated to output growth in the Misc industry.

For example, if we observed output growing by 4.6% in the Computer sector and 2.95% in the Misc sector, this Make table method would tell us that Misc commodity output produced by the computer sector also grew by 2.95% per year, and applying this to the factors of production would result in equalized (to the Misc Sector) contributions of capital, labor, and intermediate inputs. While the Make table approach is somewhat intuitive for producing commodity-level TFP estimates, applying this to the sources of growth is less so. The 2.95% real growth of the Misc industry may be of little relevance in measuring the real output growth rate of R&D in the Computer sector. The equivalent decomposition could be done for prices with a similar result; the price growth in the Misc sector may be of little relevance for the price index for the R&D output priced by the Computer hardware sector. The approach taken in this paper is to use the detailed underlying BEA data to move the relevant R&D output and corresponding prices that are included in the measures of output at the industry level out of that sector and into the Misc sector. This gives a relatively clean match between the output that is being moved and its price index. Therefore, the new output in the Misc sector reflects the new nominal R&D output that gets moved from the Computer sector and the price of this new output reflects the price of R&D that is actually produced by the Computer sector.

A second caveat in using the Make table approach at the summary level is that it assumes that all secondary commodities should be reallocated at summary level; that is, it imposes that the after redefinition Make table is diagonal. In practice, what this means is that in aligning commodities, the summary level Make table approach assumes that all secondary output is relevant for commodity level TFP estimates. While in many cases this may be reasonable, this does not coincide with the approach taken in the official after redefinition input-output accounts. For example, in the 2012 before redefinition Make table, about 12% of the output of the Broadcasting and telecommunications sector is Miscellaneous professional, scientific, and technical services. In the after redefinition table that has moved the commodities to their secondary industries, the Make table indicates that even after redefinitions, 12% of the gross output of the Broadcasting and telecommunications still is Miscellaneous professional, scientific, and technical services. What this means is that using the summary level Make table approach to determine TFP at the commodity level essentially removes this commodity in determining the after redefinition TFP growth rate of the Broadcasting and telecommunications sector even though the official after redefinition Make table indicates that this output should remain in the sector. Because the official After redefinition Make tables move output and intermediates to group items with similar production structures, this implies that the production process for the remaining 12% of gross output more closely aligns with the Broadcasting and telecommunications sector than the Miscellaneous professional, scientific, and technical services sector. Thus, the application of the summary level Make table approach would result in outputs and intermediates being reallocated to sectors that BEA has already ruled out as a target for realignment.