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ABSTRACT

This paper introduces new estimates of recent productivity developments in the United States, using an appropriate theoretical framework for aggregating industry MFP to sectors and the total economy. Our work sheds light on the sources of the continued strong performance of U.S. productivity since 2000. We find that the major sectoral players in the late 1990s pickup were not contributors to the more recent surge in productivity. Rather, striking gains in MFP in the finance and business service sector, a resurgence in MFP growth in the industrial sector, and an end to drops elsewhere more than account for the aggregate acceleration in productivity in recent years. Further, some evidence is found for a link between IT intensity and the recent productivity acceleration.

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1. Introduction

As the step-up in U.S. productivity growth in the mid-1990s became evident, research on productivity surged. Initially, the new work concentrated on estimating the contribution of information technology (IT) to the productivity pickup, with similar results obtained using industry-level or broad macroeconomic time-series data (Jorgenson and Stiroh 2000, Oliner and Sichel 2000, respectively). Later, studies exploited more detailed data and showed that, while multi-factor productivity (MFP) growth in the IT-producing industries was very high, many services industries also had substantial MFP growth in the late 1990s (Triplett and Bosworth 2004; Jorgenson, Ho, and Stiroh 2005a, 2005b).

It is not surprising that disaggregate data were needed to establish that the resurgence in U.S. productivity growth in the late 1990s went beyond the production of IT and was based, at least in part, on increases in MFP growth in services industries.[1] Detailed analysis had previously documented that many services industries had flat or declining trends in labor productivity for twenty or more years before the pickup in the late 1990s became evident (Corrado and Slifman 1999). The discovery that the "use of IT" story was mostly a services phenomenon (Stiroh 1998, Triplett 1999) also required disaggregate data to determine which industries were investing in the newer technologies. In some sense, the well documented variability in the diffusion of new technology and innovation across ranges of products (Mansfield 1968, Gort and Klepper 1982) has long suggested that the available industry data should be studied to detect and identify changes in productivity.

This paper presents key trends and developments in productivity growth at an intermediate level of aggregation in the United States, and shows links between the acceleration of MFP and IT. Six custom-made sectors were aggregated up from detailed disaggregated data using a framework that has some nice theoretical properties. Further, the six sectors were defined to provide a more meaningful view of productivity growth than can be found using standard industry hierarchies. The six sectors have highly divergent trends in MFP growth, a result that we believe, in itself, strongly suggests

[1] This refers to the conventional representation of IT in the neoclassical growth accounting framework, which does not rule out the existence of externalities (or network effects) from IT. If such effects are present, the conventional framework will attribute them to MFP.

disaggregate data are extremely useful for determining the current trend in aggregate MFP.

Similar to previous studies of sectoral productivity, we find that the U.S. productivity resurgence in the late 1990s was a sectoral story, with notable increases in the rate of change in MFP for some sectors partly offset by small step-downs in others. In terms of the sources of growth since 2000, our results using a newly developed industry-level dataset show that productivity (MFP) has been the major contributor. We estimate that the rate of change in aggregate MFP picked up notably since 2000, and we now show that this was driven primarily by striking results for finance and business services. Although the major players in the productivity pickup in late 1990s—the tech sector and retail and wholesale trade—were not players in the *acceleration* since then, the rate of MFP growth in these sectors continued to be robust. All told, we find that by 2004 the resurgence in productivity growth that started in the mid-1990s was relatively broad-based by major producing sector.

The plan of this paper is as follows: The next section spells out our theoretical framework and reviews the basic elements in our system. We then present our new results on recent sectoral productivity developments in the United States and on the role of IT.

2. Data and Methodology

This section consists of three parts that summarize detailed discussions presented in a methodological working paper (Corrado *et al.* 2006b). The first part describes the procedure used to define six sectors, or 'intermediate aggregates' made up of groups of underlying disaggregated industries. The next part is an overview of the methods used to construct productivity measures at each level of aggregation as well as decompositions of output growth for the aggregate economy and the six sectors. Finally, the construction of consistent time series on outputs, inputs, and prices for disaggregated U.S. industries is presented.

Grouping industries into sectors for productivity analysis.

A novel feature of our work is the construction of custom-made sectors, or groupings of disaggregated industries. We do not define sectors according to the hierarchy implied in the industrial classification system, NAICS. Instead, we view aggregates of industries as vertically-integrated entities and group “upstream” industries with related “downstream” industries using I-O relationships. A detailed description of the methodology used to group industries in sectors is given in Corrado *et al.* (2006b). Grouping industries according to this approach minimizes int*er*sectoral flows across a given number of groups, and the defined sectors allow looking at welfare-theoretic measures of productivity for deliveries to subsets of final demand. Further, the aggregation minimizes time series breaks that occur in underlying disaggregated data; the available data on employment and hours worked, for example, contain serious breaks.

Our first sector, the “high-tech” sector, includes producers of both IT and IT services. To group the key IT-producing industries (semiconductors, computers, communications equipment, computer software, telecommunications services, and internet services) in a single sector, it was necessary to cut across three major NAICS groupings and to further disaggregate three industries in BEA’s industry hierarchy. We did not map the entire new NAICS information sector to our high-tech sector because the NAICS information sector includes producers of cultural products (a NAICS term for newspapers, books, popular music, movies, TV programs, etc.) in addition to producers of IT products. Because cultural products are primarily consumed by persons, we assigned the industries that produced them with personal services. All in all, our definition of the high-tech sector maps more closely to IT production than do definitions used in many other productivity studies.

In addition to high-tech, the other sectors we identified were: construction, industrial, distribution, finance and business, and other (mostly personal) services. The construction sector is isolated because the sector plays an important role in economic fluctuations. The other four groupings of industries had a *primary* producing function that can be viewed as follows: producers of goods (industrial), merchandisers and transporters of goods (distribution), providers of services to businesses (finance and business), and providers of services and cultural products to persons (personal and cultural).

The resulting six sectors and their relative sizes according to several metrics are illustrated in table 1. The bottom half of column 1 shows the ‘Domar’ weights, the weights used for aggregating MFP for each sector to obtain MFP for the total private nonfarm business sector, as described in the following section. As may be seen, the industrial and the finance and business sectors have relatively large Domar weights, and the sum of the Domar weights for all sectors exceeds one by 40 percent (as explained in the next subsection). The Domar weights have shifted only slightly over time, with the weight for the industrial sector (which excludes high-tech manufacturing) dropping a bit, and weights for the high-tech and the finance and business sectors increasing.

