An Integrated Input-Output Based Method of Total Factor Productivity Measurement

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The indicated importance of productivity increase may be taken to be some sort of measure of our ignorance.

Moses Abramovitz (1956)

Abstract *In the United States, the Bureau of Labor Statistics (BLS) compiles total factor productivity (TFP) measures of output per unit of combined inputs for the private business, private non-farm business, and manufacturing sectors, and for 61 NAICS industries comprising the U.S. economy. The Bureau of Economic Analysis (BEA) has been producing components of a KLEMS database at a level of about 65 industries for several years. In the Inforum LIFT Model, we have adopted the BEA classification for the industry sectoring, and have built a block of the model in which TFP can be calculated both historically and in the forecast. The data on which the LIFT TFP modules is based are internally consistent, and relate to the IO database used to build the model. The model can also yield an economy-wide aggregate TFP estimate.*

Estimates based on the neoclassical approach to TFP measurement were presented in an earlier paper. In the current paper, we adopt a method that has been explored by Statistics Canada, that involves calculating the TFP related to the provision of each commodity of final demand. This method uses IO calculations to resolve productivity into the direct and indirect use of primary factors to produce each unit of final demand. We plan to apply this technique to the U.S. model database described above, to obtain alternative measures of TFP growth by commodity for the U.S. for the period 1997 to 2020. The current paper describes the state of our project thus far.

Background

This paper will describe some new developments in the Inforum LIFT model of the U.S. The model is grounded in a new set of detailed annual input-output tables, derived by Inforum from U.S. data published by the Bureau of Economic Analysis (BEA). This set of tables brings us closer to the goal of developing an integrated model of total factor productivity, which is consistent at the industry and aggregate level.

Since economists first started to develop economic statistics and national accounts, a motivating principal has been to measure the growth of the economy, and discover its sources. Classical economists such as Smith, Ricardo and Mill had observed that more output could be produced with a given quantity of labor by employing machinery and other capital. But it wasn't until the 1920s that comparable measures of labor and output became available, and the first estimates of labor productivity growth appeared. By the 1950s, the concept of the production function became formalized, and the idea of segregating growth in output per head into technical change and the availability of capital per head caught on, especially after Solow's (1957) introduction of the aggregate production function. Solow's work stimulated numerous studies relating real value

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added growth to real capital and labor inputs, and deriving the residual as a measure of technical change and other factors.

Research in topics of economic growth, distribution of income, sectoral price and wage analysis and capital theory have stimulated the desire for a comprehensive measure of productivity that would relate real gross output to capital, labor and intermediate inputs. A convenient classification of intermediate inputs into the categories of energy, materials and services led to KLEMS (capital, labor, energy, materials and services) databases and productivity studies. In either case, KL or KLEMS, the resulting measure of productivity is called total factor productivity[1] (TFP) defined as

$$TFP = \frac{Q}{I} \qquad \textbf{(1)}$$

where Q is real gross output, and I is a suitably defined aggregate of real inputs.

Since June 2004, BEA has been developing and improving a time series of annual input-output (IO) tables, with 71 industries. A satellite account is the BEA KLEMS dataset, which apportions intermediate inputs to energy, materials or services. An new partnership between BEA and the U.S. Bureau of Labor Statistics (BLS) was initiated in 2014, which resulted in a published dataset of an industry level production account, providing data useful for the estimation of TFP. This dataset has recently been updated through 2020[2].

A new version of the Inforum LIFT model has been developed this year, which is based on the 2012 benchmark IO table and the time series of annual IO tables. All industry data in the new LIFT model is on the same sectoral basis. These data include output, employment, investment, capital stocks and value added components. As described below, a set of production accounts have also been incorporated into LIFT, with the goal of dynamically forecasting industry and aggregate TFP. The list of industry sectors and their definitions in terms of the 2012 North American Industry Classification System (NAICS) are shown in Appendix A.

The first part of this paper will discuss the background of MFP development in the U.S. and its current status. The second part will describe the incorporation of an TFP module within the LIFT model, and present some historical and forecasted results. The third section will extend the analysis, exploring methods for determining the TFP of production of final demand by commodity, and suggesting applications of this approach. The conclusion will chart some directions for extending and improving this work.

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[1] We follow BEA and BLS in changing the terminology from multifactor productivity (MFP) to total factor productivity (TFP).

[2] Fraumeini et al. (2006) is a good conceptual presentation of the goals and methodology of integrated production accounts, and this presentation is further developed in Harper et al. (2009). The first release of the BEA/BLS accounts estimates was in Fleck, et al. (2014), and these estimates have been subsequently updated in Garner et al. (2018, 2022).

1 TFP: A Curriculum Vitae

A Productivity Index

The measure of output per unit of input is more easily considered if we ignore intermediate inputs for a moment, and write

$$pQ = wL + rK \tag{2}$$

where *p* is the price of output, *w* is the wage of labor, and *r* is the cost of capital. If we deflate to a base year, say *t*=0, we need to use a scaling factor *S* to bring both sides into equality:

$$p_0 Q_t = S_t[w_0 L_t + r_0 K_t] \tag{3}$$

The variable *S* can be viewed as an index of output over input. This method of measuring productivity was mentioned by Copeland (1937), and later implemented by Stigler (1947). Note that this index is basically a type of Laspeyres index since it uses base period quantity weights. Its growth rate over time is sensitive to the choice of the base period.

Production Functions, Sources of Growth and the "Residual"

Solow began the study of productivity using a production function with a shift parameter:

$$Q_t = A_t F(K_t, L_t)] \tag{4}$$

The shift parameter *A* was identified by Solow with technical change, although it includes many other factors. It is related to the scaling factor *S* described above, but is a more general indicator of output per unit of input, or TFP. Without imposing a specific form on the production function *F*, but making a few assumptions, we can derive an expression for the growth of *A* over time.

First, logarithmically differentiate the production function (4):

$$\frac{\dot{Q}_t}{Q_t} = \frac{\partial Q}{\partial K}\frac{K_t}{Q_t}\frac{\dot{K}_t}{K_t} + \frac{\partial Q}{\partial L}\frac{L_t}{Q_t}\frac{\dot{L}_t}{L_t} + \frac{\dot{A}_t}{A_t} \tag{5}$$

If each input is paid the value of its marginal product:

$$\frac{\partial Q}{\partial K} = \frac{r_t}{p_t} \quad and \quad \frac{\partial Q}{\partial L} = \frac{w_t}{p_t} \tag{6}$$

then we can write the unobserved output elasticities as income shares *s*:

$$\Re_t = \frac{\dot{A}_t}{A_t} = \frac{\dot{Q}_t}{Q_t} - s_t^K\frac{\dot{K}_t}{K_t} - s_t^L\frac{\dot{L}_t}{L_t} \tag{7}$$

The total differential $\Re$ is the Solow residual, or the growth in output not explained by the growth in inputs. Like *S*, it is an index number for TFP that can be calculated from prices and quantities.

Equation (7) can be rearranged to show the relationship of the growth of labor productivity to the growth of TFP and the change in the capital-labor ratio. If we write *Q*/*L* as *q,* and *K*/*L* as *k*, then

$$\frac{\dot{q}_t}{q_t} = \frac{\dot{A}_t}{A_t} + s_t^K \frac{\dot{k}_t}{k_t} \qquad \textbf{(8)}$$

The growth of labor productivity is the growth in TFP plus capital's share times the growth in the capital-labor ratio.

