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Industry Origins of the American Productivity Resurgence

DALE W. JORGENSON*, MUN S. HO**, JON D. SAMUELS† & KEVIN J. STIROH‡

*Department of Economics, Harvard University, USA, **Resources for the Future, Inc., Washington, DC, USA, †Johns Hopkins University, Baltimore, USA, ‡Federal Reserve Bank of New York, USA

ABSTRACT *This paper analyzes the industry origins of the American growth resurgence by examining output, input, and productivity growth of 85 component industries for the period 1960 to 2005. We use this detailed industry data to examine trends in particular industry groups such as those that produce information technology (IT) or use IT most intensively and to perform a 'bottom-up' comparison of alternative aggregation methodologies. The data show that while labor productivity growth was strong throughout the full period after 1995, there were important differences between 1995–2000 and 2000–2005. The period 1995–2000, for example, was marked by strong growth in labor input so aggregate output was robust, while labor input and output growth both declined substantially after 2000. IT remained an important source of both capital deepening and total factor productivity growth after 2000, but the contributions were not as large as during the technology boom of the late 1990s. We also show that the production possibility frontier, which recognizes differences in output prices across industries, remains the most appropriate methodology for aggregating industry data.*

KEY WORDS: Economic growth, USA, industry aggregation, information technology

1. Introduction

In this paper we analyze the industry origins of the American growth and productivity resurgence after 1995.[1] Jorgenson *et al.* (2005) have described the growth and productivity surge of 1995–2000 in terms of the output, inputs, and productivity growth of 44 individual industries in the US for the period 1977–2000. We extend the time period backward to 1960 to provide a longer time perspective and forward to 2005 to capture the impact of the dot-com crash of 2000, the slowdown in IT investment, and the mild recession of 2001. We present information on the performance of 85 US industries in order to provide greater detail on the origins of the resurgence after 1995 at the level of individual industries.

The longer and more detailed data facilitate our comparison of three approaches to aggregating the underlying industry-level data, which yields three alternative measures

Correspondence Address: Dale W. Jorgenson, Department of Economics, Harvard University, Littauer 122, 1805 Cambridge Street, Cambridge, MA 02138, USA. Email: djorgenson@harvard.edu.

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of aggregate output, inputs, and total factor productivity (TFP). The first approach is the 'aggregate production function,' the second is the 'production possibility frontier,' and the third is direct 'aggregation across industries.' These schemes differ in their assumptions and generate different estimates of aggregate US economic growth and its sources, so comparison across methods provides insight into the validity of the underlying assumptions. We conclude that the production possibility frontier accurately summarizes the industry data, even over relatively short periods of time, while the aggregate production function provides a very misleading picture of economic growth.

We can summarize our empirical results, briefly, by focusing on the acceleration of US output growth in 1995–2000 and the slowdown in 2000–2005, as well as the surge of US labor productivity growth that continued through both periods. In 1995–2000, US economic growth increased by nearly a percentage point relative to 1960–1995. Faster growth of total factor productivity (TFP), defined as growth in output per unit of input, in industries that produce information technology (IT) accounted for 0.26 percentage points. This acceleration in TFP growth resulted in higher rates of decline in IT prices, stimulating decisions by firms, households, and governments to invest in IT equipment and software. As a result, rising IT investment contributed 0.72 points to the jump in output growth. Jorgenson (2001) has traced the accelerated price decline to a substantially shorter product cycle in the production of the key electronic components of IT equipment.

The IT boom of the last half of the 1990s faded considerably after the dot-com crash of 2000. Slower growth of TFP in the IT-producing industries reduced the rate of decline of IT prices in 2000–2005. Investment in IT equipment and software slowed, but remained strong relative to the pre-1995 period due to the low prices already in place. Reduced TFP growth in IT production was more than offset by a sharp rise in TFP growth in the IT-using industries, principally in services.[2] This contribution had been slightly negative during the IT boom, but turned very substantially positive after 2000. TFP growth in the Non-IT industries rose. Non-IT investment continued to languish, while the contribution of labor input turned from strongly positive in 1995–2000 to modestly positive in 2000–2005.

The boom of 1995–2000 and the slowdown of 2000–2005 were both accompanied by accelerated growth in labor productivity. Relative to 1960–1995, labor productivity growth rose by 0.43% per year in the boom period of 1995–2000, while hours worked rose by 0.54%. As output growth slowed in 2000–2005, aggregate hours sank by a startling 0.33% per year while labor productivity growth increased further to 3.17% for the same period. In 1995–2000 the acceleration in labor productivity growth was due primarily to more rapid IT-capital deepening and secondarily to faster growth in TFP in the IT-producing industries. Other types of capital deepening accelerated further after 2000, but more rapid TFP growth outside of IT production growth emerged as the primary driving force. We conclude that prospects for future US economic growth are substantially brighter than suggested by growth trends before 1995. However, the boom of the late 1990s was not sustainable due to limits imposed by the growth of the labor force. The growth slowdown after 2000 with negative growth in hours worked is also unlikely to be prolonged.

2. Methodology

This section presents the methodology used to construct economy-wide estimates of output growth and the sources of growth for three alternative methods – aggregate production function, production possibility frontier, and direct aggregation across industries.

In all cases, we begin with the same underlying industry source data, namely, production data similar to that described in Jorgenson *et al.* (2005). In this version, we present estimates of gross output, value-added, labor input, capital input, intermediate input, and total factor productivity for 85 industries. This section presents the alternative aggregation techniques for transforming the industry production data into estimates for the US economy as a whole.

The most restrictive approach is the aggregate production function, which imposes highly restrictive and implausible assumptions about industry-level value-added functions and the relative prices and mobility of the primary factors of production, capital and labor. Jorgenson *et al.* (1987) show that the existence of an aggregate production function implies that industry value-added functions exist and are identical up to a scalar multiple. Moreover, the aggregation of heterogeneous types of capital and labor must be the same across industries, and each type of capital and labor must command the same price in each industry. Under these assumptions, the aggregate production function yields a valid representation of the underlying industry-level production structure.

A less restrictive approach is the production possibility frontier, introduced by Jorgenson (1966) and recently employed by Jorgenson and Stiroh (2000), Jorgenson (2001), and Jorgenson *et al.* (2005). This approach relaxes the restrictions on industry value-added functions, so that value-added prices are not required to be identical across industries. This approach, however, retains the simplifying assumption that each input receives the same price in all industries. The production possibility frontier differs from the aggregate production function in the measurement of outputs but not inputs.

A third approach is a direct aggregation across industries, which relaxes all of the restrictions on value-added functions and inputs across industries. Measures of industry output, input, and productivity growth are weighted by the relative size of the industry and summed across all industries. This approach makes no assumption about common prices of outputs or inputs across industries and treats the aggregate economy as a weighted average of the component industries. This is the least restrictive approach and can be used as a benchmark for comparison with the other aggregation schemes.

We estimate the growth of economy-wide output, inputs, and total factor productivity (TFP) for each aggregation method under the corresponding set of assumptions. Because all three aggregation schemes are implemented with the same underlying source data, differences in the estimates of economy-wide sources of growth reflect the impact of the alternative assumptions and methodologies. Divergence in results between the aggregate production function and the production possibility frontier, for example, indicates failure of the assumption of identical value added functions for all industries. The further divergence in results for direct aggregation across industries reflects failure in the assumptions about mobility of the primary factors.[3]

2.1. Aggregate Production Function

The aggregate production function has a long history in economics, dating back at least to the work of Douglas (1948). Due to its simplicity and tractability, the aggregate production function has been a workhorse of applied macroeconomics. As discussed in detail in Jorgenson *et al.* (1987), however, the existence of an aggregate production function requires a number of very stringent assumptions about the nature of production and the industry level.[4] We begin with an enumeration of these assumptions and then present a method for generating measures of output, inputs, and TFP that are consistent with the assumptions.