Table 1 also shows that in 2004, whether measured as sectoral output, deliveries-to-final demand, or value added, four sectors—industrial, distribution, finance and business, and personal and cultural—dominate U.S. business activity. The industrial sector is the largest in terms of gross output and shipments to final demand, but it is the smallest of the four—by a wide margin—in terms of employment share and does not dominate in terms of value added. The finance and business services sector is the largest in terms of value added.

Productivity aggregation and growth decompositions

Productivity for an aggregate and productivity for component industries are related using the framework of Domar (1961). The framework was extended by Hulten (1978) and Gollop (1979, 1983) and used in several prominent studies of U.S. productivity growth (e.g., Jorgenson, Gollop, and Fraumeni 1987, Gullickson and Harper 1999, and Bartelsman and Beaulieu 2005).

The Domar framework enables MFP growth at *any* level of aggregation to be decomposed into contributions from underlying sectors or industries. Below, we further develop the framework to study the role of "intermediate" aggregates, such as the just-described six sectors, in the productivity performance of the overall economy. This requires a more rigorous application of the framework than found in much of the recent work on the industry sources of productivity change. (See Corrado *et al.* 2006b.)

The concept of sectoral output—defined as the gross output of an industry or sector less the amount produced and consumed within the industry or sector—is used to model production for an industry or a sector. This output concept has an interesting property: Although it is very close to gross output at the detailed industry level, as we move up an aggregation hierarchy of producing units, sectoral output strips out what each aggregate *collectively* uses up in production and moves closer and closer to value added. Because the output of an industry, a collection of industries, or the whole economy is viewed, in effect, as production by a single vertically-integrated firm, the Domar or sectoral framework has come to be called the "deliveries-to-final demand" framework for studying industry productivity (Gollop 1979).

As shown by Hulten (1978), productivity growth defined using the Domar framework has nice theoretical properties, as productivity can be mapped into the rate of expansion of the social production possibilities frontier. As a practical matter, defining productivity in this framework means that researchers do not need to make the often-violated assumptions necessary for either value added or gross output productivity measures.

The definitions and notation we employ in this paper are grounded in industry-by-industry input-output (I-O) relationships as laid out in the table on the following page. Note that **bolded letters denote growth rates in real terms** and non-bold capital letters denote nominal expenditure flows. The items defined in the table are used to illustrate the basic Domar/Hulten result that the rate of change in multi-factor productivity at any level of aggregation ($\boldsymbol{MFP}_k$) can be expressed as a weighted average of the rates of change in multi-factor productivity of underlying or disaggregated industries ($\boldsymbol{MFP}_i$):

(1a) $$\boldsymbol{MFP}_k = \sum_{i \in k} d_i^k \, \boldsymbol{MFP}_i \quad .$$

The "Domar" weights are defined as, $d_i^k = \frac{S_{i\bullet}}{S_{k\bullet}}$, and depend on the composition of the aggregate being created as well as each underlying industry. The weights also have the property, $\sum_{i \in k} d_i^k > 1$, and reveal the effect that a change in each industry's productivity has on the change in productivity for the aggregate. Each industry *i* contributes to productivity of the aggregate *k*, *directly* through its deliveries to customers of *k* (i.e. deliveries of *k* to using industries outside of *k* and to final demand), and *indirectly* through its deliveries to other component industries of *k*.

As Domar/Hulten show, productivity growth at any level of industry aggregation also may be equivalently calculated in a residual fashion as the difference between

Notation and Definitions

A. *Notation:*		
X_{ij}	**Generic element in an industry-by-industry input-output (I-O) system**	Each element in row *i* of the table shows shipments of producer *i* to purchaser *j*, where *j* is either in the set of domestic industries T, or a component of final demand, F. $(j \in T \cup F)$ Each element of column *j* of the table shows industry *j*'s purchases of producer *i*'s output, where *i* is in the set of domestic industries T, or in the import "industry," R. $(i \in T \cup R)$
$X_{k\bullet}$	**Intra-industry shipments from/to *k*** $(k \in T)$	The shipments of producers in *k* to all other producers within *k*. Note that "*k*" can refer to a particular industry or to a collection of industries in the total set of domestic industries. The special subscript "•" indicates that $X_{k\bullet}$ is constructed from information from both rows and columns of the I-O table, and that aggregation takes place over both producing and purchasing industries.
B. *Definitions:*		
Q_k	**Gross output** $\sum_{i \in k} \sum_{j \in T \cup F} X_{i,j}$	Production in industry *k* (which may be an aggregate of underlying industries or producers) equals shipments plus work-in-progress and finished inventories for goods producers; revenue for service providers. The cost of goods sold without further processing is excluded, which especially is relevant for the trade industries.
M_k	**Intermediate inputs** $\sum_{i \in T \cup R} \sum_{j \in k} X_{i,j}$	Inputs purchased by producers in industry *k* for use in production. Examples include electricity by retailers, steel by automakers, etc. Equals:
$X_{k\bullet}$	$\sum_{i \in k} \sum_{j \in k} X_{i,j}$	Inputs purchased from, or sold to, producers *within* the own industry *k*, plus:
$N_{k\bullet}$	$\sum_{i \in T; i \notin k} \sum_{j \in k} X_{i,j}$	Inputs purchased by producers in industry *k* from *other* domestic industries. (Note that when aggregating across industries, more purchasers and fewer suppliers are included, and that N_T=0), plus:
R_k	$\sum_{i \in R} \sum_{j \in k} X_{i,j}$	Imported inputs, that is, intermediates purchased by producers in industry *k* from the import industry.
V_k	**Value added** $Q_k - M_k$ **or** $L_k + K_k$	Gross output less intermediate inputs; equal to the sum of the cost of labor (L_k) and capital (K_k) inputs. (Note that *L* denotes nominal expenditures on labor, or compensation).
$S_{k\bullet}$	**Sectoral output** $Q_k - X_{k\bullet}$ **or** $L_k + K_k + N_{k\bullet} + R_k$	Equals production in industry *k* that is shipped outside the industry, i.e. to *other* industries and to final demand. Equals the sum of the cost of labor, capital, inputs from *other* domestic industries, and inputs from the import industry.
$\boldsymbol{I}^S_{k\bullet}$	**Sectoral inputs (real)** $s^L_k \boldsymbol{L}_k + s^K_k \boldsymbol{K}_k + s^N_k \boldsymbol{N}_{k\bullet} + s^R_k \boldsymbol{R}_k$	Share-weighted growth of real inputs to production (labor, capital, and purchased inputs from other domestic industries/sectors and imports. (Note that $\boldsymbol{L}$ denotes the growth rate of real labor inputs, or hours worked).