TFP in the Input-Output Framework

In most of the analyses based on the above approach, the measure of real output *Q* used is real value added, usually obtained by double deflation. This may be done with fixed weights, where deflated intermediates are subtracted from deflated output, or using a chain index approach as is done by the BEA in the U.S. However various researchers have found a production model for real value added to be implausible[3]. Real value added is not a measure of output, but is rather a hybrid of output less some inputs.

If data are available, a measure of real gross output can be related to labor, capital and aggregates of intermediate inputs. An ideal dataset is a time series of IO tables in current and constant prices, along with estimates of labor and capital input and cost shares[4]. If intermediate goods are classified as energy, materials or services, the production function can be specified as:

$$Q_t = A_t F(K_t, L_t, E_t, M_t, S_t)] \qquad \textbf{(9)}$$

where now *Q* is real gross output (not real value added) and the corresponding TFP estimate is derived similarly to (7)

$$\Re_t = \frac{\dot{A}_t}{A_t} = \frac{\dot{Q}_t}{Q_t} - s_t^K \frac{\dot{K}_t}{K_t} - s_t^L \frac{\dot{L}_t}{L_t} - s_t^E \frac{\dot{E}_t}{E_t} - s_t^M \frac{\dot{M}_t}{M_t} - s_t^S \frac{\dot{S}_t}{S_t} \qquad \textbf{(10)}$$

The intermediate value share weights are derived from the nominal IO tables. The cost share for labor is the labor compensation over total nominal gross output. The capital share is derived as the remainder.

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[3] Jorgenson, Gollop and Fraumeini (1987) perform tests on the existence of a value added function and reject the hypothesis in 40 of 45 industries analysed. The existence of a K-L aggregate, necessary for a measure of K-L productivity has also been explored by several investigators and rejected. Meade (2007) discusses the history and problems with the real value added concept, and shows several examples of how the derivation of real value added can lead to questionable results.

[4] Gullickson and Harper (1999, unpublished, available on request) discuss the characteristics of the ideal IO dataset and the method of aggregating to the all economy MFP using the Domar (1961) aggregation technique.

When using discrete, annual data, it is common to estimate (10) using a Tornqvist index, in which the rate of change in each variable is approximated by the differences in logarithms, and the shares are the average of the current period share and the lagged share.

Domar (1961) showed that industry and aggregate productivity growth can be related using a set of ratios that sum to more than 1. Each industry share is derived as the industry nominal gross output divided by the sum of value added (GDP) in all industries. This means that intermediate transactions contribute to aggregate productivity by allowing productivity gains in successive industries to augment one another.

The Measurement of Capital

Measurement problems abound for all components of the TFP calculation. For example, in many industries, the proper calculation of output price, and therefore real output, may be based on indirect information or on theoretically derived measures of quality. However, the question of the measurement of capital has filled the equivalent of hundreds of books, and so deserves a word.

Ideally, it is not the "quantity" of capital, as measured by real capital stock, that should be important, but rather the *flow of services* provided by capital goods[5]. Since this flow of capital services is not directly observable, in practice we must make use of estimated stocks and assume that the flow is related to that stock. If we have no detail on the composition of the stock by asset type, then the stock/flow distinction is not relevant. However, if stock information is maintained by industry and asset type, then we can make use of the different service lives of different assets to derive weights to estimate the total capital service flow by industry. The essential idea is that since some assets depreciate quickly (computers) and others depreciate slowly (buildings), the contribution to service flow should reflect this. The service flow idea is related to the concept of how much capital is "used up" each period in producing output. This idea is also related to the user cost of capital, which is defined as the total cost (interest, depreciation and revaluation adjusted by tax incidence) of using a unit of capital for a definite period, such as a year.

A Short Review of Published Data for the U.S.

The Bureau of Labor Statistics (BLS) total factor productivity program has taken the lead in measuring both labor productivity and TFP at the industry and aggregate level. BLS produces two periodic releases: The Major Sector Productivity program publishes annual measures of output per unit of combined inputs for the private business, private nonfarm business sectors. The aggregate business measures are real value added per combined unit of labor and capital input. The industry measures are derived using the KLEMS method. These are published by BLS annually in "Total Factor Productivity". The datasets include TFP indices for 61 industries comprising the economy, as well as the inputs of capital, labor, energy, materials and services, both in index and in value[6].

The Industry Productivity program publishes annual measures of output per unit of combined inputs for 86 4-digit NAICS manufacturing industries, the air transportation industry, and the line-haul

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[5] BLS (1983, Appendix C) and Harper (1999) discuss the capital measurement within the BLS MFP program. Jorgenson, Gollop and Fraumeini (1987) describe an ambitious attempt to measure capital service flows by industry.

[6] The latest release can be found at http://www.bls.gov/news.release/pdf/prod5.pdf, published November, 2021, with estimates through 2020.

railroad industry. These estimates do not cover all industries in the U.S. economy. They are derived using the KLEMS method[7].

As mentioned above, the BEA has been producing a set of "KLEMS" accounts since June 2005[8]. These data are derived from the detailed database underlying the annual IO tables and GDP by industry. The intermediate data is divided into energy, materials and services, and show total nominal cost, chained quantity indexes and chained price indexes for each major component. Detailed intermediate data underlying the estimates is also available. All data are currently published from 1997 to 2020. BEA does not publish quantities and costs of labor and capital with this dataset, but the ingredients necessary for constructing these components are available in the BEA/BLS Integrated Production Accounts, described below. The GDP by industry database does show total labor compensation and gross operating surplus, which are needed to estimate the labor and capital cost shares by industry.

The BEA Fixed Assets database contains a wealth of information relating to investment and capital stocks[9]. The Fixed Assets tables present detailed estimates of net stocks, depreciation, and investment by type and by industry (for nonresidential fixed assets only) for private residential and nonresidential fixed assets, and consumer durable goods. Also included are detailed price indexes for nonresidential fixed assets and implied rates of depreciation for selected aggregates by industry. These data are used within BEA to derive depreciation estimates by industry, but are also used by BLS in the TFP program described above.

2. Incorporation of TFP into the LIFT Model

Overview of LIFT

The *LIFT* model (Long-term Interindustry Forecasting Tool) is the U.S. representative of the INFORUM style interindustry macroeconomic (IM) model.[10] As is typical of this family of models, the *LIFT* model builds up macroeconomic aggregates such as employment, investment, exports, imports and personal consumption from detailed forecasts at the industry or commodity level. This modeling framework is not only applicable to scenario analysis where the interaction of macroeconomic and industry behavior is important, but also for the development of satellite models to study issues such as energy use, greenhouse gas emissions or research and development expenditures[11]. In the current study, we make use of the consistent database of IO tables in current and constant prices, detailed investment and capital stock matrices, and the full set of value added history and forecast in the *LIFT* model to compile historical and projected measures of TFP by industry and for the aggregate economy.

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[7] The latest release can be found at http://www.bls.gov/news.release/pdf/prin3.pdf, published August 2021, with estimates through 2019.

[8] Cost, quantity indexes and price indexes for E,M and S and components of gross output are available at http://www.bea.gov/industry/gdpbyind_data.htm, in the link labeled "KLEMS". These data were updated on June 29, 2022.

[9] The Fixed Assets data are available at http://www.bea.gov/iTable/index_FA.cfm. The latest data are described in Bennett et.al. (2011).

[10] Grassini (2001) portrays the typical features of an INFORUM model. Meade (1999) introduces an earlier version of the current model.

[11] Meade (2009) is an example of using an expanded module for crops and biofuels to study economic impacts of increased ethanol production and use in the U.S.

The newest version of *LIFT* is based on the U.S. 2012 Benchmark IO table, and a series of annual IO tables from 1997 to 2020. INFORUM has compiled a time series of estimates of the detailed IO framework at the 350 commodity level, using information from the 2012 Benchmark, the annual IO, and time series of industry output from BEA and commodity imports and exports from the Census Bureau. A new version of the *Iliad* 350 commodity model of the U.S. has been developed based on these same data.