Jorgenson *et al.* (1987, 2005) and Jorgenson (1990) discuss the four key assumptions that are necessary for the existence of an aggregate production function. First, each industry must have a gross output production function that is separable in value-added, where value-added is a function of industry capital, labor, and technology. Second, the value-added function is the same across all industries, up to a scalar multiple.[5] If value-added is scaled appropriately, these constants equal one and the industry value-added functions are identical. Third, the functions that aggregate heterogeneous types of capital and labor must be identical in all industries. Fourth, each specific type of capital and labor must receive the same price in all industries. These assumptions have specific implications for internally consistent measures of aggregate output and inputs.

The first assumption guarantees that the quantity of aggregate value-added can be defined as a function of industry value-added:

$$V = V(V_1, \ldots, V_J) \tag{1}$$

where V is aggregate value-added and V_J is an index of industry value-added for industry j. Time subscripts are suppressed for convenience. As an accounting identity, the nominal value-added is the sum of value-added across all industries:

$$P_V V = \sum_j P_{V,j} V_j \tag{2}$$

where $P_{V,j}$ is the price of industry value-added. From this identity and equation (1) we obtain the aggregate price of value-added, P_V.

The second assumption – the existence of identical value-added functions across industries – implies that identical 'price of value-added' functions (or the dual cost functions) exist across all industries. When combined with the fourth assumption that capital and labor components receive the same price in all industries, the industry price of value-added must be the same in all industries and at the aggregate level so, for all j:

$$P_V^{PF} = P_{V,j} \tag{3}$$

where P_V^{PF} is the price of value-added and the superscript PF denotes variables from the aggregate production function. Equations (2) and (3) imply that aggregate value-added, given in equation (1), is simply a summation across industries:

$$V^{PF} = \sum_j V_j \tag{4}$$

where V^{PF} is the quantity of value-added from the aggregate production function. Equation (4) is the first key result: aggregate value-added is a sum of industry value-added.

Industry production accounts like those presented by Jorgenson *et al.* (2005, Chapters 5 and 6), emphasize the heterogeneity of inputs within each industry; e.g. capital includes both computers and tractors, while labor includes high-school-educated men and college-educated women. The fourth assumption states that each type of capital and labor is identical in all industries and receives the same price everywhere. This is a market equilibrium condition when there is mobility of factors across industries and holds when all factors of the same type are paid the same price in all industries. If each input receives the same price in all industries, the economy-wide quantity of each type of capital and labor is the simple sum across industries. For each k and l:

$$K_k = \sum_j K_{k,j} \quad \text{and} \quad L_l = \sum_j L_{l,j} \tag{5}$$

where the k subscript indexes the type of capital and l indexes the type of labor. This implies that the price of aggregate capital and labor of each type is the same for all industries. For all j:

$$P_{K,k} = P_{K,k,j} \quad \text{and} \quad P_{L,l} = P_{L,l,j} \tag{6}$$

Aggregate capital services and labor input are defined as the translog aggregates of heterogeneous types of capital and labor, respectively:

$$\Delta\ln K = \sum_k \bar{w}_k \Delta\ln K_k \quad \text{and} \quad \Delta\ln L = \sum_l \bar{w}_l \Delta\ln L_l \tag{7}$$

where the share of each type of capital in total capital input, and the share of each type of labor in total labor input, are defined respectively as:

$$w_k = \frac{P_{k,k}K_k}{\sum_k P_{K,k}K_k} \quad \text{and} \quad w_l = \frac{P_{L,l}L_l}{\sum_l P_{L,l}L_l} \tag{8}$$

and the two-period average share weights are defined as:

$$\bar{w}_k = 0.5^*(w_{k,t} + w_{k,t-1}) \quad \text{and} \quad \bar{w}_l = 0.5^*(w_{l,t} + w_{l,t-1}) \tag{9}$$

The aggregate prices of capital and labor inputs (P_K and P_L) are derived from the accounting identity that defines the nominal aggregate value as the sum of nominal values of the various types:

$$P_K K = \sum_k P_{K,k}K_k \quad \text{and} \quad P_L L = \sum_l P_{L,l}L_l \tag{10}$$

and the nominal values of each type of input for the aggregate economy is given by combining equations (5) and (6).

Equation (4) defines the measure of aggregate value-added that can be generated from the industry-level data in a way that is consistent with the assumptions of the aggregate production function. Similarly, Equations (5)–(10) define the aggregate measures of capital and labor input that can be generated from the corresponding input data across industries. With these definitions, we can write the aggregate production function as:

$$V^{PF} = f(K, L, T) \tag{11}$$

and the corresponding nominal value-added identity as:

$$P_V^{PF} V^{PF} = P_K K + P_L L \tag{12}$$

We define total factor productivity (TFP) growth from the aggregate production function by analogy with the industry definition. Jorgenson *et al.* (2005, Chapter 7), have decomposed industry growth into the contributions of capital, labor, intermediates and TFP, where the contribution of each input is the growth rate of the input multiplied by its value share in output. Denoting growth in TFP from the aggregate production function as v_T^{PF}:

$$v_T^{PF} \equiv \Delta \ln V^{PF} - \bar{v}_K \Delta \ln K - \bar{v}_L \Delta \ln L \tag{13}$$

where the share-weighted growth rates of capital and labor inputs are again defined as their respective contributions to output. The capital share and labor share of aggregate value-added are defined as:

$$v_K = \frac{P_K K}{P_K K + P_L L} \quad \text{and} \quad v_L = \frac{P_L L}{P_K K + P_L, L} \tag{14}$$

and the two-period average shares are defined as:

$$\bar{v}_K = 0.5^*(v_{K,t} + v_{K,t-1}) \quad \text{and} \quad \bar{v}_L = 0.5^*(v_{L,t} + v_{L,t-1}) \tag{15}$$

We can further decompose capital and labor inputs, e.g. the contribution of capital contains an information technology (*IT*) component and a Non-IT (*NON*) component, while the contribution of labor input contains college-educated labor (*COL*) and non-college-educated (*NON*) components. This decomposition of aggregate value-added growth is:

$$\begin{aligned} \Delta \ln V^{PF} &= \bar{v}_{K,\,IT} \Delta \ln K_{IT} + \bar{v}_{K,\,NON} \Delta \ln K_{NON} + \bar{v}_{L,COL} \Delta \ln L_{COL} \\ &\quad + \bar{v}_{L,\,NON} \Delta \ln L_{NON} + v_T^{PF} \end{aligned} \tag{16}$$

where the $v_\bullet$ shares again represent the two-period averages of the sub-scripted input in aggregate value-added, e.g. $v_{K,IT} = P_{K,IT} K_{IT} / P_V^{PF} V^{PF}$.

Finally, we define labor productivity from the aggregate production function as value-added per economy-wide hour worked, $v^{PF} = V^{PF}/H$. At the industry level labor productivity growth reflects capital and intermediate input intensity growth, labor quality growth and the growth of TFP. Here, growth in aggregate labor productivity can be similarly decomposed as:

$$\Delta \ln v^{PF} \equiv \bar{v}_K \Delta \ln k + \bar{v}_L \Delta \ln Q_L + v_T^{PF} \tag{17}$$

where $k = K/H$ is capital per hour worked, and Q_L is labor quality. The capital deepening term can be broken down into IT and Non-IT components as:

$$\bar{v}_K \Delta \ln k = \bar{v}_{K,IT} \Delta \ln k_{IT} + \bar{v}_{K,NON} \Delta \ln k_{NON} \tag{18}$$

where the growth of IT capital per hour and Non-IT capital per hour are weighted by the two period shares of IT and Non-IT capital in value-added, respectively.

The decomposition of the labor quality contribution into college-educated labor quality and non-college-educated labor quality is somewhat more complicated. The quality of college labor input is defined as $Q_{L,COL} = L_{COL}/H_{COL}$ and non-college labor as $Q_{L,NON} = L_{NON}/H_{NON}$, and the contribution of aggregate labor input is the weighted sum of college and non-college components. Aggregate hours, however, is simply the sum of hours of each type so there is a reallocation term in the decomposition of labor quality:

$$\begin{aligned} \bar{v}_L \Delta \ln Q_L &\equiv \bar{v}_L \Delta \ln L - \bar{v}_L \Delta \ln H \\ &= \bar{v}_{L,Col} \Delta Q_{L,COL} + \bar{v}_{L,NON} \Delta \ln Q_{L,NON} + \bar{v}_{L,Col} \Delta H_{COL} \\ &\quad + \bar{v}_{L,NON} \Delta H_{NON} - \bar{v}_L \Delta \ln H \\ &= \bar{v}_{L,Col} \Delta Q_{L,COL} + \bar{v}_{L,NON} \Delta \ln Q_{L,NON} + REALL_H \end{aligned} \tag{19}$$

The $REALL_H$ term is a residual that represents a reallocation of hours between these two groups.

