

U.S. Economic Growth at the Industry Level

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The U.S. economy has expanded rapidly in recent years with total factor productivity – the source of growth most closely identified with technological gains – rising sharply since the mid-1990s.¹ This strong aggregate performance and the well-documented explosion of investment in computers and other high-tech equipment have led many to believe that the U.S. has experienced a permanent, technology-led growth revival. It is essential, however, to disaggregate estimates of economic growth to the industry level to understand the new trends in the U.S. economy.

Productivity growth – the ability to produce more outputs from the same inputs – differs widely among industries. For the economy as a whole, negative productivity growth in one industry can offset positive productivity growth in another and Jorgenson (1990) shows a measure of productivity based solely on aggregate data is valid only under very stringent conditions. We avoid the limitations of an aggregate measure of productivity by decomposing U.S. growth across industries for the period 1958 to 1996. By breaking down the U.S. economy into 37 industries (35 private industries, Private Households, and General Government), we identify the contribution of each industry to aggregate productivity growth. This enables us to isolate the underlying sources of gains in productivity and provides a better understanding of the forces driving the U.S. economy.

Economy-wide productivity from an aggregate production function increased 0.45 percent per year for 1958-96, while methodology developed by Evsey Domar (1961) for aggregating over industries yields an aggregate estimate of 0.48 percent. Over the same period, however, industry productivity growth ranged from 1.98 percent in Electronic and Electric Equipment to –0.52 percent in Government Enterprises, highlighting fundamental differences in technology and productivity growth across industries. These results show the aggregate production function provides a reasonable estimate of productivity trends over long periods, but also masks important differences among industries.

I. Sources of Economic Growth at the Industry Level

This section summarizes the methods developed by Jorgenson, Frank Gollop and Barbara Fraumeni (1987) for allocating the sources of economic growth to the industry level. The first component consists of a

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production function for each industry with output expressed as a function of capital, labor, energy, and materials inputs and the level of technology. The second is the Domar methodology for aggregating over industries to obtain an aggregate measure of productivity.

(a) Methodology

The production function for the i th industry gives the quantity of output, say Y_i , as a function of the primary inputs, capital services, K_i , and labor services, L_i , and the intermediate inputs, energy, E_i , and materials, M_i , and the level of technology, t :

$$(1) \quad Y_i = f_i(K_i, L_i, E_i, M_i, t) \quad i = 1 \dots 37$$

where all inputs are measured as service flows rather than stocks.

The 37 industries included in our study are listed in Table 1. Under the assumptions of constant returns to scale and the exhaustion of the value of output by the value of the inputs, the growth accounting equation for each sector is:

$$(2) \quad d \ln A_i = d \ln Y_i - \alpha_{K_i} d \ln K_i - \alpha_{L_i} d \ln L_i - \alpha_{E_i} d \ln E_i - \alpha_{M_i} d \ln M_i$$

where α is the average share of the subscripted input in the i th sector and A_i is industry productivity.

An aggregate production function gives GDP as a function of aggregate capital and labor inputs, so that intermediate inputs – goods produced by one sector and sold to another – are excluded. The aggregate growth accounting equation is:

$$(3) \quad d \ln A = d \ln V - \alpha_K d \ln K - (1 - \alpha_K) d \ln L$$

where V is real, aggregate value-added, K is capital services, L is labor input, α_K is the average share of capital in value-added, and A is an index of total factor productivity (TFP). We reserve the TFP term to refer to productivity estimated from the value-added concept of output.

The conceptual distinction between industry and aggregate productivity indexes has long been recognized. Domar (1961) developed an internally consistent link by expressing the rate of aggregate TFP growth as a weighted average of industry productivity growth rates, with weights equal to the ratios of industry gross output to aggregate value-added:

$$(4) \quad d \ln A = \sum_{i=1}^{37} w_i \cdot d \ln A_i, \quad w_i = \frac{P_i \cdot Y_i}{P \cdot V}$$

where w_i is the Domar weight, $P_i Y_i$ is gross output in sector i , and $P V$ is aggregate value-added in current dollars. Note the weights do not sum to unity since both intermediate inputs and primary inputs appear in the industry production functions, while only primary inputs are in the aggregate production function. Jorgenson, Gollop, and Fraumeni (1987), particularly Chapter 2, provide details and earlier references.

¹See, for example, BLS (1999), William Gullickson and Michael J. Harper (1999), Mun S. Ho, Dale W. Jorgenson, and Kevin J. Stiroh (1999), and Daniel E. Sichel (1999).