All industry data in *LIFT* is now classified according to the same sectoring scheme, listed in Appendix A, along with the 2012 NAICS concordance. These industry data include employment, hours, labor compensation and other value added components, investment and capital stock, and industry output. The LIFT model has 121 commodities, and this is the level of detail maintained for the IO table, final demands and commodity output. The IO quantity and price solutions are calculated at the commodity level. Value added at the industry level is bridged to the commodity level using an industry to commodity value added bridge, and the commodity output solution is converted to industry output using a commodity output proportions matrix.

The typical forecast horizon of LIFT is to 2045, although many studies are done with a shorter forecast period. Long-term forecasting for the Medicare Trust Fund Panel is done to 2095, with a slightly modified version of the model. All ingredients necessary to calculate TFP are available through the forecast horizon.

Building KLEMS Accounting into LIFT

There are three main tasks involved into building a KLEMS module into *LIFT*. These are:

1. Estimating current and constant price intermediate consumption by industry, divided into energy, materials and purchased services aggregates.
2. Estimating capital stocks by industry for equipment and structures.
3. Incorporating *LIFT* data on hours worked, labor compensation and constant and current price output by industry.

Before describing step 1, we should first say a few words about the derivation of the IO database used for the *LIFT* model. This database uses detail from the 2012 Benchmark U.S. IO table and the series of U.S. annual IO tables, combined with detailed data on imports, exports and industry output to create a time series of detailed make and use matrices from 1997 to 2020[12]. These are then converted annually to a product-to-product table, based on commodity technology, as described in Almon (2000). The entire framework is converted to constant prices by deflating output by domestic output deflators, deflating imports by imports deflators, and deflating the rest of each row implicitly in a way that preserves the row sum in constant prices.

In the first step we first convert the recipe matrix derived above in flows to a 121 by 71 use table, using the formula:

$$\boldsymbol{U} = \boldsymbol{R}\boldsymbol{M}' \qquad \textbf{(11)}$$

[12] There are two versions of the benchmark and annual IO tables produced by BEA. The first version, known as 'Standard' on the BEA website, is *before redefinitions*, where industry output can be easily related to industry data on shipments and inventory change produced by the Economic Census. The second version, known as 'Supplemental', is *after redefinitions*, where certain components of commodity output have been moved from one industry to another to achieve a table closer to a pure product basis. We start with the after redefinitions tables in our work.

where ***U*** is the "new use" matrix described by Almon, and ***M*** is the 71 by 121 matrix formed by dividing each cell of the make table by the column total. Once we have obtained this matrix, it is almost straightforward to combine inputs by industry into the energy, materials and services aggregates[13]. Several exceptions to the general classification were made when an energy product was used in the form a material feedstock input, such as natural gas into chemicals or plastic, or where primary fuels were consumed in producing a final energy output, such as the fuels used in electric utilities. Crude petroleum converted to petroleum products is classified as a material input. The ***U*** matrix is also deflated to constant dollars and the same aggregates are calculated in constant prices.

Capital stocks for equipment and software investment by industry are derived from the time series of investment by industry in the LIFT model. There is still no detailed accounting of structures investment and capital stock by industry. We have derived the structures investment and capital stock keeping an eye on estimates of net stock from the BEA *Fixed Assets* database.

The derivation of the labor component is straightforward, and LIFT maintains historical and forecast data on labor hours worked and total labor compensation. Industry output is also calculated by the model, using the ***M*** matrix described above.

The Tornqvist index formula is used to estimate the growth in the TFP index based on equation (10). The cost shares are estimated as follows:

$$s_{it}^{E} = \frac{EN_{it}}{QN_{it}}, s_{it}^{M} = \frac{MN_{it}}{QN_{it}}, s_{it}^{S} = \frac{SN_{it}}{QN_{it}}, s_{it}^{L} = \frac{LAB_{it}}{QN_{it}}, \qquad \textbf{(12)}$$
$$s_{it}^{K} = 1 - s_{it}^{E} - s_{it}^{M} - s_{it}^{S} - s_{it}^{L}$$

where variables with an 'N' indicate nominal values.

Since the index relies on the growth between two periods, the average share is used:

$$\bar{s}_{it}^{j} = (s_{it}^{j} + s_{i,t-1}^{j})/2 \qquad \textbf{(13)}$$

The growth rate (gr) below is calculated as the difference in logarithms:

$$gr(A) = gr(Q) - \bar{s}_{it}^{K} gr(K) - \bar{s}_{it}^{L} gr(L) - \bar{s}_{it}^{E} gr(E) - \bar{s}_{it}^{M} gr(M) - \bar{s}_{it}^{S} gr(S) \qquad \textbf{(14)}$$

The index *A* of TFP can then be derived, and is normalized to equal 100 in 2012.

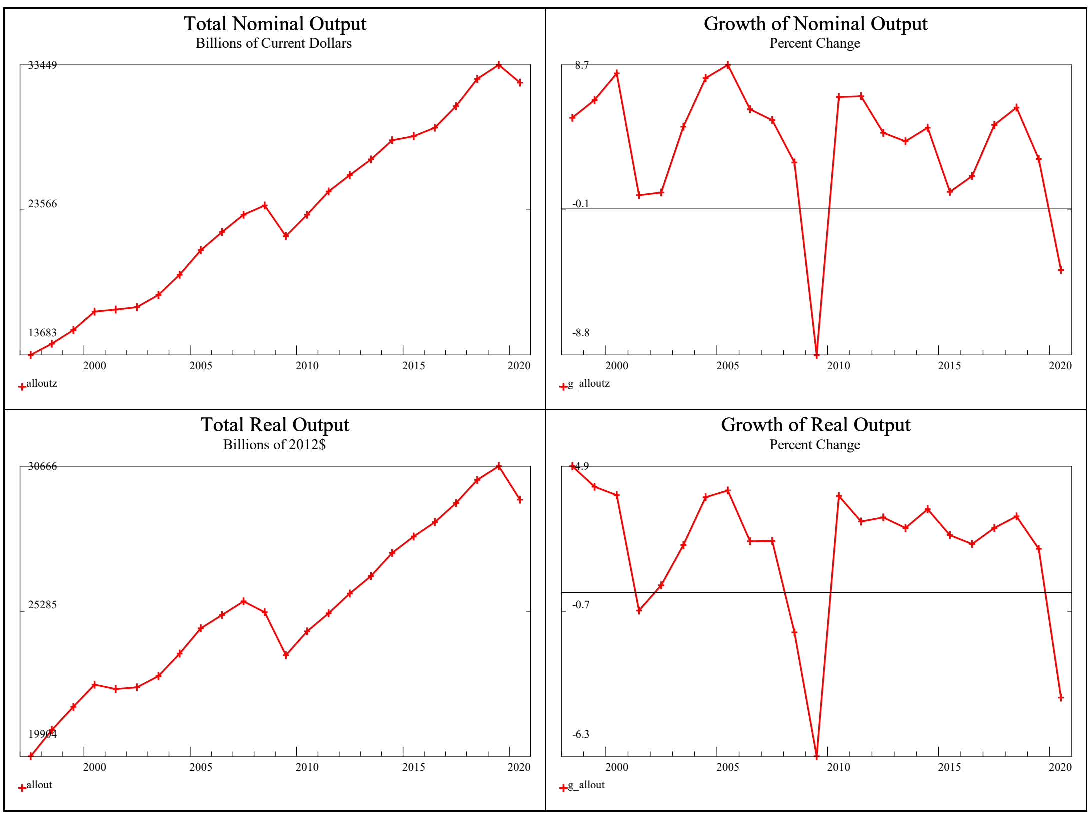
[13] 'Energy' commodities in *LIFT* are the following: Crude oil extraction (4), Natural gas extraction (5), Coal mining (6), Electric utilities (10), and Natural gas utilities (11). 'Materials' commodities are 1-3, 7-8, and 15-57. Services are 9,12-14 and 58-121. See Appendix A for the commodity definitions.