Note—Plain upper case variables are nominal values; **bolded variables are growth rates** of Divisia quantity indexes; and plain lower case variables are factor cost shares.

changes in Divisia quantity indexes for the industry's appropriately defined output ($\boldsymbol{S}_{k\bullet}$) and share-weighted inputs ($\boldsymbol{I}_{k\bullet}$):

(1b) $$\boldsymbol{MFP}_k = \boldsymbol{S}_{k\bullet} - \boldsymbol{I}_{k\bullet} \; .$$

Note that (1b) allows the standard Solow-Jorgenson-Griliches decomposition of the sources of economic growth when k represents the "total" economy (Hulten 1978).

The decomposition of sectoral output growth is written in terms of contributions of domestic inputs from outside the sector, and a Domar-weighted sum of growth accounting contributions of primary inputs and MFP of underlying industries:

(2) $$\boldsymbol{S}_{k\bullet} = s_k^N \, \boldsymbol{N}_{k\bullet} + \sum_{i \in k} d_i^k \, [\, \boldsymbol{MFP}_i + s_i^L \boldsymbol{L}_i + s_i^K \boldsymbol{K}_i + s_i^R \boldsymbol{R}_i] \; .$$

The subscript k in (2) denotes a (sub)aggregate of industries, and the first term is the share-weighted growth of domestically-produced inputs purchased from outside the sector k. As with measuring sectoral output and calculating Domar weights, accounting for purchased inputs is specific to the subaggregate and is derived from industry-by-industry I-O relationships.

In our work we calculate detailed industry-level MFP using equation (1b) and sectoral-level MFP using equation (1a). We then use the result in equation (2) to obtain sources-of-growth decompositions for the private nonfarm business sector and the six sectors just described. In this decomposition, the contribution of real growth of intermediates from outside the sector, $s_k^N \, \boldsymbol{N}_{k\bullet}$, is calculated residually.

Measures of output and inputs for individual industries.

The estimation of industry-level multifactor productivity requires the following empirical elements: growth rates of real sectoral output for each industry ($\boldsymbol{S}_{k\bullet}$), growth rates of the inputs to production (labor, capital, imported inputs, and inputs from other domestic industries) for each industry ($\boldsymbol{L}_k$, $\boldsymbol{K}_k$, $\boldsymbol{R}_k$, and $\boldsymbol{N}_{k\bullet}$), and income shares for each input for each industry (s_k^L, s_k^K, s_k^R, and s_k^N).

The nominal values of sectoral output for each industry ($S_{k\bullet}$) were determined by subtracting estimates of own-industry intermediate use ($X_{k\bullet}$) calculated using BEA's input-output accounts from the data on gross output (Q_k) in BEA's industry accounts dataset. The estimates of $X_{k\bullet}$ were also subtracted from BEA's data on total intermediate inputs (M_k) to determine the value of an industry's purchased inputs from *other* industries, that is, the sum of purchased inputs from other domestic industries and the "import" industry ($N_{k\bullet} + R_k$). The details of these computations owing to missing data and other issues are discussed in Corrado *et al.* (2006b).

The growth of real industry-level sectoral output ($\boldsymbol{S_{k\bullet}}$) is determined from quantity indexes constructed by assuming the real value of each input produced and consumed within the industry ($\boldsymbol{X_{k\bullet}}$) has the same price index as each of the outputs produced within the industry. The growth rate of imported intermediates purchased from the 'import industry ($\boldsymbol{R_k}$) is calculated by deflating the estimated the value of imports for an industry with an industry-specific import deflator. Finally, the growth rate of intermediates purchased from other industries ($\boldsymbol{N_{k\bullet}}$) is calculated by chain stripping the real values of $X_{k\bullet}$ and R_k from the real value of M_k for which price and quantity measures are available in BEA's industry accounts.

Changes in industry capital input measures ($\boldsymbol{K_k}$) were derived using BEA's detailed asset-by-industry net stocks. We follow the Jorgenson-Griliches approach taken by the BLS and aggregate asset-by-industry capital stocks using *ex post* rental prices. The BEA's capital stocks differ from the "productive" stocks compiled by the BLS, however, because the two agencies use different models of capital depreciation. We are comfortable adopting the BEA model because the differences between the two approaches are very small (see U.S. Department of Labor, 1983, pp. 56-59).

Following numerous productivity studies, we aggregate the many detailed capital asset types into two aggregates for our sources-of-growth analysis: information technology (IT) capital and other capital (equipment, structures, and inventories). IT capital is defined as computers, software, and communications equipment.

Changes in industry labor input measures ($\boldsymbol{L_k}$) are changes in hours worked of all persons (employees and the self-employed) with no explicit differentiation by characteristics of workers. Implicitly, some account is taken of worker heterogeneity by using the very detailed information on industry-level employment, hours and payrolls from the *County Business Patterns* (CBP) series issued by the Census Bureau. As indicated previously, the underlying source data on employment and hours contain serious breaks. A fairly complicated procedure, involving numerous assumptions, was needed to create a consistent time series for employment and hours worked; see Corrado *et al.* (2006b).

3. Sectoral decomposition of output and productivity growth.

The empirical decomposition of output and productivity growth for the six sectors is shown in table 2 and table 3. The tables each have three panels. The first two panels (panels A and B) show results for subperiods—1995 to 2000, and 2000 to 2004. The next two panels (C and D) shows changes (in growth rates or contributions to growth) for the 1995-2000 relative to 1987-1995 (Panel C), and for the 2000 to 2004 period relative to the late 1990s (panel D).

Each **row** of table 2 is a sources-of-growth decomposition using equation (2). Thus, the contributions from MFP and each production factor (columns 2-6) sum across the row to equal sectoral output growth (column 1). The first row in each panel reports the decomposition for private nonfarm business; the subsequent rows in the panel show decompositions for major producing sectors. As may be seen in row 1 of panel A, we estimate that aggregate sectoral output growth for the private nonfarm business sector averaged 5.4 percent from 1995 to 2000, with contributions from MFP, capital, labor, and purchased inputs all playing important roles. Because the private nonfarm business aggregate falls short of complete coverage of the total economy, accounting for the growth in its purchased inputs from other domestic producers (e.g., farms) as well as the rest-of-world sector (imports) is important: During the late 1990s, we estimate that nearly 20 percent of U.S. private nonfarm business sectoral output *growth* was accounted for by purchased inputs.

