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PRICES OF HIGH-TECH PRODUCTS, MISMEASUREMENT, AND PACE OF INNOVATION

David Byrne
Stephen Oliner
Daniel Sichel

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ABSTRACT

Two recent papers have made compelling cases that mismeasurement of prices of high tech products cannot explain the slow pace of labor productivity growth that has prevailed since the mid-2000s. Does that result indicate that mismeasurement of high-tech products has limited implications for patterns of economic growth? The answer in this paper is "no." We demonstrate that the understatement of price declines for high-tech products in official measures has a dramatic effect on the pattern of MFP growth across sectors. In particular, we show that correcting this mismeasurement implies faster MFP growth in high-tech sectors and slower MFP advance outside the high-tech sector. If MFP growth is taken as a rough proxy for the pace of innovation, our results suggest that innovation in the tech sector has been more rapid than the rate that would be inferred from official statistics (and less rapid outside high-tech). These results deepen the productivity puzzle. If the pace of innovation in high-tech sectors has been more rapid than indicated by official statistics, then it is perhaps even more puzzling that overall labor productivity growth has been so sluggish in recent years.

David Byrne
Federal Reserve Board
20th & Constitution Ave., NW
Washington, DC 20551
david.m.byrne@frb.gov

Stephen Oliner
American Enterprise Institute
1150 17th St., NW
Washington, DC 20036
and UCLA Ziman Center for Real Estate
stephen.oliner@aei.org

Daniel Sichel
Department of Economics
Wellesley College
106 Central Street
Wellesley, MA 02481
and NBER
dsichel@wellesley.edu

1. Introduction

Economists and others have offered many explanations for the slowdown in U.S. productivity growth that began in the mid-2000s, with labor productivity in the business sector rising just over ½ percent at an annual rate from 2010 to 2015, well below the pace over the boom years of 1995-2004 and even below the already reduced rate that prevailed over 2004-2010. Focusing on the supply side of the economy, Gordon (2016) argues that the IT revolution is just not as big a deal as the second industrial revolution and that the boost to productivity growth rates from IT largely is behind us.[1] Focusing on the demand side, Summers (2014) has resurrected the Depression-era term "secular stagnation," arguing that the economy is generating insufficient demand. Others have argued that the tools of economic measurement have not kept up with the digital revolution and that economic growth has been stronger than reflected in official statistics. One strand of this argument focuses on items within the current scope of GDP, positing mismeasurement of key GDP components. (See Goldman Sachs (2015 and 2016), for example.) Another strand looks beyond the current scope of GDP, making the case that economic welfare has improved much more rapidly than have measures of productivity.[2]

This paper contributes to the "within GDP" debate, focusing on the mismeasurement of prices of high-tech products. As noted, Goldman Sachs and others have made the case that the productivity slowdown can be explained, at least in part, by mismeasurement of the digital economy. Since that argument emerged, two papers have countered that claim. Byrne, Fernald, and Reinsdorf (2016) carefully examined the

[1] Fernald (2014) and Byrne, Oliner, and Sichel (2013) provide growth-accounting evidence documenting the dropback in the contribution from the use and production of high-tech products to labor and multifactor productivity (MFP) growth. Fernald, Hall, Stock, and Watson (2017) highlight the important role of slower MFP growth and a decline in labor force participation in the slowdown in labor productivity growth.

[2] For example, see Brynjolfsson and Oh (2013).

evidence and concluded that mismeasurement does not provide an explanation of the slowdown. Syverson (2016), using a completely different methodology, also made a compelling case that mismeasurement cannot explain the productivity slowdown.

But, is this the end of the story? Should we conclude that mismeasurement of high-tech prices and the digital economy have no important consequences for patterns of economic growth? This paper argues that mismeasurement does matter. In particular, mismeasurement matters for the allocation and pattern of multifactor productivity (MFP) growth across sectors. To demonstrate this, we take estimates of the amount of mismeasurement of prices of high-tech products from the literature and feed these through a standard growth accounting framework to examine the implications of this mismeasurement for sectoral MFP growth.

