Engines of Growth in the U.S. Economy

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Abstract

There is good reason to believe that R&D influences on TFP growth in other sectors are indirect. For R&D to spill over, it must first be successful in the home sector. Indeed, observed spillovers conform better to TFP growth than to R&D in the upstream sectors. Sectoral TFP growth rates are thus interrelated. Solving the intersectoral TFP equation resolves overall TFP growth into sources of growth. The solution essentially eliminates the spillovers and amounts to a novel decomposition of TFP growth. The top 10 sectors are designated "engines of growth" led by computers and office machinery. The results are contrasted to the standard, Domar decomposition of TFP growth.

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1 Introduction

Spillovers of technical change are known to drive a wedge between private and social rates of return to research and development (R&D). What is less known, is that spillovers render total factor productivity (TFP) growth in some sectors more critical than in others. While it is true by growth accounting that we may decompose macro TFP growth into sectoral components and thus identify the progressive sectors, this procedure amounts to a neutral addition of sectoral TFP growth rates. The contribution of a sector's TFP growth is determined by the value share of the sector in the total economy, without one sector being more critical than another. The picture changes slightly, but no more than that, when we regress TFP growth on R&D in a panel of sectors. Here, too, R&D may turn out to be more influential when spent in some sectors, but the mechanics of growth accounting remain the same and TFP growth is not more critical in those sectors.

The story takes a twist when R&D influences TFP growth in other sectors not directly, but indirectly, that is, only after it has been proven successful in the sector where it has been spent. If this is the case, then spillovers interrelate sectoral TFP growth rates and we may expect multiplier effects. The multipliers will depend on the spillover relationships and these need not be equal to the structure of the material balances in the economy. Hence, TFP multiplier effects are not given by the standard multiplier matrix, the Leontief inverse.

There is good reason to believe that R&D influences on TFP growth in other sectors are indirect. For R&D to spill over, it must first be successful in the home sector. Indeed, observed spillovers conform better to TFP growth than to R&D in the upstream sectors, as noted in Wolff (1997). Hence it is of utmost interest to determine which sectors transmit technical change more strongly. These sectors are the engines of growth. Engines of growth need not feature high R&D, but once they move in terms of own TFP growth, they push the entire economy.

The interdependence of sectoral TFP growth rates is given by a system of equations that account for the spillover effects. In this paper we solve the spillover equations for TFP growth rates. The reduced form of the TFP growth rates shows their dependence on sectoral R&D expenditures and the coefficients measure total returns to R&D, including the spillover effects. Observed sectoral TFP growth rates are thus ascribed to sources of growth.

Direct sectoral decompositions of TFP growth impute little to automation. As Bob Solow noticed: "You can see the Computer Age everywhere but in the productivity statistics." Our solution of the spillover structure will reveal computers as a primary engine of growth.

In the next section we review some of the literature. In section 3 we present the general equilibrium analysis of TFP spillovers. We decompose TFP growth not only by sectoral TFP growth in an accounting fashion, but also by sources of growth. We do so by solving the TFP equation for its multiplier structure. Engines of growth are defined formally. Then, in section 4, we describe the data set we use. Results for the U.S. economy are presented in section 5 and section 6 concludes.

2 Review of the Literature

R&D spillovers refer to the direct knowledge gains of customers from the R&D of the supplying industry (see Griliches, 1979). There have been several approaches to measuring R&D spillovers. Brown and Conrad (1967) base their measure of borrowed R&D on input-output trade flows (both purchases and sales) between industries. Terleckyj (1974, 1980) and Goto and Suzuki (1989) provided measures of the amount of R&D embodied in customer inputs on the basis of interindustry material and capital purchases made by one industry from supplying industries. Scherer (1982), relying on Federal Trade Commission line of business data, used product (in contradistinction to process) R&D, aimed at improving output quality, as a measure of R&D spillovers.

Another approach is to measure the "technological closeness" between industries, even if they are not directly connected by interindustry flows. For example, if two industries use similar processes (even though their products are very different or they are not directly connected by interindustry flows), one industry may benefit from new discoveries by the other industry. Such an approach is found in Jaffe (1986) who used patent data to measure technological closeness between industries. The patent approach to spillovers has been continued by Everson and Johnson (1977), Kortum and Putnam (1997), Verspagen (1997) and Los and Verspagen (2000).