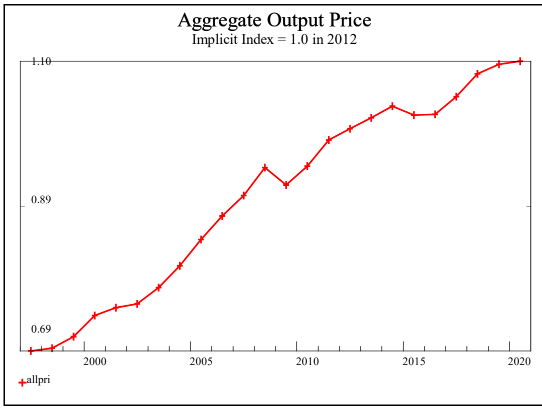
Notable Trends and Stylized Facts

The data presented here represent a system of production accounts which have been embodied into a dynamic IO model. Although the database underlying the LIFT model is unique, it is based on publicly available data. It would be useful to find out how our results compare with others, such as BEA/BLS. In this section we elucidate some general industry trends, and see how the TFP calculations from our database compare with the BEA/BLS production accounts.

Figure 1 summarizes aggregate output and price movements, from 1997 to 2020. This period of includes an interval of strong economic growth in the late 1990s, a brief slowdown in 2001, and then moderate to strong growth from 2002 to 2007. The years 2008-2009 are the Great Recession, with total real output declining in both years, along with declines in commodity prices in 2009. Growth resumes from 2010 to 2019, but with slowing of output price growth from 2015 to 2017. The Covid pandemic appeared in 2020, resulting in sharp declines in both nominal and real output, and a decline in price growth.

Figure 1. Output and Price Movements: 1997 - 2020





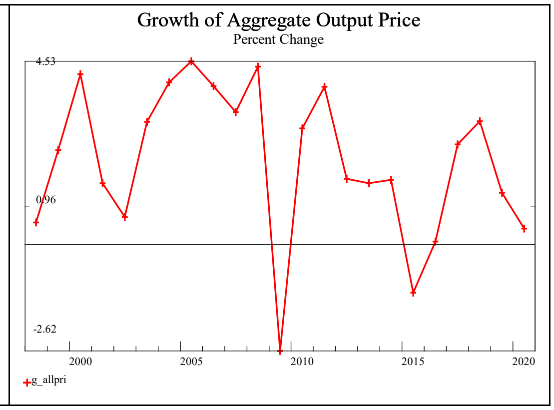


Table 1 summarizes the composition of gross output derived from the BEA value added data and the Inforum current price IO tables, over the 1997-2020 period. Input cost shares are expressed in percentages, for three major aggregations of industries. The first section of the table shows the composition for all private industries, the middle section shows the composition for the goods-producing industries, and the third section is for the service industries[14]. Within each industrial grouping, inputs are divided into value added and intermediate inputs.

Although the intermediate and value added cost shares in the private economy have historically been stable, over the 1997 to 2020 period we do see some remarkable changes. The share of value added starts at 54.8 percent in 1997, increases after the Great Recession to 56 percent in 2010, and continues to rise to 56.8 percent by 2020. The rise in value added is concentrated in Gross operating surplus (GOS), for which the share rises from 22.2 percent in 1997 to 24.8 percent by 2020. This rise in value added share and the concentration in GOS is even more striking in Goods-producing industries, shown in the middle of the table, where the share of GOS increases from 17 percent in 1997 to 22.7 percent by 2020. The rise in value added share is of course mirrored by declines in the intermediate share. Within intermediate, the materials share declines by 7 percent, from 17.6 percent to 10.8 percent. This is partially made up by about a 5 percent increase in the services share. Within Goods-producing industries, there is also a 7 percent decline in the share of materials, but a smaller rise in the services share, from 15.7 percent to 17.2 percent. Service-producing industries, which have a much smaller share of materials inputs, also see their materials share decline, and their services input share increase by 4 percent. The nominal share of energy inputs in total output is 1.9 percent in 1997, but reaches as high as 2.8 percent in 2005, partially due to relatively higher energy prices. The energy share falls back to 1.5 percent by 2020.

[14] All private industries include 1-66 from table A-1. Goods producing industries are 1-4 and 7-26. Services are 5-6 and 27-66.

Table 1. Components of Gross Output by Major Sector

	1997	2000	2005	2007	2010	2015	2019	2020
All Private Industries	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Value added	54.8	54.1	54.9	54.5	56.0	55.8	56.3	56.8
Compensation of employees	28.2	29.2	27.6	27.6	27.0	27.7	28.2	29.5
Taxes on production and imports	4.4	4.1	4.4	4.3	4.4	4.4	4.5	2.6
Gross operating surplus	22.2	20.9	22.9	22.6	24.5	23.8	23.7	24.8
Intermediate inputs	45.2	45.9	45.1	45.5	44.0	44.2	43.7	43.2
Energy	1.9	2.5	2.8	2.7	2.7	1.9	1.9	1.5
Materials	17.6	15.7	14.5	14.8	14.0	12.7	11.2	10.8
Services	25.8	27.7	27.8	27.9	27.3	29.5	30.6	30.9
Private Goods-Producing Industries	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Value added	41.3	42.7	43.6	42.8	42.1	43.5	46.1	46.7
Compensation of employees	23.1	24.8	22.0	21.1	19.7	21.3	23.0	24.4
Taxes on production and imports	1.2	1.0	1.3	1.5	1.7	1.8	1.7	-0.4
Gross operating surplus	17.0	16.9	20.3	20.2	20.7	20.4	21.4	22.7
Intermediate inputs	58.7	57.3	56.4	57.2	57.9	56.5	53.9	53.3
Energy	2.0	2.6	2.9	2.8	3.0	2.0	2.0	1.7
Materials	41.0	39.1	38.5	39.3	39.7	37.8	35.4	34.4
Services	15.7	15.7	15.0	15.0	15.2	16.6	16.6	17.2
Private Service-Producing Industries	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Value added	61.8	59.4	59.6	59.6	61.4	60.1	59.6	59.9
Compensation of employees	30.8	31.2	29.9	30.4	29.8	29.9	29.9	31.0
Taxes on production and imports	6.0	5.5	5.7	5.6	5.5	5.3	5.3	3.5
Gross operating surplus	25.0	22.7	24.0	23.6	26.0	25.0	24.4	25.4
Intermediate inputs	38.2	40.6	40.4	40.4	38.6	39.9	40.4	40.1
Energy	1.8	2.4	2.8	2.7	2.6	1.9	1.8	1.5
Materials	5.4	5.1	4.4	4.3	4.1	3.9	3.6	3.6
Services	31.0	33.1	33.2	33.4	32.0	34.0	35.0	35.0

Source: Inforum LIFT model database, derived from BEA Benchmark and Annual IO accounts

Table 2 shows the underlying data for 9 selected industries in 2019, and brings out the variation we observe between industries at this level. Farms (1) and Food, beverages and tobacco (8) and Motor vehicles (23) have the lowest shares of total value added, with high consumption of intermediate materials. Farms (1), Oil and gas extraction (3), Chemicals (15) and Computers (21) all have a fairly high share of gross operating surplus, and a small share of Labor compensation, since they are capital intensive industries. Motor vehicle parts dealers (28) and Ambulatory health care (58) on the other hand, have a much higher share of labor compensation (42.0 and 51.3 percent). Taxes on production and imports (TOPI) are high in Oil and gas (energy taxes), Motor vehicle and parts dealers (sales taxes) and Food services (sales and alcohol taxes). In 2019, the overall value added share of output ranges from only 23.1 percent in Motor vehicles to 74.1 percent in Computers. The variation in materials use is also notable, from a low of 1.9 percent in Motor vehicles and parts dealers to 60.4 percent in Chemicals.