Our results show that the mismeasurement of high-tech prices has a dramatic effect on the pattern of MFP growth across sectors. Specifically, the faster decline of prices of high-tech products implies a faster pace of MFP growth in high-tech sectors and a slower rate of MFP advance outside the high-tech sector. If we take MFP growth as a rough proxy for the pace of innovation, our results suggest that innovation in the tech sector has been more rapid than the rate that would be inferred from official statistics (and even slower outside high-tech). At the same time, our results confirm that this mismeasurement does not explain the labor productivity slowdown and has a relatively modest effect on aggregate MFP growth.

We believe these results are important for three reasons. First, they deepen the productivity puzzle. If the pace of innovation in the high-tech sectors has been more rapid than indicated by official statistics, then it is perhaps even more puzzling that overall labor productivity growth has been so sluggish in recent years. Second, we believe narratives about the prospects for growth have been improperly darkened by the view that innovation, even in the tech sector, has been weak. According to official statistics, prices of tech products have barely been falling in recent years. And, that slow rate of price decline in the tech sector has implied, via the dual approach to productivity measurement, a slow rate of MFP growth. This has led, in turn, to inferences that the pace of innovation in the tech sector has faltered.[3] Finally, a faster rate of innovation in the tech sector implies, via a multi-sector growth model, a faster steady-state rate of growth in labor productivity even with the slower rate of MFP growth outside the tech sector. Accordingly, we argue that the pattern of MFP growth across industries may presage a second wave of productivity advance supported by the digital economy.[4]

2. A Standard Framework for Growth Accounting

We use a standard framework for growth accounting, as described in Fernald (2014) and Byrne, Oliner, and Sichel (2013). That framework has two basic elements: 1) a decomposition of labor productivity growth into contributions from capital deepening, labor quality, and MFP; and 2) a decomposition of MFP growth into contributions from different sectors. For the decomposition of labor productivity, the key equation is:

$$\dot{y} - \dot{h} = \sum_{i=1}^{k} \alpha_i^K (\dot{k}_i - \dot{h}) + \alpha_L \dot{q} + \dot{mfp} \quad (1)$$

where $\dot{y}$ is the growth rate of output, $\dot{h}$ is the growth rate of total hours, $\dot{k}_i$ is the growth rate of capital services for capital of type i, α_i^K is the income share for capital of type i,

[3] For example, see figure 13-1 in Gordon (2016) and the surrounding discussion.
[4] In a similar vein, van Ark (2016) argues that the digital economy is still in the "installation" phase and that growth may pick up when the "deployment" phase is reached.

$\alpha_L \dot{q}$ is the contribution of changes in labor quality to labor productivity growth and $\dot{mfp}$ is the growth rate of MFP. Although time subscripts have been suppressed for expositional clarity, all of the variables and parameters in equation 1 (including the income shares) are time varying.

We modify Fernald's framework by disaggregating capital into five broad types: computer hardware, communications equipment, software, other intellectual property (research and development and artistic originals), and all other capital. We assume constant returns to scale so the labor income share (α_L) and the capital income shares sum to one. Finally, although not shown in equation 1, we include an adjustment for the utilization of capital.

We also extend Fernald's framework by including a more detailed decomposition of MFP growth. This decomposition is described in Byrne, Oliner, and Sichel (2013), and can be expressed as:

$$\dot{mfp} = \sum_{i=1}^{5} \mu_i \dot{mfp}_i + \mu_S \dot{mfp}_S \qquad (2)$$

where $\dot{mfp}_i$ is MFP growth in sector *i* (including computer hardware, communications equipment, software, other intellectual property, and all other final demand output), $\dot{mfp}_S$ is MFP growth in the semiconductor sector, and the μ's are Domar weights for aggregating MFP growth rates. We separate the contribution for semiconductors in equation 2 because, except for net exports, they are intermediate inputs and are handled differently in the growth accounting equations than are other products that are components of final demand.

To empirically implement the decomposition of labor productivity in equation 1, we use Fernald's data for the business sector. Note that Fernald measures output as an average of gross domestic product and gross domestic income, so the productivity figures will not match those published by the Bureau of Labor Statistics (which rely solely on gross domestic product).

To empirically implement the MFP decomposition in equation 2, we measure the sectoral MFP growth rates using the dual approach described in Byrne, Oliner, and Sichel (2013). In the dual approach, the rate of price change for output of a sector (say, semiconductors) is decomposed as a weighted average of the growth rates of labor costs and the cost of capital *less* the growth rate of MFP. The logic is that faster MFP growth would, all else equal, hold down rates of price change for a sector's output. Thus, MFP growth rates can be inferred from relative price changes. We use standard data from the Bureau of Economic Analysis, the Bureau of Labor Statistics, and data on the tech sector from some other sources. All of our data sources are described in the data appendix to Byrne, Oliner, and Sichel (2013).