Bernstein and Nadiri (1989) use as a measure of intra-industry R&D spillovers total R&D at the two-digit SIC level and apply this measure to individual firm data within the industry. Mairesse and Mohnen (1990) report similar results by comparing R&D

coefficients based on firm R&D with those based on industry R&D. If there are intra-industry externality effects of firm R&D, then the coefficients of industry R&D should be higher than those of firm R&D. However, their results do not show that this is consistently the case. (Also, see Mohnen, 1992, and Griliches, 1992, for reviews of the literature.)

A different approach was followed by Wolff and Nadiri (1993), who used as their measure of embodied technical change a weighted average of the TFP growth of supplying industries, where the weights are given by the input-output coefficients of an industry. This formulation assumed that the knowledge gained from a supplying industry is in direct proportion to the importance of that industry in a sector's input structure. Wolff (1997) updated these earlier results using U.S. input-output data for the period 1958 to 1987, and found strong evidence that industry TFP growth is significantly related to the TFP performance of supplying sectors, with an elasticity of almost 60 percent. The results also indicated that direct productivity spillovers were more important than spillovers from the R&D performed by suppliers.

A substantial number of studies, perhaps inspired by Solow's quip, have also examined the linkage between computerization or Information Technology (IT) in general and productivity gains. The evidence is mixed. Most of the earlier studies failed to find any excess returns to IT, over and above the fact that these investments are normally in the form of equipment investment. These include Bailey and Gordon (1988), who examined aggregate productivity growth in the U.S. and found no significant contribution of computerization; Loveman (1988), who reported no productivity gains from IT investment; Parsons, Gotlieb, and Denny (1993), who estimated very low returns on computer investments in Canadian banks; and Berndt and Morrison (1995), who found negative correlations between labor productivity growth and high-tech capital investment in U.S. manufacturing industries. One of the few exceptions in these earlier studies is Bresnahan (1986), who did estimate positive and significant spillovers from mainframe computers in financial services.

The later studies generally tend to be more positive. Both Siegel and Griliches (1992) and Steindel (1992) estimated a positive and significant relationship between computer investment and industry-level productivity growth. Lau and Tokutso (1992) estimated that about half of real output growth in the United States could be attributed directly or indirectly to IT investment. Oliner and Sichel (1994) reported a significant contribution of computers to aggregate U.S. output growth. Lichtenberg (1995) estimated firm-level production functions and found an excess return to IT equipment and labor. Siegel (1997), using detailed industry-level manufacturing data for the U.S., found that computers are an important source of quality change and that, once correcting output measures for quality change, computerization had a significant positive effect on productivity growth. Brynjolfsson and Hitt (1996, 1998) found a positive correlation between firm-level productivity growth and IT investment over the 1987-1994 time period, particularly when accompanied by organization changes. Lehr and Lichtenberg (1998) used data for U.S. federal government agencies over the 1987-1992 period and found a significant positive relation between productivity growth and computer intensity. Lehr and Lichtenberg (1999) investigated firm-level data among service industries over the 1977-1993 period and also reported evidence that computers, particularly personal computers, contributed positively and significantly to productivity growth.

Two studies looked, in particular, at R&D spillovers embodied in IT investment. Bernstein (1995) found a positive and highly significant influence of R&D linked (both embodied and disembodied) in communication equipment on the TFP growth of industries using this equipment. Van Meijl (1995) also estimated a positive and significant effect of R&D embodied in IT investment in general on TFP growth in other sectors. Both, moreover, found that the spillover effect was increasing rapidly over time.

Technological sources of growth have been documented by economic historians (Landes, 1969) and modeled by Amable (1993) and many others, but it is fairly recent that attempts have been made to pinpoint sources of growth in a micro-economic or at least multi-sectoral framework. The term 'engines of growth' has been coined by Bresnahan and Trajtenberg (1995). Their central notion is that a handful of 'general purpose technologies' bring about and foster generalized productivity gains throughout the economy. The productivity of R&D in a downstream sector increases as a consequence of innovation in the general purpose technology. Bresnahan and Trajtenberg (1995) proceed to construct a partial equilibrium model of an upstream sector and a downstream sector and then examine the welfare consequences of a simple one-step innovation game. Our model, however, is general equilibrium; the interaction between sectors is circular and there is no presumed engine of growth. While the terminology of Bresnahan and Trajtenberg (1995) is suggestive and useful indeed, it remains to identify the engines of growth given the body of input-output data that represent the structure of a national economy.