Table 2. Components of Gross Output: Selected Industries, 2019

	1 Farms	3 Oil and gas extraction	8 Food and beverage and tobacco products	15 Chemical products	21 Computer and electronic products	23 Motor vehicles, bodies and trailers, and parts	28 Motor vehicle and parts dealers	58 Ambulatory health care services	65 Food services and drinking places
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Value added	34.2	57.3	28.6	49.1	74.1	23.1	73.7	65.9	49.4
Compensation of employees	8.0	9.7	12.4	13.9	38.8	11.7	42.0	51.3	33.5
Taxes on production and imports	-3.0	11.4	3.0	2.4	2.2	0.6	17.3	0.9	6.3
Gross operating surplus	29.2	36.2	13.2	32.9	33.1	10.8	14.5	13.7	9.6
Intermediate inputs	65.8	42.7	71.4	50.9	25.9	76.9	26.3	34.1	50.6
Energy	2.5	2.3	1.4	4.8	0.3	0.5	1.4	0.4	3.2
Materials	37.6	15.0	51.9	31.1	13.6	60.4	1.9	6.3	9.4
Services	25.7	25.4	18.1	15.1	12.0	16.0	23.0	27.4	38.1

Source: Inforum LIFT model database, derived from BEA Benchmark and Annual IO accounts

The cost shares surveyed in tables 1 and 2 are used in developing the weights ($\bar{s}_{it}^{j}$ in equation 14) for the growth of each input in the construction of TFP by industry. The other important components in the TFP calculation are the growth rates of outputs and KLEMS inputs by industry.

Table 3 summarizes the aggregate sectors output and inputs growth rates over selected periods. Overall, growth in real private output over the period for all industries was 1.7 percent, but output of Goods-producing industries only increased at an average rate of 0.2 percent, while Services-producing industries output increased at 2.4 percent. The sub periods were chosen to highlight the effects of the "dot-com" recession in 2001, and the global slowdown that started in late 2007 or early 2008. Total output growth in the first period, from 1997 to 2001 was 2.9 percent, but Goods-producing industries output grew at only 0.5 percent slightly during this period, whereas Services-producing industries grew quite rapidly (4.3 percent). The second period includes the 2001-2002 slowdown, but also the period of rapid growth from 2004 to 2007. Average growth of all output (2.3 percent) is somewhat slower than the first period, with the slowdown occurring mostly in services (2.9 percent). Goods-producing industries output increases over this period (1.0 percent). In the period 2007 to 2010, overall growth is negative (-1.5 percent), but the decline is concentrated in Goods-producing industries (-4.4 percent), with Services-producing industries declining by only 0.2 percent.

Table 3. Aggregate Real Output and KLEMS Real Inputs
Average Annual Growth Rates

	1997-2001	2001-2007	2007-2010	2010-2019	2019-2020	1997-2020
All Private Industries						
Output	2.9	2.3	-1.5	2.5	-4.1	1.7
Inputs						
(K) Capital stock	4.8	1.9	-1.3	3.4	0.4	2.5
(L) Labor hours	1.1	0.6	-2.6	1.8	-5.7	0.5
(E) Energy	7.2	-2.9	-1.1	0.8	-11.4	0.2
(M) Materials	0.0	1.1	-4.1	1.0	-3.8	0.0
(S) Services	4.4	2.8	-1.7	3.7	-3.7	2.6
Private Goods-Producing Industries						
Output	0.5	1.0	-4.4	1.4	-3.6	0.2
Inputs						
(K) Capital stock	2.7	1.1	-2.7	2.6	-0.1	1.4
(L) Labor hours	-0.7	-0.8	-6.9	1.7	-6.4	-0.8
(E) Energy	3.5	-2.4	-1.5	-1.5	-5.1	-1.0
(M) Materials	-0.7	1.0	-4.5	0.6	-4.3	-0.4
(S) Services	-1.0	2.2	-3.7	1.7	-2.6	0.5
Private Services-Producing Industries						
Output	4.3	2.9	-0.2	2.9	-4.3	2.4
Inputs						
(K) Capital stock	6.0	2.4	-0.7	3.7	0.6	3.1
(L) Labor hours	1.8	1.1	-1.4	1.8	-5.5	0.9
(E) Energy	9.1	-3.1	-0.9	1.7	-13.7	0.7
(M) Materials	3.1	1.6	-2.8	2.6	-2.1	1.5
(S) Services	5.8	2.9	-1.3	4.0	-3.9	3.0

Source: Calculations performed with the LIFT Model database

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Table 4 shows some of the underlying information used to calculate TFP for the Chemicals industry (NAICS 325). Real output growth is shown in the top line. The next part of the table shows real KLEMS inputs growth. The bottom section shows productivity (real output/real input) in relation to each KLEMS input. For example, the line for Labor hours is the well-known measure of labor productivity growth. Finally, the calculated multifactor productivity is shown as the bottom line of the table.

Real output growth for this industry averaged only -0.1 percent over the period, with a period of faster growth (3.3 percent) from 2001 to 2007. This industry suffered from the global financial crisis, with a growth rate of -5.2 percent from 2007 to 2010. After the crisis, the average real output growth rate from 2010 to 2019 was still negative (-0.6 percent).

Labor hours worked has declined throughout the period, but the most rapid decline was also in the 2007-2010 period. Materials use declined faster than output in the 2007-2010 period. However, services and energy inputs did not decline as much, with the result the TFP growth in that period was -4.0 percent. Over the entire 1998 to 2020 period, TFP has declined by an average of 1.2 percent, with strong growth in the 2001 to 2007 period, and then a return to below the 1997 level.

Table 4. Chemicals Industry: Real Output, Inputs and Productivity Measures
Average Annual Growth Rates

	1998-2001	2001-2007	2007-2010	2010-2019	2019-2020	1998-2020
Output	**-0.7**	**3.3**	**-5.2**	**-0.6**	**0.6**	**-0.1**
Inputs						
(K) Capital stock	0.2	-0.7	-1.1	3.4	-1.1	1.0
(L) Labor hours	-2.1	-1.4	-2.1	1.2	-7.1	-0.8
(E) Energy	-2.9	1.6	-2.0	-3.8	-10.4	-2.2
(M) Materials	-1.3	5.9	-5.4	-2.5	1.1	-0.3
(S) Services	-1.3	5.0	-2.2	0.4	3.1	1.2
Productivity						
(K) Capital stock	-0.9	4.0	-4.0	-4.0	1.7	-1.2
(L) Labor hours	1.3	4.7	-3.1	-1.8	7.7	0.7
(E) Energy	2.2	1.6	-3.1	3.2	11.0	2.1
(M) Materials	0.6	-2.7	0.2	1.9	-0.5	0.1
(S) Services	0.6	-1.7	-2.9	-1.0	-2.5	-1.3
Total factor productivity	**-0.9**	**4.0**	**-4.0**	**-4.0**	**1.7**	**-1.2**

Source: Calculations performed with the LIFT Model database

Productivity growth with respect to each input component shows a mixed picture. Labor productivity growth averages 0.7 percent over the 1998-2020 period, but labor productivity actually declined between 2007 and 2010 (-3.1 percent) and 2010 to 2019 (-1.8 percent). Services productivity declines throughout the period (-1.3 percent). This could be due to outsourcing (substituting services for labor), change in output mix (a switch within Chemicals to detailed industries that consume more services, such as Pharmaceuticals), or increased use of R&D and technical services. Materials productivity improves in every sub period except for 2001 to 2007 and 2019 to 2020.