With equations 1 and 2, we have the tools needed to assess the impact of mismeasurement on labor productivity growth, total MFP growth, and MFP growth in individual sectors. In particular, we can compare estimates for those measures based on official measures of high-tech prices and on alternative measures of tech prices that adjust for likely biases in the official data.

3. Mismeasurement of Prices of High-Tech Products

While official measures of prices point to very slow rates of decline in recent years, a growing literature indicates that these measures understate the rate of price decline.[5]

For example, Byrne, Oliner, and Sichel (forthcoming) developed a new index for microprocessors (MPUs) used in desktop personal computers. Their preferred index fell at an average rate of 42 percent a year over 2009-2013, while the most comparable official price measure—the Producer Price Index (PPI) for microprocessors—reports an average decline of only 6 percent a year.

This measurement gap for MPUs arose in the mid-2000s because of a major change in the lifecycle pattern of Intel's posted prices for MPUs.[6] Prior to that time, posted prices of MPUs tended to fall over their lifecycle, and a matched-model index such as the PPI would rely on those declines to capture quality change. Since the mid-2000s, posted prices of Intel MPUs have tended to be flat. Using these relatively flat price profiles, a matched-model index will indicate little change in quality-adjusted prices even if quality is improving. Byrne, Oliner, and Sichel (forthcoming) developed a hedonic index that could capture ongoing quality change and generated the more rapid price declines reported above.

We believe measurement problems also are present for other types of high-tech products, although the sources of problems differ across products. For computer hardware, communications equipment, and software, we rely on alternative research

[5] See Byrne, Oliner, and Sichel (2016 and forthcoming), Byrne and Corrado (2016), Byrne (2015a and 2015b), and Byrne, Fernald, and Reinsdorf (2016).

[6] Byrne, Oliner, and Sichel (forthcoming) use posted prices for Intel MPUs because transaction prices are unavailable. Although BLS does not indicate which prices are included in the PPI for MPUs, we are able to replicate the trend in the PPI with a matched-model index that uses only Intel's posted prices.

indexes developed by Byrne and Corrado (2016), which are the series used by Byrne, Fernald, and Reinsdorf (2016) in their analysis demonstrating that mismeasurement of high-tech prices does not explain the mid-2000s slowdown in labor productivity growth. Byrne and Corrado did extensive work to develop these indexes, and, while additional research will surely improve on their indexes, their work provides the best available measures of the amount of bias in official price indexes for high-tech products. Table 1 reports rates of change in official price indexes and the alternative research price indexes for computers, communications equipment, software, and semiconductors.[7] (Note that the semiconductor index shown in the table is for all semiconductors rather than MPUs, and it incorporates the MPU estimates described above.)

As shown in the last column of the table, measurement gaps—which equal the difference between the percent changes of the official price index and the alternative research index—are sizable for all of the high-tech products shown. Over the period 2004-2015, these gaps range from 5.4 percentage points for communications equipment to 13.6 percentage points for semiconductors.

4. How Much Does Mismeasurement of Tech Prices Affect *Labor* Productivity?

To answer this question, we implement the standard growth accounting framework described above using official price indexes and the alternative research indexes. For the implementation relying on the alternative price indexes, we make two types of adjustments. First, we adjust real GDP to account for the more rapid declines in

[7] The alternative research prices shown in table 1 are price indexes for output. We use these output price indexes in all of our calculations with alternative research prices with one exception. The exception is for estimates of capital deepening in the decomposition of labor productivity. For those calculations we use Byrne and Corrado's investment price series as the alternative research index.

deflators for final demand of high-tech products. Second, we adjust capital services to reflect the different trends in real investment in high-tech products arising from the alternative research price measures.