Caselli (1999) and Helpman and Rangel (1999) stress the educational requirements of the new information technology. These requirements slow down productivity growth, at least initially, and create wage inequality, at least in equilibrium, with workers recouping their training costs. The invention of the new technology is exogenous and its spread is determined by the mechanics of utility maximization in a dynamic economy with a single output. These authors take the source of the new technology for granted and examine its propagation and productivity effects. We start at the other end, the sectoral productivity growth rates, and try to trace back the sources of growth, in terms of sectoral R&D activities. We do so by solving the spillover structure for its reduced form. Unlike Caselli (1999) and Helpman and Rangel (1999), we were not motivated by the information technology revolution, but by the sheer theoretical challenge to pinpoint sources of growth in a general equilibrium input-output framework.

3 Productivity Analysis of Spillovers

Our point of departure is the Solow residual definition of total factor productivity (TFP) growth, Π:

$$\Pi = (pdy - wdL - rdK)/(py) \tag{1}$$

Here y is the final demand vector, L is labor input, K is capital input, w and r their respective prices, and p is the row vector of production prices, reflecting zero profits:

$$p(I - A) = v = wl + rk \tag{2}$$

where A is the matrix of the intermediate input coefficients. As Solow (1957) showed, the zero profit condition is needed to let the residual measure technical change. More precisely, the numerator of residual (1) becomes

$$\begin{aligned} &pd[(I - A)x] - wd(lx) - rd(kx) = (-pdA - wdl - rdk)x \\ &+ [p(I - A) - wl - rk]dx \end{aligned} \tag{3}$$

where the last term vanishes only if we use production prices (2). Then TFP growth (1) reduces to

$$\Pi = -(pdA + wdl + rdk)x/(py) = \pi\hat{p}x/(py) \tag{4}$$

where

$$= -(pdA + wdl + rdk)\hat{p}^{-1} \tag{5}$$

is the row vector of sectoral TFP growth rates and $\hat{p}x/(py)$ is the column vector of Domar weights.

Important determinants of sectoral TFP growth are research and development (R&D) and spillovers. As we have seen in the previous section, a prominent way to model spillovers is a weighted average of R&D in supplying sectors, where the weights are direct or total input coefficients, with the diagonal set to zero to avoid double counting of R&D. We, however, measure spillovers as a weighted average of TFP growth in supplying sectors. We have three reasons to do so. First, for R&D to spill over into TFP growth of other sectors it must first be successful in the home sector and this success is measured by its effect in terms of TFP growth. Second, we wish to endogenize the general equilibrium transmission of spillovers. Instead of putting in total input coefficients (the standard Leontief inverse) into the equation (as do Sakurai, Papaconstantinou and Ioannidis, 1997), we want to obtain them by solving the equation. Third, TFP growth based spillovers yield the best fit, according to Wolff (1997).

We distinguish four sources of sectoral TFP growth, π_j: an autonomous source, α, R&D in sector j per dollar of gross output, denoted by

$$\rho_j = RD_j/(p_j x_j), \tag{6}$$

a direct productivity spillover $\Sigma(p_i a_{ij}/p_j)\pi_i$, and a capital embodied spillover $\Sigma(p_i b_{ij}/p_j)\pi_i$, where b_{ij} is the investment coefficient of capital good i in sector j, per unit of output. We first regress sectoral TFP growth as follows (denoting the vector with all entries equal to one by e):

$$\pi = \alpha e^\top + \beta_1 \rho + \beta_2 \pi \hat{p} A \hat{p}^{-1} + \beta_3 \pi \hat{p} B \hat{p}^{-1} + \varepsilon \tag{7}$$

where α, β_1, and β_2 are coefficients and ε is a stochastic error term (Wolff, 1997). The weights of the sources are assumed to be constant across sectors. If we denote the spillover matrix by

$$C = \beta_2 \hat{p} A \hat{p}^{-1} + \beta_3 \hat{p} B \hat{p}^{-1} \tag{8}$$

then (7) reads, ignoring the error term,

$$\pi = \alpha e^\top + \beta_1 \rho + \pi C \tag{9}$$

To interpret the regression coefficient as a return to R&D (Mohnen, 1992), we relate TFP growth to R&D both directly and indirectly, that is through the spillovers. The direct effect is obtained by substituting (6) and (9) into (4):

$$\begin{aligned}\Pi &= [\alpha e^\top + \beta_1 RD(\hat{p}\hat{x})^{-1} + \pi C]\hat{p}x/(py) \\ &= \alpha DR + \beta_1 RDe/(py) + \pi C\hat{p}x/(py)\end{aligned} \tag{10}$$