The bottom line in the table is multifactor productivity growth, which can be understood as a weighted average of the productivity growth with respect to each KLEMS input.

How do our calculations for TFP compare to those of BEA/BLS? Table 5 is a comparison of the growth rates of TFP for manufacturing industries between the Inforum and the BEA/BLS estimates, for selected industries. This table shows significant and at this point unexplained differences between the two sets of estimates. In the next section, we will discuss some considerations that may affect the estimates, and compare our approach with what we know about the BEA/BLS approach.

Table 5. Comparison of Inforum and BEA/BLS TFP for Selected Industries

	Inforum	BEABLS
4 Mining, except oil and gas	-1.2	-1.2
5 Support activities for mining	2.0	1.8
6 Utilities	-1.8	0.1
7 Construction	-2.9	-0.9
8 Food and beverage and tobacco products	-1.0	-0.2
12 Paper products	1.5	0.2
13 Printing and related support activities	1.2	1.2
15 Chemical products	-1.2	-0.5
16 Plastics and rubber products	0.0	0.3
17 Nonmetallic mineral products	-0.1	0.1
18 Primary metals	-0.8	1.0
19 Fabricated metal products	-1.1	-0.2
20 Machinery	0.9	0.1
21 Computer and electronic products	2.5	5.6
27 Wholesale trade	4.3	0.1
32 Air transportation	-0.6	-0.5
33 Rail transportation	0.1	0.3
41 Motion picture and sound recording industries	1.3	0.9
42 Broadcasting and telecommunications	0.3	0.8
44 Federal Reserve banks, credit intermediation, and related activities	-1.1	-0.7
45 Securities, commodity contracts, and investments	1.0	0.2
46 Insurance carriers and related activities	5.2	0.2
47 Funds, trusts, and other financial vehicles	5.3	-0.1
50 Rental and leasing services and lessors of intangible assets	-1.9	-1.4
51 Legal services	-1.9	-1.2
52 Miscellaneous professional, scientific, and technical services	-1.4	-0.1
53 Computer systems design and related services	3.3	2.8
56 Waste management and remediation services	-3.2	-0.3
57 Educational services	-2.0	-0.5
63 Amusements, gambling, and recreation industries	-2.9	-0.6
64 Accommodation	-2.4	-0.8
65 Food services and drinking places	0.9	-0.2
66 Other services, except government	-3.7	-1.0

Source: Calculations performed with the LIFT Model database, and BEA/BLS Integrated Production Accounts

Issues Relating to the Measurement of TFP

Inforum and BEA/BLS are both using equation (10) to calculate TFP. Differences in the calculations shown in the tables and graphs above ultimately relate to differences in the measures of output, inputs, or nominal cost shares. We will touch on some of these issues in this section. More information on the compilation of the Inforum data is in Appendix B.

Nominal Output

The Inforum series on nominal output is based on the benchmark IO table, the annual IO tables, and the detailed gross output series published by BEA. BLS constructs its own measures of industry output based on data from the economic censuses and annual surveys from the Bureau of the Census and other sources. BLS also prefers to use a concept known as 'sectoral' output, in which the diagonal component of intermediate has been removed from both output and inputs. Inforum has used gross output, and we have found that removing the diagonal does not affect the growth rate of output substantially.

Output Price

The Inforum output prices are based on those compiled by BEA as part of its gross output series, except that Inforum has chosen not to use the rapidly declining hedonic deflators for Computers (NAICS 334111), Computer storage (334112) and Semiconductors (334413). The Inforum deflator for Computer and electronic products still declines in the period 1997-2020, but not as rapidly as the BEA deflator.

Note that the different treatment of the computer deflator results in slower real growth of computer output, as evidenced by the vastly different growth in TFP between Inforum and BEA/BLS shown in table 5. This contributes significantly to the different rate of growth of durable manufacturing MFP as well. Since computers are also an important share of capital equipment investment, the Inforum computer deflator leads to a slower measured growth in real capital stock than BLS or BEA.[15] (increasing the TFP growth of other sectors, especially the computer-intense ones)

Capital

Capital input is ideally measured as a flow of capital services. One issue in the measurement of capital is to decide which types of capital to include. BLS includes equipment, structures, land and inventories. Inforum at present includes only equipment and structures. BLS assumes that real capital input is proportional to stocks, and maintains stocks at a detailed asset level for each industry. Since each type of asset has a different average service life, the service flow to stock ratio is different for each asset. The net stock and the service flow are both based on fixed "efficiency schedules" adopted for each type of asset. Inforum calculates an average service life for each industry, based on the average composition of assets of each type, and then uses this average service flow to calculate "spill" out of the stock and to derive the net stock.

BEA's measure of net stock aims to measure the value of capital goods, as the net present discounted value of future services. They use a pattern similar to exponential depreciation where a large share of the value of each asset is lost in the first few periods. BLS aims to capture a measure of "productive capital stock" in its efficiency schedules, where a slower initial depreciation reflects the fact that new capital goods lose their efficiency slowly at first.

BEA/BLS use the BEA investment deflators to deflate new gross investment. Inforum uses a set of Inforum-derived deflators that are based on the IO commodity prices and a capital flow or "**B**-matrix" that shows the composition of investment by asset for each industry over time.

Jorgenson and Griliches (1967) suggest adjusting the capital input measure by an estimate of capital utilization, and use electricity consumption as an indicator of utilization. They find that this adjustment reduces the residual and attributes a larger part of output growth to changes in capital input. BEA/BLS have chosen not to adjust for utilization.

Labor

Labor input in the BLS KLEMS-based MFP estimates consists of total hours worked, unadjusted for skill or wage levels. The BLS Current Employment Statistics and Current Population Survey are used to combine data on production and supervisory workers hours. Inforum current derives

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[15] Meade (2001), pp. 165-167 presents the several of the main arguments against using the BEA/BLS computer deflators. See also Almon (2012), pp 25-26 for a discussion of the problems of using the hedonic computer deflator in economic model building.

its data on employment and hours from the BEA data which are published as part of the National Income and Product Accounts (NIPA). Inforum is using BEA derived labor compensation from the NIPA to estimate the labor cost share.

Energy, Materials and Services

Inforum has constructed a set of energy, materials and services aggregates from a set of detailed balanced IO tables in current and constant prices, now available from 1997 to 2020. We have compared our estimates to those constructed by BEA, and found some differences may be due to the following:

1. Inforum constructs a purified "product-to-product" table at the 350 sector level in current prices. In the *LIFT* model, this has been aggregated to a 121 by 71 commodity by industry "New Use" matrix. This will differ from the BEA Use matrix used to construct the BEA KLEMS data.
2. The BEA/BLS data are based on unpublished detailed tables that underlie the published annual IO make and use tables. These of course may differ from the parallel tables estimated independently by Inforum.
3. The deflation of the BEA/BLS to constant prices is not documented by reference to a published set of constant price IO tables. The constant price estimates differ more than the current price estimates of E, M and S between Inforum and BEA.