Results for labor productivity are summarized in tables 2A-2C and figure 1. Table 2A shows the standard decomposition of growth in labor productivity using official prices. The figures show the well-known pattern of a pickup in labor productivity growth in the period from 1995 to 2004, a slowdown after 2004, and then another slowdown after 2010. The pickup after 1995 reflects a jump in contributions from capital deepening and MFP growth. The slowdown in 2004 mostly reflects a slowdown in MFP growth. As Fernald (2014) and others have highlighted, this stepdown occurred prior to the financial crisis so it is difficult to find its source in the financial crisis and Great Recession. However, the dropback in labor productivity growth after 2010 was concentrated in capital deepening. This retrenchment might well reflect effects of the Great Recession as expectations of weak future demand and heightened uncertainty restrained business investment.[8]

Table 2B reports results using the alternative research price measures. The broad patterns are the same as in the decomposition relying on official price measures. And, as shown in table 2C, the differences are fairly small between the decompositions using official and alternative research prices. Although labor productivity growth is somewhat higher using the alternative research indexes, the contribution of capital deepening also is

[8] The figures discussed here follow current U.S. national income accounting conventions, which include only some types of intangible investment—specifically, software, research and development, and artistic originals. Corrado, Hulten, and Sichel (2009) argued for the inclusion of a wider set of intangibles as business investment, including organizational capital, training, product development and design, and brand equity. Corrado, Haskel, Jona-Lasino, and Iommi (2016) note that business investment including the full set of intangibles has held up better than has business investment as reported in the U.S. National Accounts. Accordingly, capital deepening and labor productivity could be stronger than shown in the official data.

higher. Consequently, switching to the alternative research indexes has a relatively modest effect on aggregate MFP growth. These patterns also are evident in figure 1, which shows stacked bar charts for the labor productivity decomposition with both official prices and the alternative research prices.[9]

These comparisons confirm the conclusion reached by Byrne, Fernald, and Reinsdorf (2016) and Syverson (2016) that mismeasurement of tech prices does not explain the productivity slowdown around 2004. Correcting the likely biases in tech prices does boost labor productivity by about a quarter percentage point over 2004-2015, but that correction also boosts growth by similar amounts prior to 2004.

5. How Much Does Mismeasurement of High-Tech Prices Affect *MFP* Growth?

As noted, correcting the mismeasurement of tech prices has a relatively modest effect on total MFP growth because the increment to labor productivity growth is not much bigger than that to the contribution of capital deepening. However, correcting the mismeasurement of tech prices has a much more dramatic effect on the allocation of MFP growth across sectors.

For the sectoral decomposition of MFP growth, we use the dual approach to estimate MFP for each sector, relying on changes in the relative price of output in each sector to estimate MFP growth.[10] This link between price trends in each sector and MFP growth means that correcting the mismeasurement of tech prices can affect MFP growth rates. Of course, given the earlier results that switching from official measures of tech prices to the alternative price indexes had only a small effect on total MFP growth, the

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[9] Figure 1 reports contributions for aggregate MFP growth without the utilization adjustment.
[10] Details of the dual approach are described in Oliner and Sichel (2002) and Byrne, Oliner, and Sichel (2013).

changes in MFP growth rates that we identify largely are to the *allocation* of MFP growth across sectors. Our results are shown in tables 3A-3C and in figures 2 through 7.

Table 3A reports our MFP decomposition using official measures of tech prices. The estimates show the pickup in MFP growth rates across sectors after 1995 and the widespread slowdown after 2004. After 2010, growth rates stepped down in the high-tech sector (with a large dropback in semiconductors), and were little changed outside the tech sector.

Table 3B shows MFP growth rates based on the alternative research measures of tech prices, while table 3C shows the difference between growth rates using official prices and the alternative research prices. As these panels indicate, MFP growth rates for the tech sectors are noticeably more rapid using the alternative research measures for tech prices. At the same time, MFP growth rates are slower in the "All other" sector when using the alternative research prices. Put another way, using the alternative research series causes a reallocation of MFP growth across sectors, with more rapid growth in tech and less rapid growth outside the tech sector.

Turning to the details, MFP growth rates in the high-tech sector are higher over every period when the alternative research prices are used as can be seen in figures 2 through 7. The same story is evident by comparing tables 3A and 3B. And, as shown in table 3C, the gap between MFP growth rates in the high-tech sector with official and alternative research prices steps up noticeably after 1995 and increases further after 2010. Over the period from 2010 to 2015, the amount of mismeasurement for semiconductors increases dramatically, while the amount of mismeasurement for the other categories of tech products decreases. This dropback in the amount of mismeasurement for computing and communications equipment partly reflects the jump in mismeasurement in the semiconductor sector because our model estimates MFP growth in the computer and communications equipment sectors net of the contribution from semiconductors.