A few remarks are in order at this point. First, the four assumptions enumerated above are maintained throughout this derivation of aggregate TFP growth. These assumptions are required for the existence of aggregate production function; the next section examines their validity using US data. Jorgenson (1990), for example, concluded that the aggregate production function was appropriate for analyzing growth for long periods of time, but highly inappropriate over shorter periods. Second, we maintain the assumption of constant returns to scale for industries and for the US economy as a whole throughout this analysis. This is necessary for the exhaustion of income across inputs. Third, we reiterate that the aggregate production function is the most restrictive of our aggregation methods because it imposes constraints on both output and input aggregation.

2.2. Production Possibility Frontier

A second, less restrictive, approach is the production possibility frontier originated by Jorgenson (1966) and recently employed by Jorgenson and Stiroh (2000), Jorgenson (2001), and Jorgenson *et al.* (2005). The key difference between the aggregate production function and the production possibility frontier is relaxation of the restriction that industries have identical value-added functions. If the value-added functions differ, the price of value-added is no longer the same across industries and it is inappropriate simply to sum industry value-added. An aggregate production function of the form in equation (4) does not exist and substitution among industries is captured in the production possibility frontier, our preferred approach to aggregation.

We define aggregate value-added from the production possibility frontier as a translog index of industry value-added:

$$\Delta \ln V = \sum_j \bar{w}_j \Delta \ln V_j \tag{20}$$

where V_j is the industry value-added and w_j is the share of industry value-added in the aggregate:

$$w_j = \frac{P_{V,j} V_j}{\sum_j P_{V,j} V_j} \tag{21}$$

and the two-period average share is defined as:

$$\bar{w}_j = 0.5 \times (w_{j,t} + w_{j,t-1}) \tag{22}$$

where $P_{V,j}$ is the price of industry value-added. We emphasize that V without a superscript refers to the index derived from the production possibility frontier, while V^{PF} is derived from the aggregate production function. We maintain the same assumptions regarding capital and labor inputs, so that aggregate capital and labor are defined by equations (5)–(10). These assumptions yield the following relationship among aggregate value-added, aggregate inputs, and technology for the production possibility frontier:

$$V = f(K, L, T) \tag{23}$$

We define TFP growth from the production possibility frontier in the same manner as equation (13) above as output growth less capital and labor input growth weighted by their value shares:

$$v_T \equiv \Delta \ln V - \bar{v}_K \Delta \ln K - \bar{v}_L \Delta \ln L \tag{24}$$

which can also be expressed in terms of the decompositions of capital and labor as in equation (16):

$$\begin{aligned} v_T \equiv \Delta \ln V &- \bar{v}_{K,IT} \Delta \ln K_{IT} - \bar{v}_{K,NON} \Delta \ln K_{NON} - \bar{v}_{L,COL} \Delta \ln L_{COL} \\ &- \bar{v}_{L,NON} \Delta \ln L_{NON} \end{aligned} \tag{25}$$

We express the sources of labor productivity growth from the production possibility frontier as capital intensity growth, labor quality growth and TFP growth as in equations (17)–(19):

$$\begin{aligned} \Delta \ln v &\equiv \bar{v}_K \Delta \ln k + \bar{v}_L \Delta \ln Q_L + v_T \\ &\equiv \bar{v}_{K,IT} \Delta \ln k_{IT} + \bar{v}_{K,NON} \Delta \ln k_{NON} + \bar{v}_{L,COL} \Delta \ln LQ_{COL} \\ &\quad + \bar{v}_{L,NON} \Delta \ln LQ_{NON} + H_{RESID} + v_T \end{aligned} \tag{26}$$

2.3. *Direct Aggregation across Industries*

Our third approach for measuring the sources of growth for the aggregate US economy is direct aggregation across industries, as proposed by Jorgenson *et al.* (1987, Chapter 2). This methodology employs the industry production accounts presented by Jorgenson *et al.* (2005, Chapter 7), as the fundamental building blocks and begins with the industry-level sources of growth. We maintain the assumption that a value-added function exists for each industry, but impose no cross-industry restrictions on either value-added or prices of inputs, which eliminates the assumptions of identical value-added functions, mobility of inputs across industries, and equal factor prices for all industries.[6] In addition to being less restrictive, this approach allows us to trace the origins of aggregate productivity growth and input accumulation to the underlying industry sources.

2.3.1. Aggregation

We begin with the decomposition of industry-level gross output growth, written as:

$$\Delta \ln Y_j = \bar{v}_{K,j}\Delta \ln K_j + \bar{v}_{L,j}\Delta \ln L_j + \bar{v}_{X,j}\Delta \ln X_j + v_{T,j} \tag{27}$$

where output growth reflects the contribution of capital, the contribution of labor, the contribution of intermediate inputs, and TFP, all for industry j. The growth rates of the three inputs are weighted by the input shares in the value of industry output, while $v_{T,j}$ is the TFP growth rate. Aggregate output, however, is a value-added concept, so we incorporate the definition of industry value-added, written as:

$$\Delta \ln Y_j = \bar{v}_{V,j}\Delta \ln V_j + \bar{v}_{X,j}\Delta \ln X_j \tag{28}$$

where V_j is the value added in industry j and $v_{V,j}$ is the share of value-added in industry gross output. Given data on output and intermediate inputs, this equation yields the real value-added of industry j. The above two equations can be rearranged to yield an expression for the sources of value-added growth:

$$\Delta \ln V_j = \frac{\bar{v}_{K,j}}{\bar{v}_{V,j}}\Delta \ln K_j + \frac{\bar{v}_{L,j}}{\bar{v}_{V,j}}\Delta \ln L_j + \frac{1}{\bar{v}_{V,j}} v_{T,j} \tag{29}$$

We define aggregate output from the production possibility frontier, equations (20)–(22), where the rate of output growth is a weighted average of industry value-added growth rates. Combining equation (20) with equation (29) implies that aggregate value-added growth can be written as:

$$\Delta \ln V \equiv \sum_j \bar{w}_j \Delta \ln V_j = \sum_j \bar{w}_j \frac{\bar{v}_{K,j}}{\bar{v}_{V,j}}\Delta \ln K_j + \bar{w}_j \frac{\bar{v}_{L,j}}{\bar{v}_{V,j}}\Delta \ln L_j + \bar{w}_j \frac{1}{\bar{v}_{V,j}} v_{T,j} \tag{30}$$

Equation (30) shows that value added growth reflects the weighted contribution of industry capital input, labor input, and TFP. The weights on capital or labor reflect three factors: the relative size of industry value-added in aggregate value-added (w_j), the share of industry capital or labor income in industry gross output ($v_{K,j}$ and $v_{L,j}$), and the share of industry value-added in industry gross output ($v_{V,j}$). The weights on industry TFP reflect the relative size of industry value-added in aggregate value-added (w_j) and the share of industry value-added in industry gross output ($v_{V,j}$). All weights are two-period averages, as in the translog approach.