Although contributions from MFP, capital, labor, and purchased inputs are all important for understanding aggregate economic growth, the sectoral sources-of-growth results (panels A and B, rows 3 through 8) indicate that the importance of productivity and contributions of factor inputs varies notably by sector. For construction, measured productivity change is negative, and the contribution of labor and purchased inputs more than account for the real output growth of this sector. By contrast, in the industrial sector, the contribution of labor input is negative, on average, and the contribution of productivity increases and purchased inputs account for much of its real output growth, especially recently. Purchased inputs also contribute noticeably to output growth in the finance and business sector and in the personal and cultural sector (mainly purchases by industries in the NAICS food and accommodation sector). In the distribution sector, productivity increases are a dominant source of growth.

Each **column** of table 3 shows the sectoral decomposition of the contribution of primary factors and MFP to aggregate growth. Thus, the contribution of MFP or one of the production factors to sectoral growth in private nonfarm business, shown in line 1, is split into contributions from the high-tech (line 8) sector and an "excl. high-tech" aggregate (line 2); line (2) is further decomposed in lines (3) through (7) into contributions from the other sectors. In this decomposition, the role of the high-tech sector in the late 1990s resurgence in productivity growth can be seen by the substantial difference between MFP for the private nonfarm business sector and the contribution of MFP in the "excl. high-tech" subaggregate (panel A, column 1, compare rows 1 and 2). It would therefore appear that, no matter how one looks at this period, the late 1990s productivity pickup story is a sectoral story: Notable increases in the rates of change in MFP in the high-tech and distribution sectors (panel A, column 1, rows 8 and 5, respectively) drove the aggregate results, but their strong performance was partially offset by negative contributions from the industrial, construction, and finance and business sectors.

With regard to factor inputs, our results show that faster growth in IT capital services contributed importantly to the *pickup* in economic growth in the late 1990s (panel C , row 1, column 2), consistent with previous studies and the official macro productivity data. As may be seen looking down column 2, the faster growth in IT capital services was concentrated primarily in industries in the distribution and finance and business sectors. All told, therefore, our results line up very well with the analysis and conclusions of many previous studies of the industries and factors that contributed to productivity growth in the United States in the late 1990s (Jorgenson and Stiroh 2000, Oliner and Sichel 2000, Triplett and Bosworth 2004).

Panel B reports our new results for the sources of the gains in output since 2000. As may be seen, productivity has been the major driver of recent economic growth (column 1, row 1), with most sectors contributing to the increase (column 1, rows 3 through 8). As shown in panel D, column 1, there is a notable sectoral variation in the results for the *pickup* in productivity since 2000, however. This faster growth in MFP in recent years is sizeable—more than 1 percent per year, on average—but the major sectoral players in the late 1990s (high-tech and distribution) are *not* contributors to the more recent pickup. Rather, very strong MFP gains in the finance and business sector, a resurgence in MFP growth in the industrial sector, and an end to the drops in MFP in the personal and cultural sector more than account for U.S. economic growth since 2000.

In terms of primary factor inputs, a notable result is that the post-2000 gains in output occurred as businesses pulled back on labor input (panel B, row 1, column 4), leaving capital deepening (whose effect must be inferred from the results shown) and increasing MFP as the unambiguous sources of the post-2000 average gain in U.S. labor productivity. This result is pretty widespread by sector, although increases in hourly labor input in the personal and cultural sector continued to contribute to the economic growth of the post-2000 period.

In summary, we have found that by 2004 the resurgence in productivity growth that started in the mid-1990s was relatively broad-based across major producing sectors. However, the timing of the increases in sectoral MFP growth rates varied notably within this period. More fundamentally, the underlying trends in sectoral productivity growth rates themselves are highly divergent. In the high tech sector, MFP growth averaged 6 percent per year between 1995 and 2004; elsewhere, the underlying trends ranged from –3/4 percent per year for construction to 2-1/2 percent per year for distribution. We believe these findings can be exploited for forecasting changes in the current/prospective trend in MFP growth.

4. What is the underlying trend in MFP growth and what is the role of IT?

In this section, we explore two simple examples of how our findings can be used. The first example exploits only the *divergent pattern in sectoral MFP trends* just discussed and attempts to determine the current/prospective trend in aggregate MFP growth using a time-series approach.

The underlying variation in MFP growth across sectors and over time is displayed in chart 1. On the left, each panel displays the index level of actual MFP for a sector and an estimate of its trend based on the HP filter (Hodrick and Prescott 1997). The HP trends were generated using the smoothing parameter suggested by Ravn and Uhlig (2002) for annual data and have been calculated for three periods beyond the last observation on actual MFP.[2] The panel to the right shows percent changes in the actual and trend estimates of MFP, along with the period averages of MFP growth rates reported in table 2. Note that the changes in the estimated trends do not necessarily coincide with the averaged rates of actual productivity growth for the sub-periods analyzed in the tables.

We aggregate the HP-filtered sectoral trends shown in chart 1 using actual values of the Domar weights (see the "memo" column in table 3. Because Corrado *et al.* (2006b) determined that the changes in these weights did not contribute significantly to recent productivity developments, we use a simple average of the two most recent actual values as Domar weights for the extension period, which in this example covers the years 2005 to 2007.[3] The results are shown in the table below. As may be seen, although the estimate of the trend in MFP growth from 2000 to 2004 picks up less than the increase in

Sectoral-based estimates of the trend in aggregate MFP growth,

(annual percent change for period indicated)

	1987 to 1995	1995 to 2000	2000 to 2004	2005	2006	2007
Trend MFP	0.9	1.1	1.9	1.9	1.7	1.5
Memo: Actual[1]	0.8	1.1	2.3	….	….	….

1. Estimates for the private nonfarm business sector from table 2.
… not applicable.

its actual average rate (shown as a memo item), the acceleration is still very notable—from 1.1 percent per year to 1.9 percent per year. The estimated current/prospective

[2] The projected trends were obtained by first extending the underlying data for five periods using forecasts from an ARIMA model and then applying the HP filter to the extended time series. This procedure minimizes the well-known end-of-sample problem with the HP filter. We thank our colleagues Charles Gilbert and Norman Morin for developing this routine.