Equations (1) and (2) define industry-level productivity in terms of industry gross output rather than value-added. This has a crucial advantage in providing an explicit role for intermediate goods in allocating economic growth at the industry level. For example, intermediate goods such as semi-conductors are indispensable to the production of computers and other high-tech equipment. By identifying these intermediate inputs explicitly, we can allocate the economic growth from investment in computers between the production of semi-conductors and the production of computers.

Aggregating over industries has several additional advantages. First, it avoids imposing the stringent conditions needed for existence of an aggregate production function. Second, Jorgenson, Gollop and Fraumeni (1987, Chapter 7) show the separability required by the value-added production function is not consistent with the empirical evidence, although value-added remains a common measure of output in industry-level productivity studies. Finally, the sources of growth can be identified at the level of individual industries, providing a more detailed understanding of the forces driving aggregate trends.

(b) Data

Our methodology follows Jorgenson, Gollop, and Fraumeni (1987), but with industry definitions and data sources revised and brought up to date. Our data include annual time series of inter-industry transactions in current and constant prices, including final demands by commodity, and annual data on investments and labor inputs by industry.

The first building block is a set of inter-industry transactions from the Employment Projections Office at the Bureau of Labor Statistics (BLS). This includes intermediate inputs and total value-added (the sum of capital and labor inputs and taxes) for 185 industries from 1977 to 1995. We aggregate the data from the “Make” and “Use” tables to generate inter-industry transactions for 35 private business industries at approximately the two-digit Standard Industrial Classification (SIC) level. These tables provide the growth rates of industry outputs, as well as the output shares and growth rates of intermediate inputs employed in Equation (2). They also provide control totals for value-added in each industry.

We collected information from three sources to estimate prices and quantities of capital and labor inputs by industry. “Gross Product Originating,” described in Sherlene S. K. Lum and Robert E. Yuskavage (1997) from the Bureau of Economic Analysis (BEA), provides the value of capital and labor services. Investments and capital stocks by asset classes and industries are from the BEA Tangible Wealth Survey (BEA (1998), described by Arnold J. Katz and Shelby W. Herman (1997)). Mun Sing Ho, Jorgenson, and Stiroh (1999) provide details on the estimation of capital services from the Tangible Wealth Survey. Ho and Jorgenson (1999) constructed estimates of the prices and quantities of labor services across industries from the decennial Census of Population and the annual Current Population Survey. These data allow division of value-added between capital and labor services as needed to estimate labor and capital inputs in Equation (2).

We also estimate capital and labor services for the Private Household sector and the Government

sector.² For Private Households, labor income is the value of labor services in private households, while capital income reflects the imputed flow of capital services from residential housing, consumers' durables, and household land. For Government, labor income is the labor compensation of general government employees and capital income reflects the imputed flow of capital services from the stock of government capital. BEA includes a similar imputation for the flow of government capital services in the national accounts, but our methodology includes a return to capital, as well as depreciation as estimated by BEA. Note Government Enterprises are treated as a private business industry separate from General Government.

A major advantage of the BLS inter-industry data is that they provide the necessary interpolation between benchmark years. An important limitation, however, is the relatively short time frame, extending from 1977 to 1995. We have linked these data to estimates going back to 1958, described by Stiroh (1998), but we are constrained going forward since 1995 is the latest year for which the inter-industry transaction tables are currently available. 1996 estimates were extrapolated using current BLS industry output data. In addition, these data are not consistent with the latest National Income and Product Account data from the BEA Benchmark Revision in October 1999.

II. Empirical Results

We report estimates of Equations (2) and (4) for the 37 industries described above. Due to space constraints, we report results only for the full period from 1958 to 1996. Jorgenson and Stiroh (2000) provide more detailed results, including industry and aggregate growth accounts for sub-periods and links between the two, based on the Domar aggregation scheme.

(a) Industry Growth Accounting

Table 1 reports the sources of economic growth for each of the 37 industries. This corresponds to Equation (2) and shows the annual growth of industry output, the contributions of the capital, labor, energy, and materials, and productivity growth, where the contribution of an input is defined as growth rate of that input weighted by its average share in nominal output. We also provide estimates of labor productivity growth (output per hour worked) across industries for 1958-96 and the average Domar weight for the period.