The BLS Office of Productivity and Technology (OPT) makes its own estimates of energy, materials and services, from yet another IO database. This IO framework is developed by the BLS Office of Economic Projections (OEP), and consists of a time series of current and constant price tables at about 190 sectors, based on the BEA data, but using BLS methodologies to estimate a time-series from 1993 to 2020[16]. The BLS E, M & S estimates are further adjusted to bring them into consistency with other data BLS has compiled for the MFP project. We have not yet made an exhaustive comparison of the Inforum and BEA/BLS production account estimates.

Aggregation

Both the BLS and BEA make extensive use of chained index number techniques to aggregate the detailed inputs and outputs. BEA generally uses the Fisher chained index, whereas BLS has chosen the Tornqvist aggregation formula for almost all of its needs. The data that Inforum has used for this project is aggregated by simple adding up. While this may lead to substitution bias, we have found that it is simpler to check the aggregates using this method. A comparison of the aggregation techniques would highlight how important this issue actually is.

Projections of TFP

The new version of the *LIFT* model has an TFP function added, that forms the KLEMS components and moves forward the historical estimates of TFP, using the same data and techniques that were used to calculate TFP in the historical period. The TFP function simply reports the calculated MFP by industry, based on the forecasted *LIFT* inputs and outputs, including labor hours worked and capital stock.

Including the module within *LIFT* is useful in the following ways:

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[16] These data can be accessed at http://www.bls.gov/emp/ep_data_input_output_matrix.htm.

1. Forecasts of labor, capital and other factors can be examined for reasonableness by comparing projected TFP growth rates with historical growth rates. This provides an independent check on both the labor productivity and the capital investment equations.
2. Alternative scenarios can be studied to analyze the effect of exogenous changes in other variables on TFP, or to examine what changes in labor, capital and other factors would be necessary to achieve a certain rate of TFP growth.
3. By assuming fixed or constant pre-specified rates of future TFP growth, we could impose a direct link between capital investment and labor productivity, which is difficult to establish empirically using industry time-series data.
4. The effects on TFP of alternative trends in the efficiency of energy use or the use of other intermediate inputs can be traced.
5. Since *LIFT* calculates prices endogenously, from the bottom-up, the impacts of alternative growth rates of TFP on industry price growth or aggregate inflation can be determined.

The *LIFT* model with TFP was run to 2030 using the current Inforum Summer 2022 Outlook forecast. For some 20 industries, the projected TFP growth rates show a smooth transition from history, with either a gradual rise or decline from the historical rate.[17] Other industries show significant changes. For example, TFP in all of the mining industries had negative growth between 1998 and 2020, but has positive growth of over 1 percent in the forecast. About 20 industries display this switch from negative to positive TFP growth. For the remaining 20 industries, the results are somewhat in between, with projected growth generally increasing between 0.5 and 1.0 percent from the 1998-2020 historical period.

These differences could be due to the fact that the historical period we are using is relatively short, and includes 3 years of significant economic slowdown, whereas the forecast is generally smoother and does not include any deep recessions.

3. Conclusions and Further Research

The goal of this project has been to create a comprehensive and internally consistent modeling framework for multifactor productivity. This modeling framework is integrated within the database of the Inforum *LIFT* model of the U.S. which forecasts output, hours worked, investment, capital stocks and intermediate purchases in current and constant prices. In many respects, this database satisfies the underlying requirements of a set of "production accounts", as defined in Fraumeini (2006). A consistent set of such accounts allows for the analysis of the interrelationships of structural change, outsourcing, changes in import and export patterns, labor and multifactor productivity and wage and price changes. For the most part, Inforum has adhered to the BEA/BLS methodology for IO tables, output, investment, employment, value added and prices. BEA does not publish a constant price IO framework, although they generate one internally to derive the (KL)EMS and production account estimates in real terms. Inforum has traditionally built its models using constant price IO tables, but only recently has BEA provided enough source data to attempt to build a balanced time series of tables in current and constant prices. Inforum compiles a time series of product-to-product tables for the U.S., and intermediate estimates derived from such a "recipe" matrix will differ from those derived by BEA or BLS.

[17] This includes industries 11-13, 16, 20, 24, 26-27, 29-30, 35, 40-42, 49, 59 and 60.

To extend and improved what has been developed so far, we anticipate that we will:

1. Derive detailed matrices of capital stock by industry by asset for equipment and structures, and experiment with Tornqvist or Fisher chain-aggregation (using asset-specific user cost weights) to obtain a better measure of capital service flows.
2. Identify and try to resolve important differences in labor and intermediate inputs between the Inforum database and the BEA/BLS TFP database.
3. Use scenario analysis to understand the implications of faster or slower TFP growth on labor productivity, prices and capital investment.
4. Use the database developed for this project to develop improved equations for capital investment and labor demand, and prices.
5. Focus more detailed attention on the health care and air transportation sector to understand the impact of differing assumptions about deflators, capital stock and output measures on TFP.

The TFP model in LIFT, while still in its early stages, is already a useful tool for understanding productivity growth of the U.S. economy in a consistent and comprehensive way.

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Appendix A. *LIFT* Sectoring Schemes

A-1. Industry Sectors in *LIFT*

#	Description	2012 NAICS
1	Farms	111-12
2	Forestry, fishing, and related activities	113-15
3	Oil and gas extraction	211
4	Mining, except oil and gas	2121-3
5	Support activities for mining	2131
6	Utilities	2211-3
7	Construction	23
8	Food and beverage and tobacco products	311, 312
9	Textile mills and textile product mills	313, 314
10	Apparel and leather and allied products	315, 316
11	Wood products	321
12	Paper products	322
13	Printing and related support activities	323
14	Petroleum and coal products	324
15	Chemical products	3251-6, 3259
16	Plastics and rubber products	3261-2
17	Nonmetallic mineral products	327
18	Primary metals	331
19	Fabricated metal products	332
20	Machinery	333
21	Computer and electronic products	334
22	Electrical equipment, appliances, and components	335
23	Motor vehicles, bodies and trailers, and parts	3361-3
24	Other transportation equipment	3364-6, 3369
25	Furniture and related products	337
26	Miscellaneous manufacturing	339
27	Wholesale trade	42
28	Motor vehicle and parts dealers	441
29	Food and beverage stores	445
30	General merchandise stores	452
31	Other retail	442-4, 446-8, 451, 453-4
32	Air transportation	481
33	Rail transportation	482
34	Water transportation	483
35	Truck transportation	484
36	Transit and ground passenger transportation	484, S00201
37	Pipeline transportation	486
38	Other transportation and support activities	487-8, 492
39	Warehousing and storage	493
40	Publishing industries, except internet (includes software)	511
41	Motion picture and sound recording industries	512
42	Broadcasting and telecommunications	515, 517
43	Data processing, internet publishing, and other information services	518, 519
44	Federal Reserve banks, credit intermediation, and related activities	521, 522
45	Securities, commodity contracts, and investments	523
46	Insurance carriers and related activities	524
47	Funds, trusts, and other financial vehicles	525
48	Housing services	n/a
49	Other real estate	531
50	Rental and leasing services and lessors of intangible assets	532-3
51	Legal services	5411
52	Miscellaneous professional, scientific, and technical services	5412-4, 5416-9
53	Computer systems design and related services	5415
54	Management of companies and enterprises	55
55	Administrative and support services	561
56	Waste management and remediation services	562
57	Educational services	611
58	Ambulatory health care services	6211-6, 6219
59	Hospitals	622
60	Nursing and residential care facilities	623
61	Social assistance	624
62	Performing arts, spectator sports, museums, and related activities	711, 712
63	Amusements, gambling, and recreation industries	713
64	Accommodation	721
65	Food services and drinking places	722
66	Other services, except government	8111-4, 812-4
67	Federal general government defense	S00500
68	Federal general government nondefense	S00600
69	Federal government enterprises	491, S00102
70	State and local general government	S00700
71	State and local government enterprises	S00203