As noted, the use of the alternative research prices reduces the growth rate of MFP in the rest of the economy (the “All other” sector), with MFP estimated to be little changed since 2004. This result is, perhaps, puzzling. Is it credible that MFP growth in a large swath of the economy was essentially flat on average for a decade?[11] We believe several factors may account for this weak performance.

First, it is possible that mismeasurement also is present in final demand prices for products in the “All other” sector. If inflation is overstated in this sector, then correcting this mismeasurement would boost real output growth and MFP growth. One area of possible mismeasurement is related to so-called “factoryless” manufacturing, where a company’s U.S. establishment provides product designs and maintains control of the production process by approving inputs and outputs, but outsources the actual fabrication to a contract manufacturer abroad.[12] A key measurement question is, what price deflator to use for the design, development, and management value added that occurs within the United States? Currently, that value added is not uniformly included in the manufacturing sector, and it is not deflated with prices of the products produced by the company. Thus, for high-tech companies in this situation, much of their U.S. value added is not deflated with high-tech prices deflators even though the company is producing high-tech products. Using high-tech deflators for this design and development work would boost the growth of measured real output, labor productivity, and MFP.

[11] Corrado and Slifman (1999) raised a similar question about labor productivity growth in the noncorporate business sector and in services.
[12] See Bayard, Byrne, and Smith (2015) for a discussion of factoryless manufacturing.

Another possibility is that the very weak pattern of MFP in the “All other” sector is correctly capturing economic developments. As highlighted by van Ark (2016), the U.S. economy could be characterized as in a transition period, in which a host of technologies are being developed and installed but are not yet generating significant productivity gains. Put another way, firms may be paying adjustment costs as they begin to utilize new technologies, as discussed in Basu, Fernald, and Shapiro (2001). More generally, the historical record suggests that new technologies boost productivity with a significant lag.[13]

It also is possible that weak MFP growth across parts of the U.S. economy reflects a decline in business dynamism. According to an important strand of recent research, just such a decline has occurred in recent decades.[14] And, as noted by Decker, Haltiwanger, Jarmin, and Miranda (2015), since 2000 this decline in dynamism “has been accompanied by a decline in high-growth young firms.” Perhaps these forces are restraining MFP growth.

Providing an explanation of the weak performance of MFP growth in the “All other” sector is beyond the scope of this paper. That being said, we can easily imagine that its roots lie in some combination of the explanations given above.

6. Implications of Faster MFP Growth Rates in the Tech Sector

MFP growth rates often are used by macroeconomists as rough proxies for rates of innovation. Thus, the reallocation of MFP growth rates across sectors suggests that the

[13] See David (1990).
[14] See Decker , Haltiwanger, Jarmin, and Miranda (2014).

pace of innovation in tech sectors has been more rapid than would be inferred from figures based on official measures of high-tech prices.

We believe that these faster implied rates of innovation in the tech sector are important for three reasons. First, these results deepen the productivity paradox. If the pace of innovation in the tech sector has been more rapid than implied by official data, then it is perhaps even more of a puzzle that productivity growth has remained so weak.

Second, as a rhetorical point, we believe that the sluggish rates of high-tech MFP growth implied by official price measures have improperly supported darker narratives about future prospects for productivity growth. The apparent weak pace of innovation in the tech sector provides fuel for the story that little scope remains for the tech sector to boost aggregate labor productivity growth.

Third, we believe that these faster rates of growth in high-tech could presage a second wave of higher productivity growth spurred by the digital revolution.[15] To make this argument, we rely on steady-state values from the multi-sector growth model used above.

Table 4A shows the actual growth in labor productivity and steady-state estimates of labor productivity growth over the full period from 1974 to 2015. The steady-state estimates shown—which are derived using the methodology described in Byrne, Oliner, and Sichel (2013)—confirm that the model fits long trends in the data reasonably well. As can be seen on the first line of the table, using official prices for tech products, the model implies steady-state growth in labor productivity of 2.0 percent a year, just about

[15] If views were to pivot toward greater optimism, such a shift could, according to Blanchard, Lorenzoni, and L'Hullier (2017), spur faster growth. Their work provides evidence that the economy's weak performance may, in part, reflect a self-fulfilling prophecy in which expectations of sluggish growth in potential output feed back to weaken actual economic growth.

the same as the actual average growth rate over that period. Repeating these calculations using the alternative research price series, the actual growth rate of labor productivity is 2.1 percent (accounting for the faster price declines of tech products in final demand), while the steady-state estimate is slightly higher at 2.4 percent.