To quantify the impact of the assumptions behind the production possibility frontier, we compare the weighted average of the industry-level sources of economic growth in equation (30) to the decomposition derived from the production possibility frontier in equation (24). More precisely, we subtract equation (30) from equation (24) and rearrange to find:

$$
\begin{aligned}
v_T &= \left(\sum_j \frac{\bar{w}_j}{\bar{v}_{V,j}} v_{T,j}\right) + \left(\sum_j \bar{w}_j \frac{\bar{v}_{K,j}}{\bar{v}_{V,j}} \Delta \ln K_j - \bar{v}_K \Delta \ln K\right) + \left(\sum_j \bar{w}_j \frac{\bar{v}_{L,j}}{\bar{v}_{V,j}} \Delta \ln L_j - \bar{v}_L \Delta \ln L\right) \\
&= \sum_j \frac{\bar{w}_j}{\bar{v}_{V,j}} v_{T,j} + REALL_K + REALL_L \qquad (31)
\end{aligned}
$$

Equation (31) shows how aggregate TFP growth from the production possibility frontier relates to the sources of growth at the industry level. The first source of TFP growth is a weighted average of industry TFP growth rates. This ingenious weighting scheme, originated by Domar (1961), plays a key role in our framework for aggregation over industries and reflects the ratio of two proportions. The first is the proportion of each industry's value-added in aggregate value-added (w_j), and the second is the proportion of industry value-added in the industry's gross output ($v_{V,j}$). This yields an approximation to the ratio of industry gross output to aggregate value-added $P_{Y,j}Y_j/P_V V$, which is the usual interpretation of the Domar weight. A distinctive feature of Domar weights is that they typically sum to more than one, reflecting the fact that an improvement in industry TFP can have two effects – a direct effect on industry output and an indirect effect via the output that is sold to other industries as intermediate goods.

The second and third terms in equation (31) reflect the reallocations of capital and labor across industries, $REALL_K$ and $REALL_L$, respectively. These reallocations create a divergence between the growth rate of aggregate TFP and the sum of the Domar-weighted industry TFP growth rates. In terms of the theoretical framework we have described, the reallocation terms quantify the departure from the assumptions on inputs required for the production possibility frontier. For example, TFP growth from the production possibility frontier exceeds Domar-weighted industry TFP when the reallocation terms are positive. This happens when capital and labor inputs command different prices in different industries and the industries with higher prices have faster input growth rates. In this case, aggregate capital or labor inputs grow more slowly than weighted averages of their industry counterparts.[7]

We can also quantify the importance of the additional assumptions required for the existence of the aggregate production function. As discussed above, the price of value-added is the same in all industries in the aggregate production function, while the production possibility frontier does not require this assumption. This leads to different growth rates for the two alternative definitions of aggregate value-added. We define the reallocation of value-added as the difference in the growth rates of value-added from the aggregate production function and from the production possibility frontier as:

$$REALL_{VA} = d \ln V^{PF} - d \ln V = d \ln V^{PF} - \sum_j \bar{w}_j d \ln V_j \qquad (32)$$

where V^{PF} is aggregate value-added from the aggregate production function in equation (4), V is aggregate value-added from the production possibility frontier in equation (20) or from direct aggregation in equation (30), and V_j is value-added for industry j.

2.3.2. Aggregation by IT groups

An important feature of our methodology is that we can explicitly quantify how much an individual industry or set of industries contributes to value-added growth, the growth of capital and labor inputs, or TFP growth by applying the appropriate weight to the industry growth rates. We are particularly interested in the growth contributions of the industries that produce information technology goods (IT-producing), the industries that use information technology most intensively (IT-using), and the other industries (Non-IT), as identified in the Appendix Table. To analyze the contributions of these groups we simply rearrange the decompositions given above.

Equations (30) and (31) show how much each industry contributed to aggregate value-added, capital input, labor input, and TFP. We refer to the components of equation (30) as the industry contribution to value-added ($CT_{VA,j}$), the industry contribution to capital input ($CT_{K,j}$), the industry contribution to labor input ($CT_{L,j}$), and the industry contribution to TFP ($CT_{TFP,j}$). These are defined as:

$$CT_{VA,j} = \bar{w}_j \Delta \ln V_j;\ CT_{K,j} = \bar{w}_j \frac{\bar{v}_{K,j}}{\bar{v}_{V,j}} \Delta \ln K_j;\ CT_{L,j} = \bar{w}_j \frac{\bar{v}_{L,j}}{\bar{v}_{V,j}} \Delta \ln L_j;\ CT_{TFP,j} = \frac{\bar{w}_j}{\bar{v}_{V,j}} v_{T,j} \quad (33)$$

To quantify the importance of each set of industries to economic growth, we rewrite Equation (30) for the growth of value-added as the sum of the contribution of these three types of industries:

$$\Delta \ln V = \sum_{j \in IT-PRODUCE} \bar{w}_j \Delta \ln V_j + \sum_{j \in IT-USE} \bar{w}_j \Delta \ln V_j \sum_{j \in OTHER} + \bar{w}_j \Delta \ln V_j \quad (34)$$

where each summation refers to the contribution of the industries in each group to aggregate value-added growth. Similarly, we estimate the contribution of these sets of industries to aggregate TFP growth by breaking down the Domar-weighted contributions from equation (31) as:

$$\sum_j \frac{\bar{w}_j}{\bar{v}_{V,j}} v_{T,j} = \sum_{j \in IT-PRODUCE} \frac{\bar{w}_j}{\bar{v}_{V,j}} v_{T,j} + \sum_{j \in IT-USE} \frac{\bar{w}_j}{\bar{v}_{V,j}} v_{T,j} + \sum_{j \in OTHER} \frac{\bar{w}_j}{\bar{v}_{V,j}} v_{T,j} \quad (35)$$

This type of decomposition allows us to break the many industries into more manageable groups, but any decomposition of this type is somewhat arbitrary. Corrado *et al.* (2007), for example, present an alternative scheme, based on input–output linkages, that results in six sectors, while Bosworth and Triplett (2007) focus on the service sector. Moreover, if there are both positive and negative growth rates within a group, this type of summation over industries necessarily obscures the underlying contribution of individual industries.[8] Nonetheless, this is a useful way to present and analyze the data from industry-level production accounts.

3. Empirical Results

This section reports estimates of output growth and the sources of growth for the US economy. We begin with estimates from the production possibility frontier, constructed from industry data. We then compare results from the production possibility frontier to the aggregate production function and direct aggregation across industries by quantifying the reallocation terms. Finally, we examine the contributions of individual industries and groups of industries to US economic growth and its sources. We reiterate that these estimates are obtained by alternative aggregation techniques, using the same underlying industry source data. Note that these data differ from those reported by Jorgenson *et al.* (2005), which reflect an earlier vintage of the US national accounts, a shorter time period, and a less detailed classification of industries.

3.1. Estimates of the Production Possibility Frontier

Table 1 presents estimates of the sources of growth for the US economy from the production possibility frontier. The first line gives the growth rate of aggregate value added, followed by the contribution of IT-producing, IT-using, and Non-IT industries, as in equation (34). We decompose the aggregate estimates into the specific contributions of individual industries, allowing us to trace economic growth to its industry origins. The remainder of Table 1 presents the familiar aggregate decomposition of the contributions of capital, labor, and total factor productivity (TFP), as in equation (25), while Table 2 presents the average growth rates and shares used to calculate the contributions. All growth rates and contributions are average annual growth rates or contributions for each period.

Value-added from the production possibility frontier grew 3.22% per year for the full period 1960–2005. The decomposition into the three sets of industries from equation (34) shows that the Non-IT industries accounted for nearly two-thirds of aggregate growth. The magnitude of this contribution is not surprising because these industries account for almost three-quarters of value-added over this period. The IT-using industries, which account for almost another quarter of value-added, contributed 0.87 percentage points and the IT-producing industries, which account for the remaining 2% of

Table 1. Growth in aggregate value-added and the sources of growth. Aggregate production possibility frontier

	1960–2005	1960–1995	1995–2000	2000–2005	1995–2000 less 1960–1995	2000–2005 less 1960–1995
Value-Added	3.22	3.15	4.13	2.84	0.98	−0.31
IT-Producing Industries	0.29	0.25	0.70	0.21	0.46	−0.04
IT-Using Industries	0.87	0.86	1.20	0.66	0.35	−0.20
Non-IT Industries	2.06	2.05	2.22	1.97	0.17	−0.07
Capital Input	1.72	1.68	2.28	1.41	0.60	−0.26
IT Capital	0.49	0.38	1.11	0.65	0.72	0.27
Non-IT Capital	1.22	1.30	1.17	0.77	−0.12	−0.53
Labor Input	1.03	1.12	1.32	0.12	0.20	−1.00
College Labor	0.63	0.65	0.76	0.38	0.11	−0.27
Non-college Labor	0.39	0.46	0.56	−0.26	0.10	−0.72
Aggregate TFP	0.48	0.35	0.52	1.30	0.17	0.95

Notes: All figures are average annual percentages. The contribution of an output or input is the growth rate multiplied by the average value share. The IT-producing. IT-using, and non-IT industries are defined in the Appendix Table. IT capital input includes computer hardware, computer software, and telecommunications equipment.