Where RD is the row vector with elements RD_j given by (6) and $DR = (px)/(py)$, the Domar ratio, and RDe is the total R&D expediture, summed over sectors. There are two, equivalent interpretations of β_1. First, since Π is a growth rate, β_1 measures the *rate of return to R&D intensity*, where the latter is taken with respect to the value of net output or GDP. Second, since the denominator in the definitions of Π, (1), is also py, the equality of the numerators in (10) reveals that β_1 measures the *return to R&D*, in terms of output value per dollar expenditure. β_1 measures the direct rate of return to R&D intensity or, equivalently, the direct return to R&D. Now notice that the last term of (10), the intermediate inputs and embodied TFP growth rates, features the row vector of sectoral TFP growth rates, π, and, therefore, reinforces the effect of R&D on productivity through the spillovers.

The total return to R&D is obtained by taking into account the spillover effects. This is done by solving regression Equation (9) for π, that is by taking the Leontief inverse of matrix C. Thus we define multiplier matrix M by

$$M = (I - C)^{-1} = I + C + C^2 + \cdots \tag{11}$$

Sakurai, Papaconstantinou and Ioannidis (1997) model indirect spillover effects by putting the standard Leontief inverse directly into the TFP regression equation. We, however, model the direct spillovers and determine the indirect ones by general equilibrium analysis of the transmission mechanism, solving (9) using (11):

$$\pi = (\alpha e^\top + \beta_1 \rho)M \tag{12}$$

The direct rate of return to R&D was based on $\beta_1\rho$. The total rate of return is obtained by inflation through multiplier matrix M in Equation (11). Here I reproduces the direct rate of return, C, specified in (8), produces the direct spillover effect, and $C^2 + \cdots$ the indirect spillover effects. TFP growth expression (4) becomes

$$\Pi = \pi\hat{p}x/(py) = (\alpha e^\top + \beta_1\rho)M\hat{p}x/(py) \tag{13}$$

Equation (13) reduces TFP growth not only to sectoral TFP growth rates, but also to autonomous TFP growth and sectoral R&D expenditures. The middle expression in

(13) is the usual Domar decomposition of TFP growth, (4). The right hand side of (13) is an alternative, novel decomposition:

$$\Pi = [(\alpha + \beta_1\rho_1)\sum_j m_{1j}p_jx_j + \cdots + (\alpha + \beta_1\rho_n)\sum_j m_{nj}p_jx_j]/(py) \tag{14}$$

Again, there are two, equivalent measures for the productivity effect of R&D. The *total rate of return to R&D intensity* ρ_i amounts to $\beta_1(\sum_j m_{ij}p_jx_j)/(py)$. Here β_1 is deflated by multipliers m_{ij} because of the spillover effects and also by gross-net output ratios as the sectoral R&D intensities ρ_i are defined as the R&D/gross output ratios (which are small because of the denominators.)

Once more, the second interpretation is derived from the observation that either side of Equation (14) has py as denominator. Hence the *total return to R&D*, in terms of output value per dollar expenditure in sector i, amounts to $\beta_1(\sum_j m_{ij}p_jx_j)/(p_ix_i)$, using (6). Notice that the direct return to R&D, β_1, is inflated by the factor $(\sum_j m_{ij}p_jx_j)/(p_ix_i)$ because of the spillover effects stemming from sector i. Notice also that some sectors have stronger spillover effects than others, as determined by the rows of the multiplier matrix. The factors $(\sum_j m_{ij}p_jx_j)/(p_ix_i)$ reinforce the returns to R&D and are, therefore *spillover multipliers*. Spillover multipliers are related to the standard forward multipliers of input-output analysis (the row totals of the standard Leontief inverse), but there are two differences. First, spillover multipliers are based on the Leontief inverse of spillover matrix C rather than technology matrix A. Second, spillover multipliers are not straight row sums, but weighted by output value ratios $(p_jx_j)/(p_ix_i)$. We shall compare spillover multipliers to standard forward multipliers for the U.S. economy. Spillover multipliers account for the ratio of the total to the direct return to R&D and, therefore, measure the external effect of sectoral R&D.