[3] For additional precision in a practical forecasting setting, the sectoral weights could be developed from elements of macroeconomic data and/or a forecast in conjunction with the latest information on I-O relationships and actual MFP at the sectoral level could be estimated for another year (in this case, 2005). To estimate sectoral MPF for another year, the methods described in Beaulieu and Bartelsman (2006) could be used to estimate industry output from data on final demand components, and simplified methods for estimating capital input (e.g., of Oliner and Sichel 2000) could be adapted for use in a sectoral format using the tools described in Bartelsman and Beaulieu (2003).

trends during 2005, 2006, and 2007—though at lower rates than during the preceding period—remain robust and average nearly 1-3/4 percent per year.

As seen in chart 1, the continued robust pace of aggregate productivity growth occurs primarily because most sectors are expected to continue to contribute to the overall gain. This is seen especially for the high-tech sector, in which the prospective trend in MFP growth continues to be relatively strong. Quality-adjusted price measures are important for gauging the pace of technological innovation in this sector. As a result, confidence in the estimated prospective MFP trend depends in large part on believing that the sector's price measures are capturing recent developments in technology. In future work we plan to further disaggregate this sector so that we may incorporate the results of more recent research on price measures for communications equipment that are not in BEA's figures but are included in the annual price indexes used to benchmark the Federal Reserve's industrial production index.[4] The Federal Reserve's measures attempt to capture the effects of relatively recent developments, such as fiber optics, wireless networking, and IP (internet protocol)-based telephony.

The prospective trends in MFP for the aggregate economy would be even higher were it not for the projected step-down in trend MFP for finance and business and the persistently negative--almost implausible--change in actual MFP for the construction sector.

With regard to the finance and business sector, the large turnaround in post-2000 MFP growth is striking. Moreover, the result appears to be widespread by industry within the sector (see detailed tables in Corrado *et al.* 2006b). The largest contributions are from the banking and commercial real estate industries; increases in MFP growth in these industries, along with an increase for the broad business services group, more than account for the step-up in the sector.[5] Because the sector's demand drivers would appear to be relatively diverse and the measurement of its output long a subject of debate, the

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[4] These price indexes are based on research reported in Doms and Foreman (2005) and Doms (2005). Corrado (2001, 2003) and Bayard and Gilbert (2006) report on what has been developed for inclusion in the Fed's industrial production index.

[5] Using SIC-based data, Triplett and Bosworth (2004) found that the securities industry posted a notable acceleration in productivity in the late 1990s. We estimate that MFP for this industry continued to expand post-2000, although the rate of growth was not nearly as rapid as in the late 1990s.

specific productivity stories within this sector are deserving of much further scrutiny and study.

As for construction, recall that we isolated the sector because it is an important driver of aggregate demand. In addition, our input-output analysis did not strongly suggest that the sector should be integrated with industries in the BEA hierarchy that primarily produce its inputs. However, given the materials-using nature of the sector's production (and the fact that real gross output grows substantially faster than real value added), a more detailed representation of supplying industries would be needed to create a more vertically-integrated construction sector. Another possibility would be to integrate the real estate industry with the construction sector. All told, therefore, the productivity of a more integrated construction (or construction and real estate) sector might look more plausible than the results for the construction industry alone.[6]

A second example uses only the *cross-sectional variation in MFP at the industry level* to analyze recent productivity developments.[7] Specifically, we ask whether the recent strong results for MFP are partly a reflection of earlier investments in IT. As noted in the introduction, the neoclassical growth accounting framework that we use may attribute part of what we think of "the use of" IT effects to MFP to the extent that network effects (and other externalities) are present. Furthermore, if firms experience adjustment costs (or must engage in learning) prior to factoring newly acquired IT technologies in production processes, the waning of those effects will have a temporary "accelerating" effect on MFP. Anecdotal and other information suggest that some of the recent productivity gains reflect firms making better use of existing capital and improving business processes, especially as they discover new and better methods for using the existing IT capital stock (Basu, et al. 2003, Gordon 2004, Bies 2006).

If some of the recent productivity gains are a lagged realization of the large run-up in IT investment in earlier years, then we would expect to see a pattern in which MFP growth for industries that invested especially heavily in IT in the late 1990s

[6] Of course, the results for productivity of the aggregate economy would be different only if the output price of the construction sector was mismeasured. Construction prices received much attention as a possible "culprit" for mismeasurement during the 1970s and 1980s period of lackluster productivity growth (e.g., Baily and Gordon 1988). The BEA recently revisited the measurement of construction prices, but the new results did not materially change the picture (Grimm 2003).

[7] We are grateful to Larry Slifman for suggesting this example to us.

accelerated more strongly than did MFP growth for industries whose IT investments were not especially strong. Chart 2 shows a simple scatter plot and regression relationship between the *acceleration* in MFP growth by industry in 2000 to 2004 (relative to 1995 to 2000) and the extent to which IT investment by industry was above trend in the late 1990s. As may be seen, the relationship is statistically significant. Furthermore, although the regression explains only a small portion of the cross-sectional variance in productivity gains by industry in recent years, the effect appears despite the fact that the period analyzed contains a recession.

All told, the result shown in chart 2 suggests that the productivity-enhancing effects of installed IT capital (above and beyond the usual attribution in growth accounting) may still have been part of the story of the remarkable pace of U.S. economic growth since 2000. Because this "above and beyond" effect should only prove temporary, the result is consistent with the time-series analysis in suggesting that the underlying growth rate of aggregate productivity is likely to slow, albeit to a pace that would still be quite strong by historical standards.

5. Conclusion.

This paper introduces new estimates of aggregate, sectoral, and industry productivity. The estimates are based on an appropriate theoretical framework for how industry and sectoral MFP feed into aggregate MFP, and are developed using industry data classified according to NAICS from 1987 on.

The six sectors we studied were designed to highlight differences among groups of industries in terms of their deliveries to final demand. Using this approach, we were able to provide new decompositions of economic growth and paint a rich picture of recent productivity developments in the United States. Our results indicate that the six sectors have had very different trends in multifactor productivity growth and made contributions to aggregate productivity that varied notably within the period from 1995 to the present. Nonetheless, by 2004 the resurgence in productivity growth that started in the mid-1990s was found to have been relatively broad-based and likely still driven by IT.