Table 2. Growth and shares of aggregate variables. Aggregate production possibility frontier

	1960–2005	1960–1995	1995–2000	2000–2005	1995–2000 less 1960–1995	2000–2005 less 1960–1995
Growth Rates						
Value-Added	3.22	3.15	4.13	2.84	0.98	−0.31
IT-Producing Industries	15.85	15.87	24.25	7.33	8.38	−8.54
IT-Using Industries	3.76	3.82	4.55	2.53	0.73	−1.30
Non-IT Industries	2.75	2.69	3.14	2.78	0.45	0.09
Capital Input	4.03	3.96	5.25	3.26	1.29	−0.71
IT Capital	14.95	15.00	19.28	10.27	4.29	−4.73
Non-IT Capital	3.10	3.25	3.12	2.06	−0.13	−1.19
Labor Input	1.80	1.95	2.34	0.23	0.39	−1.73
College Labor	3.87	4.32	3.17	1.44	−1.15	−2.88
Non-college Labor	0.98	1.13	1.72	−0.81	0.59	−1.94
Shares						
Value-Added	100.0	100.0	100.0	100.0	0.0	0.0
IT-Producing Industries	1.8	1.5	2.9	2.9	1.4	1.4
IT-Using Industries	23.5	22.7	26.3	26.2	3.6	3.5
Non-IT Industries	74.7	75.8	70.7	70.9	−5.0	−4.9
Capital Input	42.6	42.3	43.4	43.5	1.1	1.2
IT Capital	3.4	2.6	5.7	6.3	3.1	3.7
Non-IT Capital	39.2	39.2	37.7	37.2	−2.0	−2.5
Labor Input	57.4	57.4	56.6	56.5	−1.1	−1.2
College Labor	17.8	15.8	23.9	26.1	8.2	10.4
Non-college Labor	39.6	41.9	32.6	30.4	−9.3	−11.6

Notes: Growth rates are average annual percentages. Shares are the mean two-period average for each period in percentages.

value-added, contributed an additional 0.29 percentage points. Despite their small size, the rapid growth of the IT-producing industries enabled these industries to make a sizable contribution to US economic growth.

The productivity revival in 1995–2000 highlights the disproportionate contribution of the IT-producing industries. These four industries accounted for only 3% of value-added during 1995–2000, yet they contributed almost half the growth increase in the penultimate column of Table 1 (0.46 out of the 0.98 percentage point increase). In contrast, the Non-IT industries accounted for more than 70% of value-added, but contributed less than a fifth of the post-1995 gain in value-added growth (0.17 of 0.98). The IT-using industries contributed the remaining 35% (0.35 of 0.98). The final column of Table 1 shows a decline of 0.31% in the growth rate of value added during 2000–2005, relative to 1960–1995. The IT-using industries contributed the most to the decline, 0.20 percentage points, followed by the Non-IT and IT-producing industries.

The standard decomposition of the sources of growth between primary inputs and TFP (equation (25)) shows that capital input dominates the sources of growth for the period 1960–2005 with a contribution of 1.72 percentage points out of the total of 3.22%. Labor input contributed 1.03 percentage points and aggregate TFP contributed the remaining 0.48 percentage points. Thus, capital and labor inputs account for a great preponderance of US economic growth since 1960. Two important features of the TFP contribution are the increase after 1995 and, especially, the remarkable surge after 2000. The contribution of TFP was 0.52 percentage points for 1995–2000 and 1.30 after 2000, compared to 0.35 during the period 1960–1995.

A further decomposition of capital and labor inputs into their components shows that Non-IT capital has been the most important source of growth for the full period, but IT capital has made a significant contribution for the recent periods 1995–2000 and 2000–2005. Given the relatively small share of IT capital, only 6.3% of value-added from 2000–2005, these contributions indicate the importance of IT. College-educated labor has been the most important source of labor input growth for all three sub-periods and the contribution of non-college labor actually declined after 2000. As described in greater detail by Jorgenson *et al.* (2005, Chapter 6), the increase in non-college labor contribution during 1995–2000 was due to large declines in rates of unemployment among the least educated workers.

The top panel of Table 2 presents the growth rates of the value-added, capital, and labor sub-aggregates, while the bottom panel presents the average shares of aggregate value-added. The IT-producing industries have made a relatively large contribution to value-added growth during 1995–2000 due to the extremely rapid growth rate, 24.25% per year for the IT-producing industries for 1995–2000, by comparison with 4.55% for the IT-using industries and 3.14% for the Non-IT industries. Despite this rapid growth, the IT-producing industries have remained small in relation to the whole economy, only 2.9% of the value-added. Large declines in the relative prices of IT assets have kept nominal shares relatively small.[9] Growth in the IT-producing industries after 2000 fell to only 7.33%, contributing to the substantial slowdown, while IT-using industries grew at 2.53%, and Non-IT industries at 2.78%.

Table 3. Decomposition of aggregate labor productivity. Aggregate production possibility frontier

	1960–2005	1960–1995	1995–2000	2000–2005	1995–2000 less 1960–1995	2000–2005 less 1960–1995
Growth Rates						
Aggregate Value-Added	3.22	3.15	4.13	2.84	0.98	−0.31
Average Labor Productivity	1.90	1.68	2.11	3.17	0.43	1.49
Hours	1.33	1.47	2.01	−0.33	0.54	−1.80
Contributions						
Average Labor Productivity	1.90	1.68	2.11	3.17	0.43	1.49
Capital Deepending	1.15	1.05	1.40	1.55	0.35	0.50
IT Capital	0.45	0.34	0.99	0.67	0.65	0.33
Non-IT Capital	0.70	0.71	0.41	0.88	−0.30	0.17
Labor Quality	0.27	0.28	0.19	0.32	−0.09	0.04
College Labor Quality	−0.01	−0.02	−0.01	0.01	0.00	0.03
Non-College Labor Quality	0.11	0.12	0.06	0.08	−0.05	−0.03
Reallocation of Hours	0.18	0.18	0.14	0.22	−0.04	0.04
Aggregate TFP	0.48	0.35	0.52	1.30	0.17	0.95

Notes: All figures are average annual percentages. The contribution if an output or input is the growth rage multiplied by the average value share. IT capital includes computer hardware, computer software, and telecommunications equipment.

Table 3 presents the decomposition of labor productivity shown in equation (26). The growth rate of value-added is the sum of growth rates of labor productivity and hours worked. As in other research on aggregate productivity, our calculations show a substantial acceleration of labor productivity from 1.68% for 1960–1995 to 2.11% during 1995–2000. Labor productivity growth accelerated again after 2000, rising to 3.17%. By contrast, growth in hours worked declined substantially after 2000. The bottom panel shows the sources of the two labor productivity accelerations. We see a jump in the contribution of capital deepening of 0.35 percentage points and a gain in TFP growth of 0.17 percentage points after 1995. Relative to 1960–1995, capital deepening increased by 0.50 percentage points after 2000, while TFP growth soared by 0.95 percentage points. Labor quality made a smaller contribution after 1995 and was thus a drag on the acceleration of labor productivity, but revived after 2000.

There is substantial variation across types of inputs within the capital deepening and labor quality contributions. IT-capital deepening, for example, showed a huge increase during 1995–2000, but receded to a more moderate level after 2000. Non-IT-capital deepening actually made a smaller contribution in 1995–2000, but revived after 2000. Firms clearly responded to the incentives provided by falling IT prices and altered their investment patterns by substituting toward IT capital after 1995. We note that while IT capital deepening slowed after 2000 when compared with the boom of the late 1990s, it remains considerably larger than during 1960–1995.

While the contribution of labor quality in equation (20) declined after 1995, college labor quality was flat, while non-college labor quality and the reallocation of hours declined. The trends in college and non-college labor quality continued after 2000, but reallocation of hours reversed course, raising its contribution to labor quality. These trends suggest significant substitution both within and between our categories of college-educated and non-college-educated workers. The hours of high-wage workers in each category were growing most rapidly, as reflected in the growth in labor quality. The ongoing reallocation of hours toward more highly compensated college-educated workers contributed to labor quality growth in all three sub-periods.