Equation (14) shows that the contribution of a sector to TFP growth can be high for two reasons. First, the intensity of R&D can be high. Second, the spillover factor $\sum_j m_{ij}p_jx_j$ may be high. Decomposition (14) reduces overall TFP growth to sources of growth, $\alpha+\beta_1\rho_1$ for sector 1 to $\alpha+\beta_1\rho_n$ for sector n, aggregated by the (forward) linkages, $\sum_j m_{1j}p_jx_j$ for sector 1 to $\sum_j m_{nj}p_jx_j$ for sector n. Whereas the first decomposition, (4), is a TFP growth accounting identity, the second decomposition, (14), imputes TFP growth to sources of growth taking into account the general equilibrium spillover effects. Sectors that pick up much TFP growth in decomposition (14) are the *engines of growth*. The greatest engine of growth is the vector, say i, with the greatest value of $(\alpha + \beta_1\rho_i)\sum_j m_{ij}p_jx_j$. Whereas sectors with high TFP growth can be identified by direct growth accounting in the sense of Domar, engines of growth reveal themselves only after solving the intersectoral TFP growth rates equation for spillover effects to its reduced form, (13).

4 Data Sources

The basic data are 85-sector U.S. input-output tables for years 1958, 1967, 1977, and 1987.[1] Labor coefficients were obtained from Bureau of Labor Statistics' Historical Output and Employment Data Series (obtained on computer diskette).[2]

Capital stock by input-output industry for 1967 and 1977 was calculated directly from the net stocks of plant and equipment by input-output industry provided on computer tape by the U.S. Bureau of Industry Economics (the BIE Capital Stocks Data Base as of January 31, 1983). These series ran through 1981 for manufacturing industries and through 1980 for the other sectors. They were updated to 1987 on the basis of the growth rate of constant dollar net stock of fixed capital between 1980 (or 1981) and 1987 calculated from the National Income and Product Accounts (NIPA).[3]

Sectoral price indices were calculated from the Bureau of Labor Statistics' Historical Output Data Series (obtained on computer diskette) on the basis of the current and constant dollar series.[4]

Five sectors - research and development, business travel and office supplies, scrap and used goods, and inventory valuation adjustment - appeared in some years but not in

[1] Details on the construction of the input-output tables can be found in the following publications: 1967 - U.S. Interindustry Economics Division (1974); 1977 - U.S. Interindusty Economics Division (1984); and 1987 - Lawson and Teske (1994). We aggregate sectors 1-4, 5&6, 9&10, 11&12, 20&21, 22&23, 33&34, 44&45, and delete 74 and 80-85. Thus we partition the U.S. economy in 68 sectors.

[2] Data on hours worked by sector, though the preferable measure of labor input to employment, are not available by sector and year and therefore could not be incorporated.

[3] The source is Musgrave (1992). Since there are fewer industries in the NIPA breakdown than in the input-output data, we applied the same percentage growth rate across all input-output industries falling within a given NIPA classification. Data on government-owned capital stock for all years were obtained from Musgrave (1992).

[4] In addition, the deflator for transferred imports was calculated from the NIPA import deflator, that for the Rest of the World industry was calculated as the average of the NIPA import and export deflator, and the deflator for the inventory valuation adjustment was computed from the NIPA change in business inventory deflator. The source is U.S. Council of Economic Advisers (1992), Tables B-1, B-2, and B-3.

others (the earlier years for the first three sectors and the later years for the last two sectors). In order to make the accounting framework consistent over the four years of analysis, we eliminated these sectors from both gross and final output. This was accomplished by distributing the inputs used by these sectors proportional to either the endogenous sectors which purchased the outputof these five sectors or the final output.[5]

Data on the ratio of R&D expenditures to GDP were obtained from the National Science Foundation, *Research and Development in Industry*, various years, for 32 manufacturing industries covering the period 1958 to 1987. We were able to allocate these figures to 48 manufacturing industries in the input-output data.[6]

5 Results

Table 1, upper panel, shows that standard forward multipliers for the 68 industries in each of the four years. In 1987, not surprisingly, wholesale and retail trade is the sector with the highest forward linkage, since, by construction, it supplies almost all industries in the economy. The second most important supplier is the business service sector, followed by primary iron and steel, transportation, utilities, and industrial chemicals. On the bottom of the list are the consumer-oriented sectors, including tobacco products, ordinance (that is, armaments), household appliances, and footwear and leather products. Cross-industry correlations in forward linkages are very high, though they tend to attenuate over time. The correlation coefficient between the 1987 and 1977 forward linkages is 0.96, compared to a correlation of 0.92 between the 1958 and 1987 linkages; the respective rank correlations are 0.97, 0.96, and 0.90.