Given the macroeconomic importance of productivity, along with our finding that productivity has been the major source of the output gains since 2000, we believe it is especially important to understand the sources of productivity and to assess their implications for the period going forward. This paper has taken a modest step in this direction, but our work also raises questions, such as how the finance and business services sector experienced such a remarkable turnaround in productivity in recent years. The role of IT capital is often discussed in the context of productivity in financial services (e.g., Triplett and Bosworth), but it is important to remember that human capital also is an important input in the financial and business services industries more broadly (Jorgenson, Ho, and Stiroh 2005a, 2005b). Our results do not include an explicit adjustment to account for the role of human capital in business sector productivity statistics. Furthermore, if the economy's aggregate production depends on uncounted intangible capital as in Corrado, Hulten, and Sichel (2005, 2006a), the expanded view heightens the importance of this sector. Uncounted investments in innovation (R&D, for example), organizational practices, and business strategies are not just inputs to production in the finance and business sector as in other sectors. Many of these intangibles are part of *the output* of this sector.

Stepping back from our specific results, an inherent advantage of approaching productivity at an "intermediate" level of aggregation is that the effects of the underlying economic mechanisms may be discerned. In this paper, we chose to construct intermediate aggregates using vertical chains as a grouping principle. As mentioned in section 4, our interpretation of productivity developments in, for example, construction may change if the construction sector were to be grouped with construction materials, real estate, and mortgage finance. Other aggregations of the same underlying industry productivity estimates are possible in the Domar framework used in this paper. For example, one could combine industries into aggregates that reflect the cyclicality of final demand (i.e., industries that supply consumer durables, cyclical business equipment, exports, intermediates, and so on), the cyclical sensitivity of productivity, the level of innovative activity, the dependence on suppliers, purchases of IT capital, the competitiveness of markets, the average quality of labor input, the sensitivity to energy prices, and so on. These explorations remain the topic for future work.

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Table 1

The Private Nonfarm Business Sectors and their Relative Sizes, 2004

Billions of dollars	Total Sectoral Output[1] (1)	Deliveries to Final Users[2] (2)	Deliveries to PNFB Sectors (3)	Gross Output (4)	Value Added (5)	Employment[3] (6)
Private nonfarm business	9,504	9,504	0	16,480	8,616	97,949
High-tech	995	715	280	1,187	562	3,713
Excluding high-tech	9,169	8,789	380	15,293	8,054	94,236
Construction	1,050	991	59	1,051	550	8,250
Industrial	3,299	2,436	863	4,687	1,735	14,579
Distribution	2,660	1,899	761	2,835	1,791	23,644
Finance and business	3,308	1,773	1,535	4,525	2,730	25,206
Personal and cultural	2,014	1,691	323	2,197	1,249	22,557
Shares (percent)						
High-tech	10.5	7.5	---	7.2	6.5	3.8
Construction	11.0	10.4	---	6.4	6.4	8.4
Industrial	34.7	25.6	---	28.4	20.1	14.9
Distribution	28.0	20.0	---	17.2	20.8	24.2
Finance and business	34.8	18.7	---	27.5	31.7	25.7
Personal and cultural	21.2	17.8	---	13.3	14.5	23.0
Sum of six sectors	140.2	100.0	---	100.0	100.0	100.0

--- not applicable.

1. The shares in the lower half of column (1) are Domar weights.

2. Final users is final demand plus industries excluded from private nonfarm business.

3. Thousands, persons engaged in production (full-time equivalent workers plus self-employed workers).

Note—The industry composition of each sector is reported in Corrado *et al.* (2006b).

Table 2

Sources of growth in sectoral output for major and "intermediate" sectors of the U.S. economy[1]

	Sectoral Output (1)	MFP (2)	IT Capital[2] (3)	Other Capital[3] (4)	Labor (5)	Purchased Inputs[4] (6)
A. 1995 to 2000						
1. Private nonfarm business	5.4	1.1	1.0	.8	1.5	1.0
2. Excl. high-tech	4.6	.4	.8	.8	1.2	1.4
3. Construction	4.8	-.8	.2	.3	1.8	3.3
4. Industrial	2.6	.2	.3	.3	-.1	1.9
5. Distribution	5.3	2.3	.5	.6	.7	1.1
6. Finance and business	6.6	-.6	1.5	1.1	1.8	2.8
7. Personal and cultural	3.6	-.6	.3	.4	1.1	2.3
8. High-tech	17.6	6.8	1.5	.6	2.4	6.4
B. 2000 to 2004						
1. Private nonfarm business	2.3	2.3	.4	.3	-.8	.0
2. Excl. high-tech	2.0	1.8	.4	.3	-.5	.0
3. Construction	.9	-.2	.1	.2	-.1	1.0
4. Industrial	.6	1.1	.1	.1	-1.2	.5
5. Distribution	3.1	2.5	.2	.1	-.4	.7
6. Finance and business	2.8	1.9	.7	.4	-.3	.1
7. Personal and cultural	2.1	.2	.2	.3	.6	.8
8. High-tech	3.2	5.3	.4	.2	-2.3	-.3
C. Difference in Annual Averages, (1995 to 2000) vs. (1987 to 1995)						
1. Private nonfarm business	2.4	.3	.5	.2	.7	.7
2. Excl. high-tech	2.0	-.1	.4	.2	.5	.9
3. Construction	4.6	-.5	.1	.3	1.3	3.4
4. Industrial	.8	-.4	.1	.1	.0	1.0
5. Distribution	1.2	.7	.3	.3	.2	-.3
6. Finance and business	3.2	-.2	.7	.1	.9	1.7
7. Personal and cultural	.8	.1	.1	.0	-.3	.8
8. High-tech	8.0	2.6	.9	.0	2.0	2.6
D. Difference in Annual Averages, (2000 to 2004) vs. (1995 to 2000)						
1. Private nonfarm business	-3.1	1.2	-.5	-.5	-2.2	-1.0
2. Excl. high-tech	-2.6	1.5	-.4	-.5	-1.8	-1.4
4. Construction	-3.9	.6	-.1	-.2	-1.9	-2.3
3. Industrial	-2.0	.9	-.2	-.2	-1.1	-1.4
5. Distribution	-2.2	.2	-.3	-.5	-1.1	-.5
6. Finance and business	-3.8	2.5	-.8	-.7	-2.1	-2.7
7. Personal and cultural	-1.5	.8	-.1	-.1	-.5	-1.6
8. High-tech	-14.4	-1.6	-1.1	-.4	-4.7	-6.7

1. Average annual rate for period shown. Column (1) is percent change. Columns (2) through (6) are percentage points.

2. Computers and peripheral equipment, software, and communication equipment.

3. Non-IT equipment, structures, and inventories.

4. Combined contribution of domestic and imported purchased inputs.

Note—For each row, column (1) equals the sum of columns (2) through (6).