The results show the importance of high-tech industries like Industrial Machinery and Equipment (SIC 35), including computer production, Electronic and Electric Equipment (SIC 36), including semiconductor production, as well as Instruments (SIC 38) and Communications (SIC 48), which grew rapidly in both output and productivity. Slowly growing sectors include Tobacco Products, Leather Products, Petroleum and Gas, and Gas Utilities, which show below average output growth and low or even negative productivity growth.

The results presented in Table 1 also highlight the wide variation among industries, posing a

²The Private Household and Government sectors include only capital and labor as inputs. Output in these sectors is defined via a Tornqvist index of capital and labor inputs, so productivity growth is zero by definition.

challenge for aggregation. The growth rate of output, for example, ranges from 5.5 percent in Electronic and Electrical Equipment to –2.1 percent in Leather Products. Similarly, productivity growth ranges from 2.0 percent in Electronic and Electrical Equipment to –0.5 percent in Government Enterprises. From one perspective, this is not surprising since these industries produce different outputs, face changing consumer and business demands, and respond differently to evolving technologies. Nonetheless, we emphasize the difficulties in interpreting aggregate TFP growth when it reflects such disparate trends within industries.

It may be somewhat more surprising that many industries – 9 of the 35 business industries – experienced negative productivity growth for a period of nearly 40 years. Some of these are declining sectors like Tobacco Products or Petroleum and Gas, but others include large, fast-growing sectors like FIRE and Services. This corresponds to similar findings by William Gullickson and Michael Harper (1999) and Carrol Corrado and Lawrence Slifman (1999), which show slow or negative productivity growth over long periods of time for some of the same industries. One can debate whether these negative productivity estimates are real or the result of unresolved measurement problems, e.g., Edward R. Dean (1999), Gullickson and Harper (1999) and Robert H. McGuckin and Stiroh (2000). However, the heterogeneity among industries reinforces our main point that the aggregate production function masks large and important differences in growth among industries. To understand the driving forces in economic growth it is essential to allocate aggregate growth to the level of individual industries.

(b) Aggregate Growth Accounting

Chart 1 displays the Domar aggregation from Equation (4). The sum across 37 industries equals 0.48 percent per year for 1958-96 and provides one estimate of aggregate TFP growth. We can compare this to the aggregate production function estimate from Equation (3) of 0.45 percent. These estimates are nearly identical, indicating the aggregate production function provides a good approximation over a long time horizon, as shown by Jorgenson, Gollop, and Fraumeni (1987) and Jorgenson (1990). The two estimates diverge over shorter time horizons, however, as reallocations of inputs and outputs across industries become relatively more important.

BLS (1999) reports TFP growth of 1.07 percent for the private business sector for 1958-96; Jorgenson and Stiroh (1999) report growth of 0.88 percent for 1948-96; and Sichel (1999) reports growth of 0.66 percent for 1970-95. The divergence of these estimates reflects coverage differences, time periods, and methodology. Our estimates, for example, include the private business economy, Private Households, and the Government, while Jorgenson and Stiroh (1999) exclude the Government. BLS (1999) and Sichel (1999) exclude both Private Households and Government, which have zero productivity growth by definition. In light of these differences the divergences among estimates are not unexpected.

Chart 1 reveals the wide range of industry contributions to TFP growth, reflecting the variation in both industry productivity growth and Domar weights. For example, the Electronic and Electric Equipment

industry experienced rapid productivity growth of 1.98 percent, while contributing 0.07 percentage points to TFP. By contrast, the Trade sector shows slower productivity growth, only 0.98 percent, but makes a much larger contribution of 0.19 percentage points, due to its larger size. Industries with negative productivity growth rates make negative contributions to economy-wide TFP growth. Services are the greatest drag on TFP growth, lowering aggregate TFP growth by -0.07.

We conclude it is inappropriate to attribute all of U.S. TFP growth to any one industry. Many industries have made important positive contributions to TFP growth, while other show negative productivity growth that pulls down the aggregate. This heterogeneity is lost in relying exclusively on the aggregate production function. To understand the full breadth and complexity of productivity growth, it is essential to examine each industry individually.

III. Conclusions

This paper presents an industry decomposition of aggregate growth for the U.S. economy from 1958 to 1996. The results show productivity growth is a complicated and heterogeneous process that is impossible to capture in a single, aggregate, measure of TFP growth. Only by looking beneath the aggregate data and examining the component industries can analysts understand the growth process. This is especially critical in evaluating the validity of explanations of economic growth that rely on developments at the level of individual industries, such as technology-led growth.