3.2. Alternative Aggregation Methods and Reallocations

We now examine the alternative estimates generated by the aggregate production function and direct aggregation across industries, and compare them to the production possibility frontier. As outlined above, the aggregate production function is the most restrictive of the approaches, while direct aggregation across industries is the least. Reallocation terms quantify the impact of the restrictions and show how much their violation distorts the picture of aggregate economic growth and its sources. We begin with the comparison of value-added growth in the aggregate possibility frontier and the aggregate production function in equation (32) and report estimates in the top panel of Table 4. The reallocation of value-added is the difference between these two approaches, and quantifies the failure of the assumption that all industries face the same value-added price.

The results show the essential similarity of the two approaches for the full period 1960–2005, when value-added growth from the production possibility frontier was 3.22% per year compared with 3.36% for the aggregate production function. The reallocation of value-added was 0.14 percentage points. There are quite large differences, however, for the three sub-periods with value-added from the aggregate production function growing

Table 4. Aggregate reallocation effects

	1960–2005	1960–1995	1995–2000	2000–2005	1995–2000 less 1960–1995	2000–2005 less 1960–1995
Aggregate Production Possibility Frontier vs. Aggregate Production Function						
Aggregate Production Function Value-Added	3.36	2.87	5.02	5.15	2.15	2.28
Aggregate Production Possibility Frontier Value-Added	3.22	3.15	4.13	2.84	0.98	−0.31
Reallocation of Value-Added	0.14	−0.28	0.89	2.31	1.17	2.59
Aggregate Production Possibility Frontier vs. Direct Aggregation Across Industries						
Aggregate TFP	0.48	0.35	0.52	1.30	0.17	0.95
Domar-Weighted Productivity	0.57	0.43	0.70	1.38	0.27	0.95
IT-Producing Industries	0.20	0.17	0.43	0.22	0.26	0.05
IT-Using Industries	0.07	0.03	−0.10	0.50	−0.13	0.46
Non-IT Industries	0.29	0.23	0.37	0.66	0.15	0.43
Reallocation of Capital Input	−0.06	−0.07	−0.14	0.06	−0.07	0.13
Reallocation of Labor Input	−0.02	−0.01	−0.04	−0.14	−0.03	−0.13

Notes: All figures are average annual percentages. The contribution of an output or input is the growth rage multiplied by the average value share.

slower for the period 1960–1995 and considerably faster for the periods 1995–2000 and 2000–2005. Growth in value-added from the aggregate production function has averaged 5.02% per year for the period 1995–2000, compared with only 4.13% for the production possibility frontier, leaving a large reallocation of value-added of 0.89%. Growth in value-added from the aggregate production function increased further to 5.15% for the period 2000–2005, compared with 2.84% for the production possibility frontier with an even larger reallocation of value-added of 2.31 percentage points. This indicates that the aggregate production function is appropriate for long time periods, but is highly inappropriate for shorter periods, a result that echoes Jorgenson (1990) and Jorgenson et *al.* (2005).

The substantial reallocation of value-added in recent years highlights a major violation of the assumption that underlies the aggregate production function, namely, that the price of value-added is the same for all industries. For the most recent period since 1995, the positive reallocation terms indicate that industries with declining relative prices were growing the fastest, as consumers and firms responded to changing price signals and altered their investment and consumption decisions. After 1995, many of the high-tech industries saw declining relative prices and rapid growth, which contributed to the large, positive reallocation terms.

The bottom panel of Table 4 compares the production possibility frontier to the direct aggregation across industries. We decompose aggregate TFP growth among the Domar-weighted TFP growth rates of the component industries and the reallocations of capital and labor. These input reallocations reflect deviations from the assumption that each type of capital and labor input faces the same price in all industries. We also report the decomposition of Domar-weighted productivity of industries into the IT-producing, IT-using, and Non-IT industries in equation (35).

Our main finding is that aggregate TFP growth primarily reflects TFP growth in the underlying industries. For the full period 1960–2005, for example, growth in TFP from the production possibility frontier grew 0.48% per year, while the Domar-weighted contributions of TFP growth in the underlying 85 industries totaled 0.57%. Reallocations accounted for −0.09%. The reallocations are similar in magnitude for the three sub-periods. This implies that the production possibility frontier is a reasonable approximation of the industry data, even for short time periods. Some reallocation effects, however, are non-negligible. Capital grew relatively rapidly in industries with high capital service prices in 2000–2005, so that the reallocation of capital is positive, while labor grew relatively slowly in industries with high labor input prices so the reallocation of labor is negative in all periods. Similar patterns of substitution were apparent in Jorgenson *et al.* (1987, Table 9.5), who reported reallocations of capital that were typically positive and reallocations of labor that were typically negative for the 1948–1979 period.

The breakdown of Domar-weighted TFP growth into the sets of IT-producing, IT-using, and Non-IT industries highlights the critical role of accelerating TFP growth in the high-tech industries. The four IT-producing industries, for example, accounted for nearly all of the acceleration of aggregate TFP in 1995–2000, but produced only 3% of aggregate value-added. The contribution of these industries to the much greater acceleration in 2000–2005 relative to 1960–1995 was far smaller, however, as IT-using and Non-IT industries made larger positive contributions. The IT-using industries made a negative contribution to aggregate TFP growth in 1995–2000, before reversing their course and contributing almost half of the aggregate acceleration in 2000–2005. The Non-IT industries showed a continuous acceleration, from a net contribution of 0.23% for 1960–1995 to 0.37% for 1995–2000 and 0.66% for 2000–2005. These support the findings of Jorgenson *et al.* (2005, Chapter 7), showing the broad-based character of the US productivity revival. After 2000, however, the dominant sources have changed with the IT-producing industries becoming less important.[10]

3.3. Industry Contributions

We now turn to the direct contributions from each of the 85 industries that comprise the US economy. Rather than examine the wealth of information from the detailed growth accounts of each of these industries, we focus here on the industry contributions to aggregate value-added ($CT_{VA,j}$) and to aggregate TFP ($CT_{TFP,j}$), as defined in equation (30). Recall that aggregate value-added growth from the production possibility frontier equally reflects the weighted growth of industry value-added and the sum of the appropriately weighted growth of industry capital, labor, and TFP, so it is useful to identify which industries contributed to aggregate value-added growth and which industries held back aggregate growth.

Figure 1 ranks the industries by their contribution to value-added growth for the period 1960–2005. The industries that make the largest contributions are Private Households, Wholesale Trade, and Real Estate. These large contributions reflect both relatively strong growth rates and also large value-added shares. These three industries, for example, accounted for nearly one-quarter of value-added over this period, with Households by far the largest single industry with a 13.6% share over the full period. In comparison, the value-added weight for Computers and Office Equipment of 0.3% and Electronic Components of 0.5% are quite small. Even though these IT-producing industries experienced extraordinary growth, the relatively small shares have prevented these industries