Table 3

Sectoral decomposition of sources of growth for private nonfarm business[1]

	MFP (1)	IT Capital[2] (2)	Other Capital[3] (3)	Labor (4)	*Memo:* Domar Wght. (5)
A. 1995 to 2000					
1. Private nonfarm business	1.11	.98	.84	1.46	-----
2. Excl. high-tech	.34	.81	.77	1.19	95.3
3. Construction	-.09	.02	.03	.19	10.3
4. Industrial	.07	.11	.12	-.02	37.8
5. Distribution	.66	.14	.17	.21	28.3
6. Finance and business	-.19	.48	.36	.60	32.3
7. Personal and cultural	-.12	.06	.09	.22	20.2
8. High-tech	.78	.17	.07	.27	11.5
B. 2000 to 2004					
1. Private nonfarm business	2.34	.44	.30	-.76	-----
2. Excl. high-tech	1.76	.39	.28	-.50	95.9
3. Construction	-.03	.01	.02	-.01	10.9
4. Industrial	.38	.04	.03	-.42	34.6
5. Distribution	.70	.06	.03	-.11	27.6
6. Finance and business	.66	.24	.14	-.09	34.5
7. Personal and cultural	.04	.04	.07	.14	21.1
8. High-tech	.56	.05	.02	-.25	10.9
C. Difference in Annual Averages, (1995 to 2000) vs. (1987 to 1995)					
1. Private nonfarm business	.30	.52	.21	.69	-----
2. Excl. high-tech	-.09	.41	.20	.45	-1.6
3. Construction	-.06	.01	.03	.13	0.2
4. Industrial	-.19	.04	.03	-.01	-5.2
5. Distribution	.20	.08	.09	.04	-0.6
6. Finance and business	-.07	.26	.06	.33	3.4
7. Personal and cultural	.02	.02	.00	-.04	0.5
8. High-tech	.39	.11	.01	.24	2.3
D. Difference in Annual Averages, (2000 to 2004) vs. (1995 to 2000)					
1. Private nonfarm business	1.23	-.54	-.54	-2.22	-----
2. Excl. high-tech	1.42	-.42	-.49	-1.69	0.5
3. Construction	.06	-.01	-.02	-.20	0.6
4. Industrial	.31	-.07	-.08	-.39	-3.2
5. Distribution	.04	-.08	-.14	-.32	-0.6
6. Finance and business	.84	-.23	-.23	-.69	2.2
7. Personal and cultural	.17	-.02	-.02	-.09	1.0
8. High-tech	-.22	-.13	-.05	-.52	-0.6

---- not applicable

1. Average annual rate for period shown. All entries (except memo item) are percentage point contributions to the growth of private nonfarm business sectoral output.

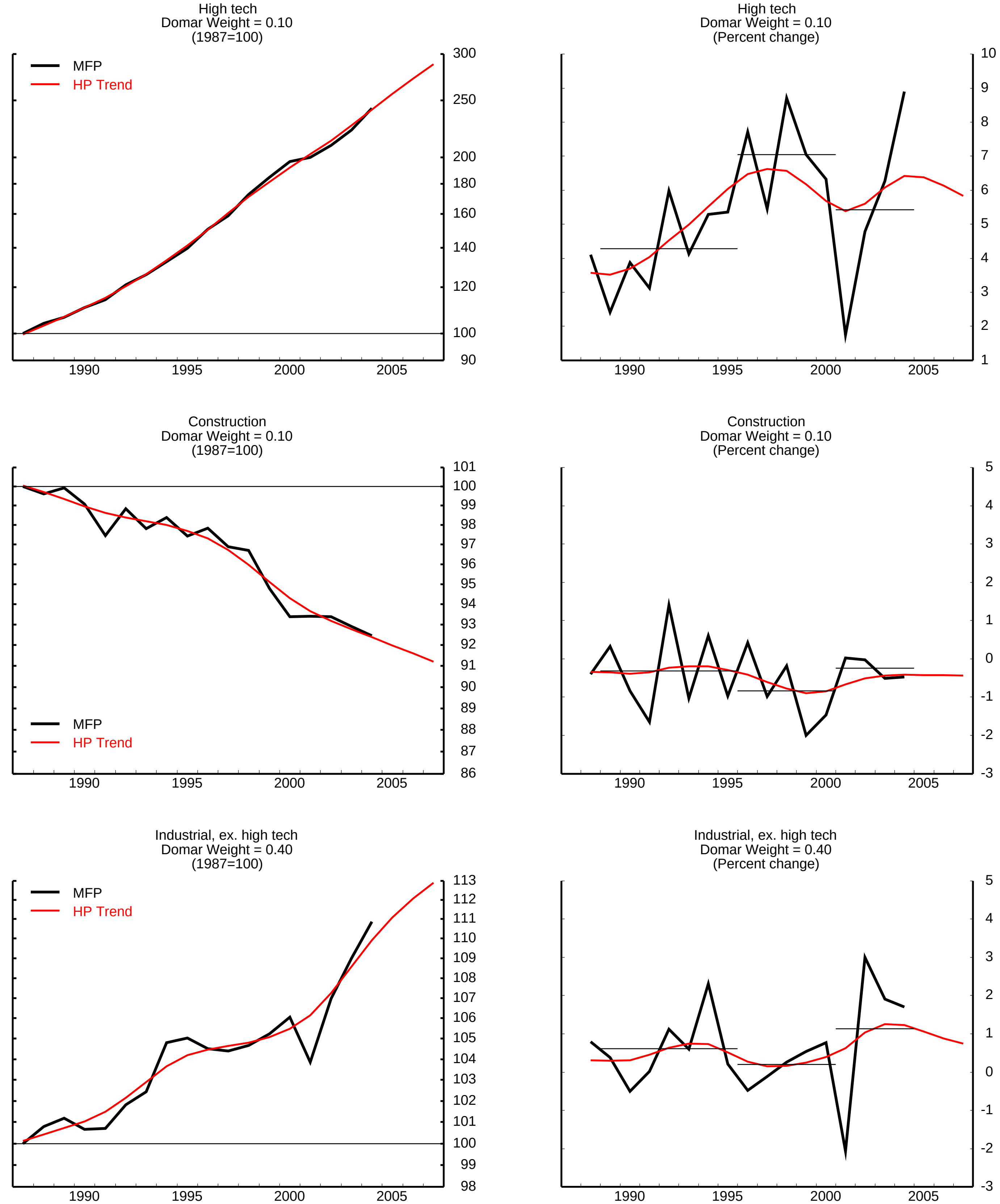
2. Computers and peripheral equipment, software, and communication equipment.