A fruitful next step will be the comparison of patterns of industry growth across countries. A crucial part of any such comparison is the implementation of a consistent methodology that correctly identifies the differences among industries and between countries. The appropriate methodology has been developed by Jorgenson, Masahiro Kuroda, and Mieko Nishimizu (1987) and employed for Japan-U.S. comparisons. However, this methodology remains to be implemented across a broad set of countries. The papers presented in this session, using a common framework to compare U.S. and Canadian growth, are a first step on this important research agenda.

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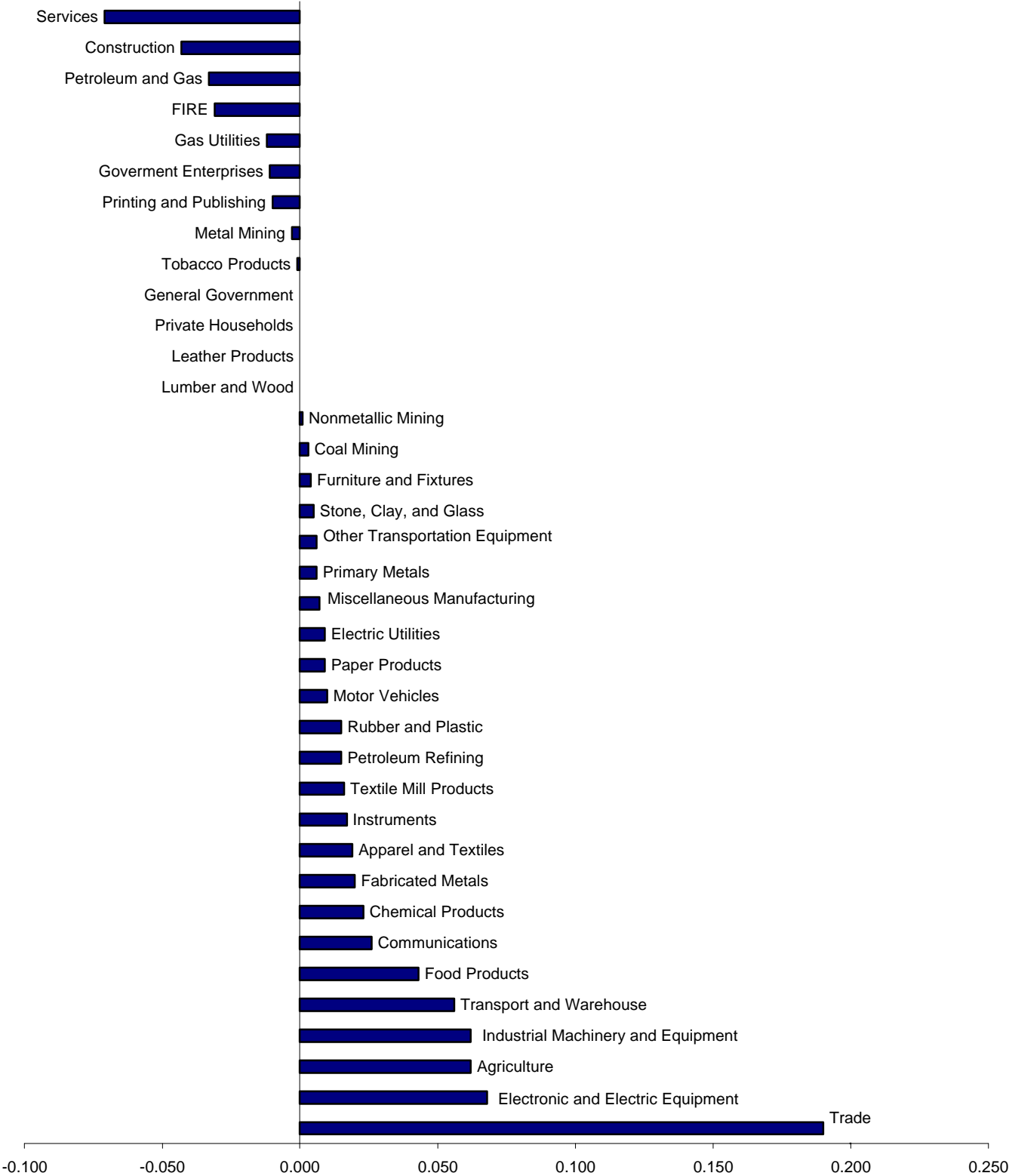
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Table 1: Sources of U.S. Economic Growth by Industry, 1958-96