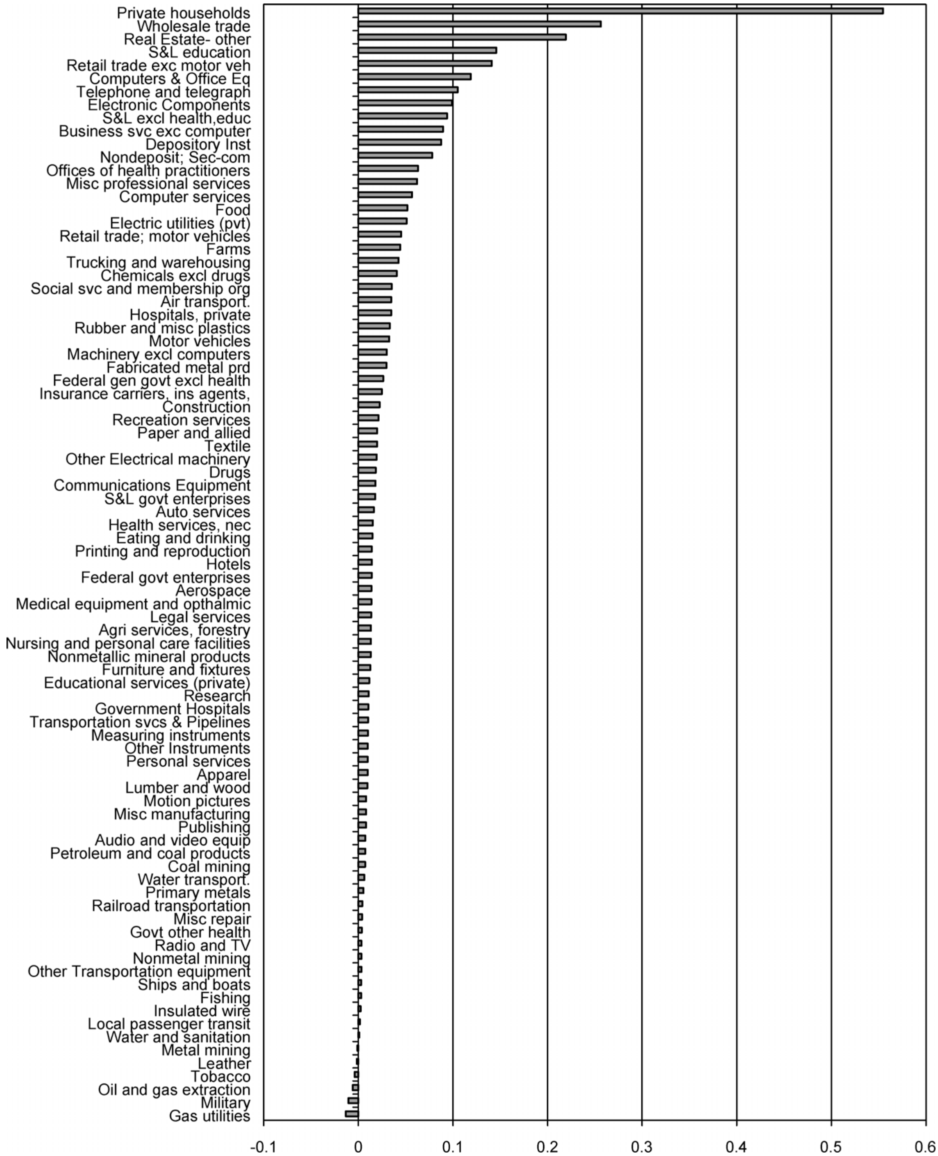

Figure 1. Industry contributions to value-added growth, 1960–2005

from making large contributions to aggregate value-added growth. Other private industries like Gas Utilities, Oil and Gas Extraction, and Tobacco make negative contributions.

Figure 2 provides a similar ranking, but for the contribution to aggregate TFP growth. These results contrast sharply with those for value-added. As discussed earlier, the IT-producing industries, particularly Computers and Office Equipment and Electronic Components, show extremely rapid growth and have made important contributions to the aggregate. Computers and Office Equipment leads all industries with a contribution of 0.11%, while Electronic Components added 0.08. Other leading industries include

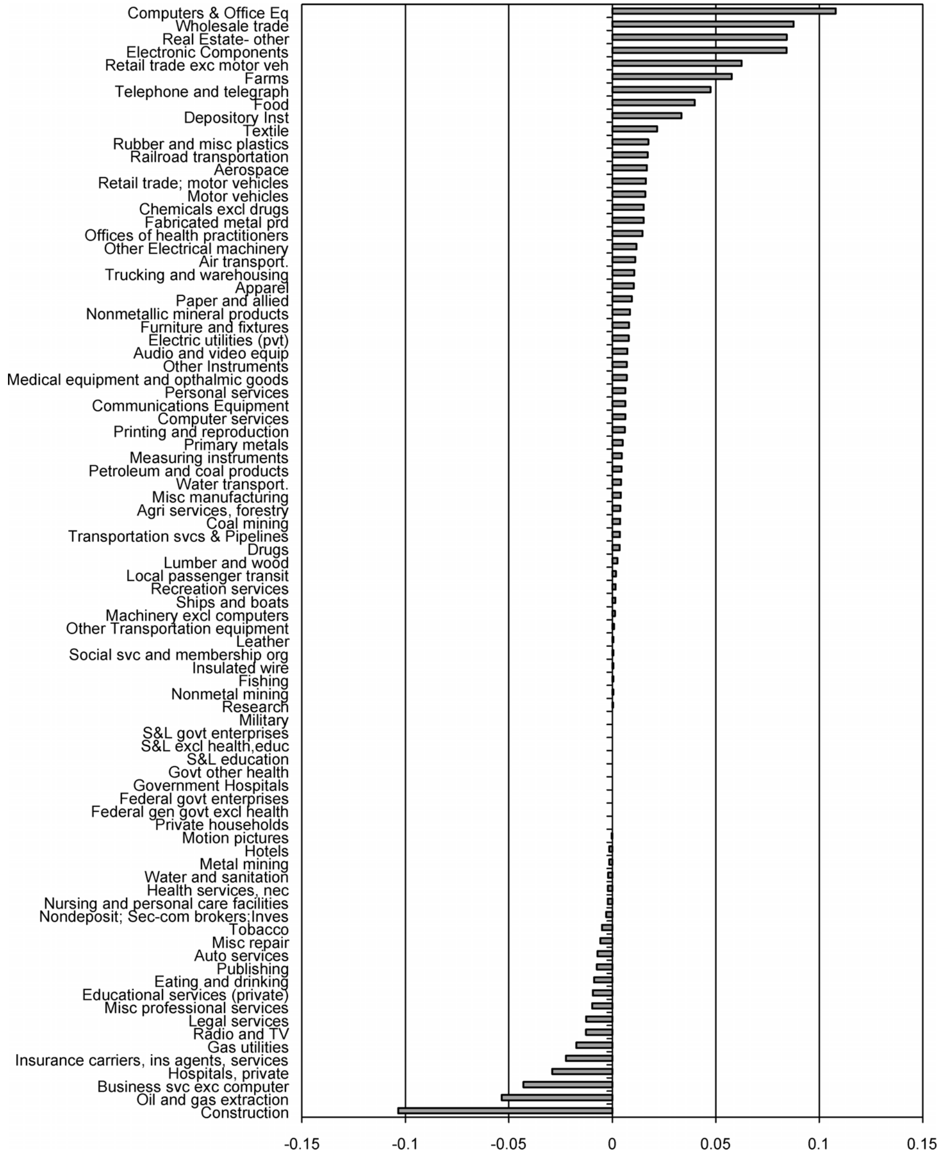

Figure 2. Industry contributions to total factor productivity growth, 1960–2005

Wholesale Trade, Real Estate, and Retail Trade. Our data show that many industries (22 out of 76 for which we measure TFP growth) have negative TFP growth for the period 1960–2005.[11] In particular, Construction, Oil and Gas Extraction, Business Services, Hospitals, and Insurance all make large negative contributions that reduce the growth of aggregate TFP.

This brief look at the production data for individual industries reveals enormous heterogeneity. In particular, we show that industry-level total factor productivity growth can be either negative or positive and one must properly account for both when tracing the origins of aggregate growth to individual industries.

4. Conclusions

This completes our analysis of the industry origins of US economic growth. We have aggregated estimates of value-added, capital and labor inputs, and total factor productivity across industries to provide a new perspective on critical growth trends in the US economy. We have shown how fundamental changes in technology, production processes, and input decisions across industries contribute to changes in growth for the economy as a whole. Comparison of the three alternative aggregation schemes provides insight into the appropriateness of the assumptions underlying each framework. This also facilitates in understanding the conflicting results obtained by the alternative aggregation techniques.

Our first conclusion is that the production possibility frontier provides a close approximation to the underlying TFP growth derived from the industry-level data, i.e. aggregate TFP growth is a good estimate of the Domar-weighted sum of TFP growth rates from the underlying industry data. The relatively small values of the capital and labor reallocation terms (Table 4) imply that the assumptions of input mobility and equal input prices across all industries are not grossly violated. This is reasonable in a well-functioning and relatively efficient economy like the US and shows that the production possibility frontier is an appropriate aggregation methodology.