3. Non-IT equipment, structures, and inventories.

Note—In each panel, row (1) equals the sum of rows (3) through (8).

Chart 1

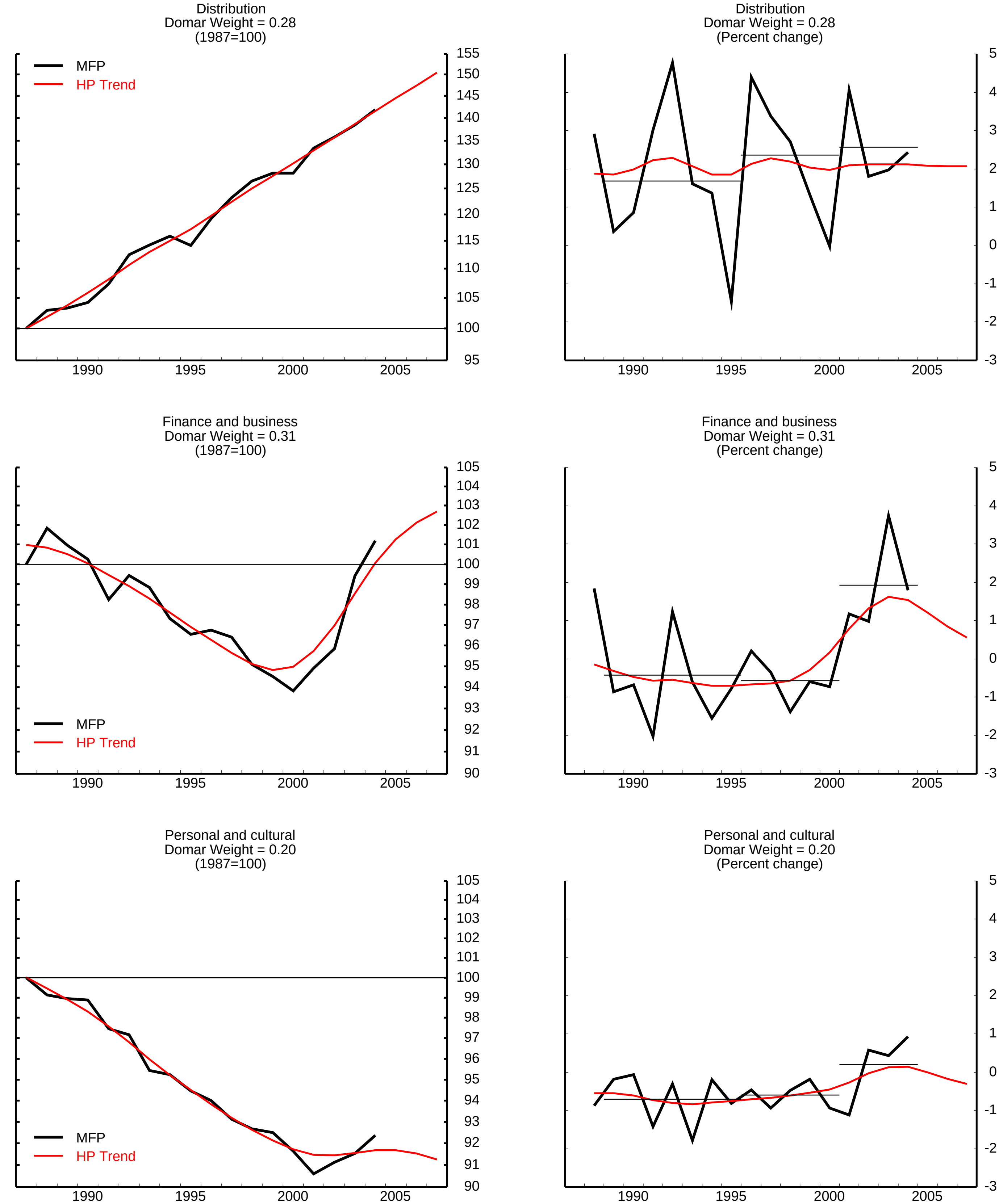
Multifactor Productivity
Major Producing Sectors



Note: Domar weights are 1987-2004 averages.

Chart 1 (continued)

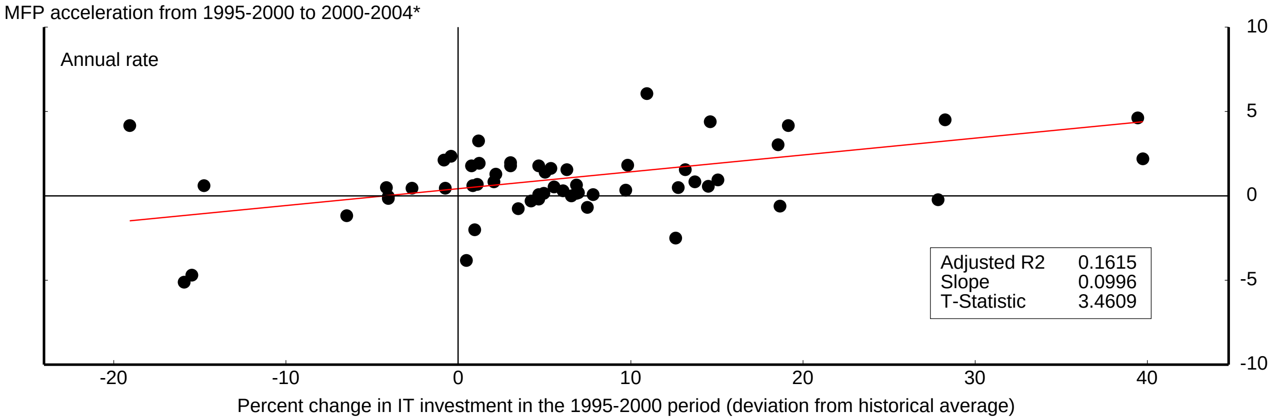
Multifactor Productivity
Major Producing Sectors



Note: Domar weights are 1987-2004 averages.

Chart 2

IT Investment and MFP by Industry



*Excludes High Tech industries. The acceleration in MFP is the percent change in MFP between 2000 and 2004 (annual rate) minus the percent change between 1995 and 2000 (annual rate).