The question we ask is, how far below its steady-state pace is the recent rate of increase in labor productivity? To answer this question, we compare the growth rate of actual labor productivity during 2010 to 2015 to our estimate of its current steady-state growth rate. To obtain the current steady state, we update the estimates in Byrne, Oliner, and Sichel (2013) using our best estimate of the current underlying trend in MFP growth in the "All other" sector and the model parameters that determine MFP growth in the high-tech sectors.[16] In our model, just as in a one-sector Solow growth model, the steady-state value of labor productivity growth is the sum of steady-state MFP growth, the amount of capital deepening induced by the steady-state MFP growth, and growth in labor quality.

Table 4B provides the numbers. Using official prices for high-tech products, actual labor productivity growth over 2010-2015 averaged just 0.8 percent. This figure is about ¾ percentage point below our estimate of the steady-state value of 1.5 percent based on current underlying trends and the official measures of high-tech prices.

The gap between recent actual growth rates of labor productivity and the steady state based on current underlying trends becomes larger if we use the alternative research prices. As shown in the lower panel of table 4B, labor productivity growth averaged 1.0

[16] Our procedure is to set a lower bound and upper bound for "All other" MFP growth and the many other parameters of the model. These bounds are set based on the historical and recent performance of each series. Our estimate of the current steady state is based on each parameter's midpoint value (between the lower and upper bounds).

percent over 2010-2015 with these alternative prices. The steady-state value using these prices stepped up to 2.2 percent, boosted by the greater capital deepening induced by the faster rates of innovation in the tech sector. Thus, using the alternative price series, the average growth rate of labor productivity over 2010-2015 is about 1¼ percentage points below its steady-state value. This gap primarily reflects a shortfall in capital deepening relative to what would occur in steady state.[17]

We recognize that steady-state values are relatively weak attractors, that convergence could take a long time, and that some recent work has expressed skepticism about a revival of investment.[18] Nonetheless, we believe that this evidence raises the possibility that the faster rates of innovation implied by the alternative research price measures could spur faster labor productivity in the future.[19]

7. Conclusion

In the recent debate about the labor productivity slowdown in the U.S., Byrne, Fernald, and Reinsdorf (2016) and Syverson (2016) showed that mismeasurement of high-tech prices cannot explain the slowdown. Nevertheless, available evidence points to considerable mismeasurement of high-tech prices, and this mismeasurement does have important implications. In particular, the evidence that prices of high-tech products are falling more rapidly than is reflected in official statistics implies a reallocation of MFP

[17] Alexander and Eberly (2016) and Gutierrez and Phillipon (2016) document that the weakness in investment began in the early 2000s, and both papers explore possible explanations.

[18] Fernald, Hall, Stock, and Watson (2017) argue that the actual value of the capital-output ratio currently is close to its cyclically-adjusted or trend level. However, they also note that the capital-output ratio is less than the steady-state value implied by standard growth theory, raising the possibility that the ratio has been pushed down by factors that may recede in the future.

[19] For additional reasons to be more optimistic about productivity, see Branstetter and Sichel (2017).

growth across sectors, with faster growth rates of MFP in high-tech sectors and slower growth rates elsewhere in the economy.

Macroeconomists often use growth rates of MFP as proxies for the pace of innovation so the faster rates of MFP growth in the high-tech sector indicate that rates of innovation in the digital economy have been more rapid than implied by official price measures. We believe this finding is important for three reasons. First, it deepens the productivity paradox; that is, the recent sluggish rates of productivity growth become even more puzzling given faster rates of innovation in the tech sector. Second, it raises questions about the darkened narratives about future prospects for productivity growth that have been based on the official price measures. Finally, the research price indexes that better capture the faster rates of innovation in the tech sector provide a reason to be more optimistic about future prospects for labor productivity growth.