We next compute the new forward linkages based on matrix C. Results on forward linkage multipliers based on Equation (7) with $\alpha = 0.003, \beta_1 = 0.106, \beta_2 = 1.101$ and $\beta_3 = 0.753$ (following Wolff, 1997) are shown in Table 1, lower panel. There are now

[5] The allocation of the scrap sector was handled differently in the make-use framework of the 1967, 1977, and 1987 tables. See ten Raa and Wolff (1991) for details.

[6] This was calculated in two steps. First company R&D from the Federal Trade Commission Line of Business Data was averaged over 1974, 1975, and 1976 and then divided by the average of industry GDP over the same three years. Second, using the National Science Foundation data, we computed the average ratio of R&D expenditures to net sales at the 32-industry level for the 1958-1987 period and adjusted the first set of R&D to gross output ratios accordingly. It should be noted that the R&D data at this level of detail are not available prior to 1958, which prevented us from also including the 1947-1958 period in the regression analysis. The net sales are net of intra-company sales.

some interesting differences between these new multipliers and the standard forward linkage multipliers. On the basis of the 1987 multipliers, the trade sector ranks first and the construction sector ranks second, which is not unexpected since new investment is incorporated in the multiplier calculation. Business services now ranks third, followed by primary iron and steel and transportation. The correlation coefficients between the new forward linkage multipliers and the standard forward linkage multipliers are now around 0.9, and the rank correlations range from 0.89 to 0.96. Cross-industry correlations in these new forward linkages are high and increase over time. The correlation coefficient between the 1987 and 1958 forward linkages is 0.94, that between the 1987 and 1967 multipliers is 0.95; and that between the 1987 and the 1977 multipliers is 0.97; the corresponding rank correlations are 0.91, 0.94, and 0.95.

We next look at the major spillover sectors over the 1958-1987 period. These are defined as sectors i with high spillover terms $\pi_i(c_{i1} \ \ldots \ c_{in})$ which reflect both the strength of their forward linkages and their TFP growth. These sectors, shown in Table 2, are the ones which contributed most to the overall TFP growth of the economy. Over the whole 1957-1987 period, the most important source of overall growth was the trade sector, reflecting its very high forward linkage value. The second most important sector was computer and office equipment, a reflection of its very high TPF growth. Indeed, in the 1977-1987 period, it made by far the greatest contribution to embodied TFP growth. The third most important sector over the 1958-1987 period was electronic components, followed by transportation and plastics and synthetics. At the bottom of the list are the low (actually negative) TFP growth sectors, including clude petroleum and gas, finance and insurance, business services, radio and TV broadcasting, and metallic mining.

It is also of interest is that there is very little correlation over time in the rank order (or values) of sectors in terms of πC. The correlation coefficient between the 1958-1967 and the 1977-1987 values is 0.27 and the rank correlation is 0.22; the corresponding figures between the 1967-1977 and 1977-1987 values are -0.03 and 0.12. This is a reflection of the fact that sectoral TFP growth is very variable over time.

Our final step is to decompose overall TFP growth into sectoral contributions. The decomposition is based on Equation (14) and the figures are percentages of the positive growth contributions only, to avoid that engines of growth make more than one hundred percent. The results are shown in the bottom panel of Table 3. The results are quite striking. Over the full 1958-1987 period, the computer and office equipment industry was directly or indirectly responsible for over one fifth of the positive contributions to

TFP growth of the economy. It was the leading sector in both the 1967-1977 and the 1977-1987 sub-periods. Indeed, in the 1977-1987 period, it accounted for one fifth of the positive contributions overall TFP growth. A reason for this large effect is that TFP growth in computers and office equipment averaged 9.94 percent per year during this period. The next largest growth rates during this period were for electronic components and accessories, at 3.88 percent per year, and nonmetallic minerals mining, at 3.70 percent per year. It is also of interest that annual TFP growth in computers and office equipment accelerated from 1.22 percent in the 1958-67 period to 2.58 percent in 1967-77 and 9.94 percent in 1977-87. The next leading sector was electronic components, which accounted for 14 percent of the positive contributions of overall TFP growth over the full 1958-1987 period and for 6 percent in 1977-1987. Plastics and synthetics ranked third over the three decades, followed by scientific and control equipment and then aircraft and parts. Together, the top five industries were responsible for 41 percent of the positive contributions of overall TFP growth over the full 1958-1987 period and for 31 percent in 1977-1987. It is also notable that the top 10 industries are all manufacturing industries.