Our second conclusion is that the picture of the US economy based on the aggregate production function is extremely misleading. Our estimates show a wide divergence between the estimates of aggregate value-added growth derived from the production possibility frontier and the aggregate production function, particularly for short periods of time. The assumption of equal value-added prices necessary for the aggregate production function is highly inappropriate and can lead to a greatly distorted view of economic performance.

A third conclusion is that vast heterogeneity exists beneath the aggregate data where a few leading industries dominate the growth of output and productivity over extended periods of time. The role of the leading industries, however, can shift dramatically: the TFP boom of 1995–2000 was generated by the IT-producing industries, while IT-using industries, many of them in services, came to the fore in the aftermath of the dot-com crash of 2000. These dramatic changes can be captured only through aggregation over data for individual industries using the production possibility frontier.

As a result, analysis of data for aggregates, even if carried out appropriately, has significant limitations. Most important, the aggregate data obscure the enormous variation in performance across US industries. Industries like Computers and Office Equipment and Electronic Components have shown truly remarkable growth in total factor productivity over extended periods of time. This reflects highly distinctive production processes, spectacular rates of technological innovation, and rapidly evolving market conditions, all of which have led to dramatic differences in productivity outcomes. Moreover, heterogeneity of performance within classes of industries, such as the IT-producing, IT-using, and Non-IT industry groups we have employed, implies that even these summary numbers provide an incomplete picture. In a dynamic economy like the US, where industries make both positive and negative contributions to output and productivity growth, attribution of economic growth to industry groups can conceal important variations at the level of individual industries.

Our final conclusion, then, is that one must also examine the full range of industry-level data, like that presented in Figures 1 and 2, to understand the origins of US productivity growth. Aggregate data are more tractable, are available on a timelier basis than industry data, and provide a reasonable approximation to underlying industry trends over lengthy periods of time. However, these data conceal striking variations among industries and prevent analysts from tracing the evolution of productivity to its industry sources. It is only at the industry level that production analysts can seek to understand the specific changes in technology, business practices, and input choices that firms make in response to changing economic incentives and opportunities. We conclude that it is more fruitful to examine the full range of contributions across industries and to analyze the evolving sources of growth at the industry level.

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Notes

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[2]See Bosworth and Triplett (2007) for a more detailed discussion of the role of services in the US, and Inklaar *et al.* (2007) for a comparison with Europe.

[3]We discuss this in detail because there has been some confusion about the specifics of our aggregation procedures. Hercowitz (1998), for example, misreads Jorgenson's (1966) production possibility frontier as representing output as a simple sum of the outputs of consumption and investment goods, as in the aggregate production function.

[4]See Fisher (1993) for additional details.

[5]See Denny (1972) and Hall (1973).

[6]This method is similar to Domar (1961), except that Domar assumes factor immobility across industries.

[7]Note that if we used capital stocks rather than capital services, there would be no $REALL_K$ term because a given asset has the same price across all industries by construction. This implies that simple sums and translog indexes across industries are identical. Service prices for each asset, however, do differ across industries due to differences in rates of returns and taxes, so the term $REALL_K$ is non-zero.

[8]This point has been made by Stiroh (2002), Triplett and Bosworth (2004), and Jorgenson *et al.* (2005).

[9]The product of the average growth rate and the average shares does not equal the average contribution given in Table 1, which is calculated as the average of the product of the growth rates and shares. The growth of value-added for each set of industries is the growth of the translog index for the component industries.

[10]Stiroh and Botsch (2007) provide evidence that the link between IT and labor productivity growth weakened after 2000, while Oliner *et al.* (2007) document evolving sources of growth in an extended framework that includes intangibles.

[11]As discussed in Jorgenson *et al.* (2005, Chapter 6), we cannot estimate TFP growth for Private Households and the Government sectors.

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Appendix

Appendix. Classification of industries by IT share

Industry	IT Share of Capital (1995)(%)	Classification
1 Farms	0.7	Non-IT
2 Agri services, forestry	2.5	Non-IT
3 Fishing	2.1	Non-IT
4 Metal mining	5.7	Non-IT
5 Nonmetal mining	3.1	Non-IT
6 Coal mining	3.5	Non-IT
7 Oil and gas extraction	2.9	Non-IT
8 Construction	6.8	Non-IT
9 Lumber and wood	3.7	Non-IT
10 Furniture and fixtures	8.2	Non-IT
11 Nonmetallic mineral products	5.4	Non-IT
12 Primary metals	4.3	Non-IT
13 Fabricated metal prd	7.0	Non-IT
14 Machinery excl computers	19.8	IT-Using
15 Computer & Office Eq	19.8	IT-Producing
16 Insulated wire	15.5	IT-Using
17 Audio and video equip	15.5	IT-Using
18.Other Electrical machinery	15.5	IT-Using
19 Communications Equipment	15.5	IT-Producing
20 Electronic Components	15.5	IT-Producing
21 Motor vehicles	4.5	Non-IT
22 Aerospace	17.6	IT-Using
23 Ships and boats	15.1	IT-Using
24 Other Transportation equipment	17.6	IT-Using
25 Measuring instruments	45.3	IT-Using
26 Medical equipment and opthaln	45.3	IT-Using
27 Other Instruments	45.3	IT-Using
28 Misc manufacturing	6.9	Non-IT
29 Food	4.4	Non-IT
30 Tobacco	4.7	Non-IT
31.Textile	9.6	Non-IT
32 Apparel	8.5	Non-IT
33 Leather	3.7	Non-IT
34 Paper and allied	4.3	Non-IT
35 Publishing	26.7	IT-Using
36 Printing and reproduction	26.7	IT-Using
37 Chemicals excl drugs	6.1	Non-IT
38 Drugs	6.1	Non-IT
39 Petroleum and coal products	3.0	Non-IT
40 Rubber and misc plastics	7.5	Non-IT
41 Railroad transportation	9.0	Non-IT
42 Local passenger transit	8.6	Non-IT
43 Trucking and warehousing	8.5	Non-IT
44 Water transport	5.3	Non-IT
45 Air transport	18.0	IT-Using
46 Transportation svcs & Pipelines	26.2	IT-Using

(*Table continued*)

Appendix. Continued

Industry	IT Share of Capital (1995)(%)	Classification
47 Telephone and telegraph	60.8	IT-Using
48 Radio and TV	40.5	IT-Using
49 Electric utilities (pvt)	5.6	Non-IT
50 Gas utilities	19.1	IT-Using
51 Water and sanitation	6.3	Non-IT
52 Wholesale trade	34.2	IT-Using
53 Retail trade exc motor veh	10.2	Non-IT
54 Retail trade; motor vehicles	10.2	Non-IT
55 Eating and drinking	10.2	Non-IT
56 Depository Inst	12.0	Non-IT
57 Nondeposit; Sec-com brokers;	27.1	IT-Using
58 Insurance carriers, ins agents,	26.5	IT-Using
59 Real Estate- other	3.9	Non-IT
60 Hotels	4.7	Non-IT
61 Personal services	8.4	Non-IT
62 Business svc exc computer	39.0	IT-Using
63 Computer services	39.0	IT-Producing
64 Auto services	2.8	Non-IT
65 Misc repair	20.1	IT-Using
66 Motion pictures	29.6	IT-Using
67 Recreation services	5.5	Non-IT
68 Office of health practitioners	8.4	Non-IT
69 Nursing and personal care facili	8.4	Non-IT
70 Hospitals, private	8.4	Non-IT
71 Health services, nec	8.4	Non-IT
72 Legal services	29.7	IT-Using
73 Educational services (private)	18.6	IT-Using
74 Social svc and membership org	35.1	IT-Using
75 Research	35.1	IT-Using
76 Misc professional services	35.1	IT-Using
77 Private households	6.5	Non-IT
78 Federal gen govt excl health	10.5	Non-IT
79 Federal govt enterprises	10.5	Non-IT
80 Government Hospitals	10.5	Non-IT
81 Govt other health	10.5	Non-IT
82 S&L education	10.5	Non-IT
83 S&L excl health, educ	10.5	Non-IT
84 S&L govt enterprises	10.5	Non-IT
85 Military	10.5	Non-IT