Industry	Output Growth	Contributions of Inputs				Productivity Growth	ALP Growth	Domar Weight
		Capital	Labor	Energy	Materials			
Agriculture	1.701	0.189	-0.128	-0.038	0.509	1.169	3.210	0.062
Metal Mining	0.780	0.732	-0.069	-0.067	-0.256	0.440	0.994	0.003
Coal Mining	2.354	0.823	-0.005	0.065	0.633	0.837	2.319	0.005
Petroleum and Gas	0.430	0.605	-0.007	0.064	0.205	-0.437	0.885	0.022
Nonmetallic Mining	1.617	0.593	0.181	0.058	0.335	0.461	1.521	0.003
Construction	1.431	0.071	0.873	0.016	0.913	-0.442	-0.382	0.113
Food Products	2.201	0.211	0.183	0.001	1.270	0.535	1.594	0.076
Tobacco Products	0.428	0.590	0.047	0.001	-0.012	-0.200	0.881	0.004
Textile Mill Products	2.227	0.120	0.016	0.007	0.856	1.230	2.536	0.013
Apparel and Textiles	2.027	0.238	0.167	0.001	0.817	0.804	2.013	0.022
Lumber and Wood	2.241	0.213	0.333	0.019	1.697	-0.020	1.551	0.015
Furniture and Fixtures	2.909	0.308	0.580	0.019	1.441	0.562	1.785	0.007
Paper Products	2.891	0.504	0.404	0.054	1.513	0.416	1.963	0.022
Printing and Publishing	2.513	0.548	1.198	0.023	1.188	-0.445	0.145	0.024
Chemical Products	3.471	0.740	0.474	0.089	1.585	0.584	2.018	0.048
Petroleum Refining	2.211	0.443	0.237	0.492	0.712	0.327	0.796	0.033
Rubber and Plastic	5.171	0.470	1.156	0.076	2.426	1.043	1.936	0.016
Leather Products	-2.056	-0.112	-1.131	-0.023	-1.075	0.285	2.078	0.004
Stone, Clay, and Glass	1.860	0.261	0.368	0.002	0.815	0.414	1.302	0.014
Primary Metals	1.139	0.128	0.048	-0.029	0.769	0.224	1.514	0.040
Fabricated Metals	2.280	0.262	0.279	0.003	1.088	0.648	1.881	0.035
Industrial Machinery and Equipment	4.786	0.520	0.746	0.016	2.044	1.461	3.154	0.048
Electronic and Electric Equipment	5.457	0.760	0.649	0.034	2.038	1.975	4.078	0.036
Motor Vehicles	3.611	0.277	0.294	0.020	2.778	0.242	2.279	0.043
Other Transportation Equipment	1.306	0.225	0.374	0.004	0.520	0.183	0.999	0.027
Instruments	5.226	0.648	1.440	0.029	1.989	1.121	2.568	0.017
Miscellaneous Manufacturing	2.530	0.343	0.408	0.004	0.953	0.821	2.079	0.008
Transport and Warehouse	3.250	0.204	0.720	0.122	1.343	0.863	1.741	0.061
Communications	5.004	1.616	0.528	0.023	1.954	0.882	3.926	0.033
Electric Utilities	3.219	1.006	0.196	0.673	0.829	0.515	2.522	0.026
Gas Utilities	0.564	0.663	-0.045	0.136	0.050	-0.241	0.945	0.016
Trade	3.658	0.620	0.827	0.038	1.194	0.979	2.488	0.195
FIRE	3.423	1.139	0.940	-0.001	1.521	-0.176	0.664	0.131
Services	4.343	0.839	1.701	0.071	1.922	-0.190	0.920	0.208
Government Enterprises	2.863	1.241	1.084	0.225	0.830	-0.516	0.491	0.022
Private Households	3.497	3.553	-0.056	0.000	0.000	0.000	5.981	0.137
General Government	1.354	0.603	0.751	0.000	0.000	0.000	0.464	0.131

Output Growth is the average annual growth in gross output. Contributions of Inputs are defined as the average, share-weighted growth of the input. Productivity Growth is defined in Equation (2). ALP Growth is the growth in average labor productivity. Domar Weight is the average ratio of industry gross output to aggregate value added. All numbers except Domar Weights are percentages.

**Chart 1: Industry Contributions to
Aggregate Total Factor Productivity Growth, 1958-96**



Each industry's contribution is calculated as the product of industry productivity growth and the industry Domar weight, averaged for 1958-1996.