There is very little correlation over time in the rank order of sectors in terms of their contribution to overall TFP growth. The rank correlations between the 1958-1967 and the 1977-1987 values is 0.40 and that between the 1967-1977 and 1977-1987 values is 0.23. This again is a reflection of the fact that sectoral TFP growth in the U.S. economy can change radically over time. It also suggests that the engines of growth in the U.S. economy can change radically over time. In the real estate sector, for example, annual TFP growth, after rising from 1.42 percent in the 1958-67 period to 2.97 percent in 1967-77, plummeted to -0.76 percent in 1977-87. This, together with its linkages to other industries in the economy, also accounts for its very low ranking in the 1977-87 period.

A comparison with the standard decomposition of overall TFP growth based on Domar factors (Equation (4)) is also instructive (see the top panel of Table 3). Here, the top four industries, in rank order, over the 1958-1987 period are wholesale and retail trade (including restaurants), real estate, agriculture, and transportation. Computers and office equipment rank only six, compared to their top rank on the basis of matrix C. Like the engines of growth, there is a positive but low correlation in rank order of these industries over time, because of the high variability of TFP growth between periods. However, overall, the Domar rankings are similar to those based on matrix C, with rank correlations of 0.8 or so for most periods and for the entire 1958-1987 period. This result reflects the fact that industry level TFP growth is in the main determinant of the contribution of an industry to overall TFP growth.

6 Conclusion

Because of spillovers of technical change, sectoral productivity growth rates depend on each other. Solving this interdependence, by taking the Leontief inverse of the spillover matrix, amounts to imputation of total factor productivity growth to sectoral sources. The decomposition is not the one of standard growth accounting, because productivity growth is not counted in the sector where it occurs, but in the sectors that trigger it. The sectors to which most productivity growth is imputed are computers & office equipment and electronic components. In the standard growth accounting decomposition they rank 6 and 9 only. Productivity spillovers explain their status as leading engines of growth.

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Table 1

Ranks and Values of Forward Linkage Multipliers Based on $\hat{p}A\hat{p}^{-1}$ (Traditional) and Matrix C Spillovers, 1958-1987, with Sectors Ranked by 1987 Multipliers (Top 10 Only)

		1987		1958		1967		1977	
Traditional									
59	Trade, restaurants	1:	5.71	2:	4.79	3:	4.18	1:	5.08
63	Business services	2:	4.77	4:	3.40	2:	4.32	3:	3.89
28	Primary iron and steel	3:	3.55	1:	4.83	1:	4.79	2:	4.41
55	Transportation	4:	3.35	3:	3.77	5:	3.37	5:	3.31
58	Utilities	5:	3.19	10:	2.34	8:	2.52	7:	3.07
19	Industrial chemical	6:	3.19	6:	3.09	6:	3.28	6:	3.30
61	Real estate	7:	2.95	5:	3.31	4:	3.88	10:	2.74
6	Construction	8:	2.59	12:	2.26	11:	2.30	11:	2.69
4	Crude petroleum & gas	9:	2.57	13:	2.21	16:	2.06	4:	3.37
29	Primary nonferrous metals	10:	2.51	7:	2.78	7:	2.87	9:	2.79
Correlations with 1987 Forward Linkages				0.917		0.929		0.956	
Rank Correlations with 1987 Forward Linkages				0.903		0.957		0.973	
Matrix C Spillovers									
59	Trade, restaurants	1:	8.22	2:	6.93	3:	6.06	2:	7.72
6	Construction	2:	8.11	1:	7.83	1:	7.16	1:	8.44
63	Business services	3:	6.44	5:	4.35	4:	5.54	4:	5.12
28	Primary iron and steel	4:	4.33	3:	6.35	2:	6.10	3:	5.69
55	Transportation	5:	4.21	4:	4.85	6:	4.30	6:	4.25
61	Real estate	6:	3.93	6:	4.23	5:	4.96	9:	3.72
58	Utilities	7:	3.83	11:	2.77	9:	2.97	8:	3.75
19	Industrial chemicals	8:	3.75	7:	3.66	7:	3.85	7:	3.95
4	Crude petroleum & gas	9:	3.07	12:	2.62	17:	2.40	5:	4.27
29	Primary nonferrous metals	10:	2.94	8:	3.39	8:	3.51	11:	3.42
Correlations with 1987 Forward Linkages				0.938		0.945		0.966	
Rank Correlations with 1987 Forward Linkages				0.909		0.944		0.952	
Correlations with Traditional Forward Linkage Multiplier		0.905		0.880		0.903		0.898	
Rank Correlations with Traditional Forward Linkage Multiplier		0.963		0.916		0.927		0.890	