A-2. Commodity Sectors in *LIFT*

Sec #	Description	2012 NAICS
1	Crop production	111
2	Animal production	112
3	Forestry, fishing and agriculture support activities	113, 114, 115
4	Crude oil extraction	211 pt.
5	Natural gas extraction	211 pt.
6	Coal mining	2121
7	Metal ore mining	2122
8	Nonmetallic mineral mining	2123
9	Support activities for mining	2131
10	Electric utilities	2211, S00101, S00202
11	Natural gas distribution	2212
12	Water, sewage and other systems	2213
13	New construction	23
14	Maintenance and repair construction	23
15	Dairy products, meat and seafood	3115, 3116, 3117
16	Other foods	3111, 3112, 3113, 3114, 3118, 3119
17	Beverages	3121
18	Tobacco	3122
19	Textiles and textile products	313, 314
20	Apparel and leather	315, 316
21	Wood products	321
22	Paper	322
23	Printing	323
24	Petroleum and coal products	324
25	Resin, synthetic rubber and fibers	3252
26	Pharmaceuticals	32541
27	Other chemicals	3251,3253,3255,3256,3259
28	Plastic products	3261
29	Rubber products	3262
30	Nonmetallic mineral products	327
31	Iron and steel	3311,3312,33151
32	Nonferrous metals	3313, 3314, 33152
33	Fabricated metal products	332
34	Agriculture, construction and mining machinery	3331
35	Industrial machinery	3332
36	Commercial and service industry machinery	3333
37	Ventilation, heating, air-conditioning and ventilation equipment	3334
38	Metalworking machinery	3335
39	Engine, turbine and power transmission equipment	3336
40	Other general purpose machinery	3339
41	Computers and peripheral equipment	3341
42	Communications and audio-video equipment	3342, 3343
43	Semiconductors and other electronic components	3344
44	Electromedical and electrotherapeutic apparatus	334510, 334517
45	Search, detection and navigation equipment	334511
46	Measuring and control instruments, and media	334512,3,4,5,6,9, 3346
47	Household appliances	3352
48	Electrical equipment	3353
49	Other electrical equipment and components	3351, 3359
50	Motor vehicles	3361, 3362
51	Motor vehicle parts	3363
52	Aerospace products and parts	3364
53	Ship and boat building	3366
54	Other transportation equipment	3365, 3369
55	Furniture	337
56	Medical equipment and supplies, dental labs, ophthalmic goods	3391
57	Miscellaneous manufacturing	3399
58	Wholesale trade	42
59	Motor vehicle and parts dealers	441
60	Food and beverage stores	445

A-2. Commodity Sectors in *LIFT* (continued)

Sec #	Description	2012 NAICS
61	General merchandise stores	452
62	Other retail	442-4, 446-8, 451, 453-4
63	Air transportation	481
64	Rail transportation	482
65	Water transportation	483
66	Truck transportation	484
67	Transit and ground passenger transportation	485, S00201
68	Pipeline transportation	486
69	Transportation support, sightseeing, couriers	487,488,492
70	Warehousing and storage	493
71	Publishing, except internet and software	511, exc. 5112
72	Software	51121
73	Motion picture and sound recording	512
74	Broadcasting: Cable, TV and radio	5151, 5152
75	Telecommunications	517
76	Information and data processing	5182,519
77	Banks, credit cards and finance	521, 522
78	Securities and commodities brokers	5231-2
79	Other financial investment activities	5239
80	Insurance	524
81	Funds, trusts and other financial vehicles	525
82	Housing services	n/a
83	Other real estate	531
84	Rental and leasing of goods	532
85	Royalties	533
86	Legal services	5411
87	Architectural, engineering and related services	5413
88	Computer systems design and related services	5415
89	Scientific research and development services	5417
90	Advertising	5418
91	Other professional, scientific and technical services	5412, 5414, 5416, 5419
92	Management of companies and enterprices	55
93	Administrative and support services	561
94	Waste management and remediation	562
95	Educational services	611
96	Offices of physicians	6211
97	Offices of dentists	6212
98	Offices of other health practitioners	6213
99	Outpatient care centers	6214
100	Medical and diagnostic laboratories	6215
101	Home health care services	6216
102	Other ambulatory health care services	6219
103	Hospitals	622
104	Nursing and residential care facilities	623
105	Child care and social assistance	624
106	Performing arts, spectator sports and museums	711, 712
107	Amusements, gambling and recreation	713
108	Accomodation	721
109	Food services and drinking places	722
110	Automotive repair and maintenance	8111
111	Other repair and maintenance, personal services	8112,-3,-4, 812
112	Religious, grantmaking and other organizations	813
113	Private households	814
114	Postal service and federal government enterprises	491, S00102
115	State and local government enterprises	S00203
116	Federal government defense	S00500
117	Federal government nondefense	S00600
118	State and local general government	GSLGE, GSLGH, GSLGO
119	Scrap, used and secondhand	S00401, S00402
120	Noncomparable imports	S00300
121	Rest of the world adjustment to final uses	S00600

Appendix B. Data Sources

This appendix describes the data used for this paper. Unless otherwise noted, all series used in the paper are annual and cover the period from 1997 to 2020.

A. Nominal Output by Industry

The nominal output data are derived from the 2012 benchmark input-output table, the series of annual IO tables from 1997 to 2020, and the BEA gross output series, which includes current and constant prices industry output (before redefinitions). The Inforum concept of industry output is closest to the BEA series "industry output after redefinitions" from the annual IO tables.

B. Output Price

To deflate industry output, we have compiled a series of make tables in current prices. We use commodity deflators to deflate the make tables down the column, and form the real industry output as the row sum of the deflated make table. The industry output price is formed as the ratio of nominal industry output over real industry output.

C. Labor Hours

The NIPA table 6.9 "Hours worked by full-time and part-time employees" is used as the control totals for hours worked for employees. The distribution to more detailed industries is achieved by sharing the hours worked by shares of employment in each industry. Finally, hours for self-employed and family workers are added by adjusting hours by the share of employment of self-employed and family workers to full-time and part-time employment.

D. Labor Compensation

Labor compensation includes wages and salaries plus supplements. Inforum uses the NIPA data directly. The average "wage" per hour is defined as the total labor compensation divided by total hours worked, for each industry.

E. Investment and Capital Stocks

Data on nominal investment series by owning industry is taken from the BEA *Fixed Assets* data. Fixed ratios are used to convert these series to a user basis, as defined by the 1997 Capital Flow Table published by BEA as part of the 1997 U.S. Benchmark IO table. Average service lives by industry are used to derive time series of real capital stocks. The LIFT model also includes its own time-series of capital flow tables, estimated and balanced by Inforum, for the period 1997 to 2020. There are in nominal and constant 2012 dollars.

F. Intermediate Purchases, Aggregated as Energy, Materials and Services

The intermediate aggregates used for the Inforum KLEMS data are drawn from the IO database used for the *LIFT* model. This database uses detail from the 2012 Benchmark U.S. IO table and the series of U.S. annual IO tables, combined with detailed data on imports, exports and industry output to create a time series of detailed make and use matrices from 1997 to 2020. These are then converted annually to a product-to-product table, based on commodity technology The entire framework is converted to constant prices by deflating output by domestic output deflators, deflating imports by imports deflators, and deflating the rest of each row implicitly in a way that preserves the row sum in constant prices.