Table 2

Embodied Total Factor Productivity Growth Rates, Based on $\pi_i(c_{i1} \ \dots \ c_{in})$ in Equation (9), 1958-1987, with Sectors Ranked by 1958-1987 Values (Top 10 Only, figures in percent per annum)

		1958-1987		1958-1967		1967-1977		1977-1987	
59	Trade, restaurants	1:	7.9	4:	5.9	3:	7.4	2:	8.9
41	Computer & office equip.	2:	6.4	50:	0.7	7:	3.5	1:	14.5
47	Electronic components	3:	5.7	9:	4.0	5:	4.7	3:	7.6
55	Transportation	4:	5.1	1:	10.0	2:	7.6	58:	-1.9
20	Plastics and synthetics	5:	5.1	6:	4.9	4:	5.3	6:	4.8
61	Real estate	6:	4.9	3:	6.5	1:	12.9	62:	-2.9
1	Agriculture	7:	3.1	29:	2.0	6:	4.0	11:	3.0
53	Ophthalmic & photographic equip.	8:	2.5	18:	3.1	10:	2.8	25:	2.0
10	Fabrics, yarn & thread mills	9:	2.4	17:	3.1	23:	1.4	12:	2.9
24	Rubber, miscel. plastics	10:	2.4	14:	3.2	43:	0.3	9:	3.7
Correlations with 1977-1987 Values				0.274		-0.028			
Rank Correlations with 1977-1987 Values				0.222		0.120			

Table 3

Percentage Decomposition of Overall TFP Growth by Sector, Based on Equations (4) (Domar) and (14) (Sources of Growth), with Sectors Ranked by 1958-1987 Values (Top 10 Only, figures in percent per annum, with denominator the sum of positive elements only)

		1958-1987		1958-1967		1967-1977		1977-1987	
Domar									
59	Trade, restaurants	1:	21.6	2:	11.4	2:	16.0	1:	19.1
61	Real estate	2:	16.5	1:	11.9	1:	30.6	66:	-8.3
1	Agriculture	3:	8.6	6:	4.1	4:	7.8	4:	5.5
55	Transportation	4:	7.3	3:	9.0	3:	8.4	59:	-1.8
8	Food products	5:	5.5	5:	5.1	5:	3.5	5:	3.6
41	Computer & office equip.	6:	3.6	52:	0.2	14:	1.5	2:	8.2
12	Apparel	7:	2.9	16:	1.8	11:	1.9	7:	3.1
21	Drugs & cleaning prods.	8:	2.4	19:	1.4	10:	2.0	11:	2.5
47	Electronic components	9:	2.3	23:	1.1	12:	1.7	6:	3.1
56	Communications	10:	2.2	12:	2.2	6:	3.1	58:	-1.4
Rank Correlations with 1977-1987 Values				0.31		0.11			
Engines of Growth									
41	Computer & office equip.	1:	18.0	19:	0.8	1:	14.3	1:	19.2
47	Electronic components	2:	9.2	8:	3.6	3:	11.8	2:	5.9
20	Plastics and synthetics	3:	5.7	6:	4.2	4:	9.2	5:	1.9
52	Scientific & control instruments	4:	4.3	68:	-0.5	8:	3.8	3:	3.6
50	Aircraft & parts	5:	4.2	1:	15.3	62;	-0.5	55:	0.0
46	Audio, video & commun. equip.	6:	3.8	4:	6.9	13:	2.3	6:	1.8
21	Drugs & cleaning prod.	7:	3.7	11:	2.2	5:	5.9	8:	1.5
49	Motor vehicles	8:	3.2	3:	7.2	2:	13.0	68:	-4.8
24	Rubber, miscel. plastics	9:	2.5	12:	1.8	19:	1.2	7:	1.8
44	Household appliances	10:	2.3	9:	2.9	7:	4.5	14:	0.4
Rank Correlations with 1997-1987 values				0.400		0.231			
Rank Correlations with Domar values		0.812		0.691		0.809		0.807	