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Table 1
Official and Alternative Research Price Indexes for High-Tech Products
average percent change, 2004-2015

	Official Index	**Alternative Research Index**	**Measurement Gap (pct pts)**
Computing equipment	-11.2	-18.9	7.7
Communications equipment	-2.4	-7.9	5.4
Software	-.2	-7.0	6.8
Semiconductors	-15.5	-29.1	13.6

Note: Measurement gaps calculated as "official" less "alternative."

Source: Official indexes for computing equipment, communications equipment, and software are from the Bureau of Economic Analysis; the official index for semiconductors is from the Bureau of Labor Statistics. Alternative research indexes are from Byrne and Corrado (2016), including some detail provided by Byrne and Corrado that are not reported in their paper.

Table 2A
Contributions to Labor Productivity Growth with *Official* Prices
1974-2015, percentage points

	1974-1995	**1995-2004**	**2004-2010**	**2010-2015**
Output per hour	1.65	3.27	1.90	.80
Capital deepening	.66	1.19	1.12	-.07
IT hardware	.29	.52	.25	.04
Intel. property	.18	.37	.31	.07
Other capital	.18	.30	.56	-.19
Labor quality	.28	.26	.37	.19
MFP	.72	1.81	.41	.68
Utilization adjustment	.05	-.20	-.04	.26
MFP adjusted	.67	2.01	.46	.41

Table 2B
Contributions to Labor Productivity Growth with *Alternative Research* Prices
1974-2015, percentage points

	1974-1995	**1995-2004**	**2004-2010**	**2010-2015**
Output per hour	1.79	3.61	2.19	1.03
Capital deepening	.73	1.38	1.35	.18
IT hardware	.36	.62	.38	.19
Intel. property	.19	.47	.38	.17
Other capital	.18	.30	.59	-.19
Labor quality	.28	.26	.37	.19
MFP	.78	1.97	.46	.66
Utilization adjustment	.05	-.20	-.04	.26
MFP adjusted	.73	2.17	.51	.40

Table 2C
Difference between Contributions with *Alternative Research* and *Official* Prices
1974-2015, percentage points

	1974-1995	**1995-2004**	**2004-2010**	**2010-2015**
Output per hour	.14	.35	.28	.24
Capital deepening	.07	.19	.23	.25
IT hardware	.07	.10	.13	.15
Intel. property	.01	.10	.07	.10
Other capital	.00	.00	.03	.00
Labor quality	.00	.00	.00	.00
MFP	.06	.16	.05	-.01
Utilization adjustment	.00	.00	.00	.00
MFP adjusted	.06	.16	.05	-.01

Note: Calculated as "alternative" less "official."

Table 3A
MFP Growth with *Official* Prices
1974-2015, percent

	1974-1995	1995-2004	2004-2010	2010-2015
MFP adjusted	.67	2.02	.47	.41
In sector				
High-tech sector	9.9	11.3	5.6	3.1
Computing equipment	15.1	12.5	9.6	8.1
Communications equip	1.0	1.1	1.5	2.7
Software	5.7	4.3	2.4	2.2
Semiconductors	26.2	44.7	25.0	6.4
All other	.37	1.48	.23	.29

Table 3B
MFP Growth with *Alternative Research* Prices
1974-2015, percent

	1974-1995	1995-2004	2004-2010	2010-2015
MFP adjusted	.74	2.17	.52	.40
In sector				
High-tech sector	13.9	17.4	11.8	10.9
Computing equipment	17.5	17.7	17.7	9.5
Communications equip	5.7	8.0	6.3	3.9
Software	13.7	12.7	9.1	8.4
Semiconductors	26.1	44.1	27.7	32.6
All other	.30	1.29	-.01	-.06

Table 3C
Difference between MFP Growth with *Alternative Research* and *Official* Prices
1974-2015, percentage points

	1974-1995	1995-2004	2004-2010	2010-2015
MFP adjusted	.06	.16	.05	-.01
In sector				
High-tech sector	4.0	6.1	6.1	7.9
Computing equipment	2.4	5.2	8.1	1.4
Communications equip	4.7	6.9	4.8	1.2
Software	7.9	8.5	6.7	6.2
Semiconductors	-.1	-.6	2.7	26.3
All other	-.07	-.19	-.23	-.35

Note: Calculated as “alternative” less “official.”

Table 4A
Actual and Steady-State Labor Productivity Growth Rates (percent)

	Actual 1974-2015	**Steady-state 1974-2015**
Official prices	1.9	2.0
Alternative research prices	2.1	2.4

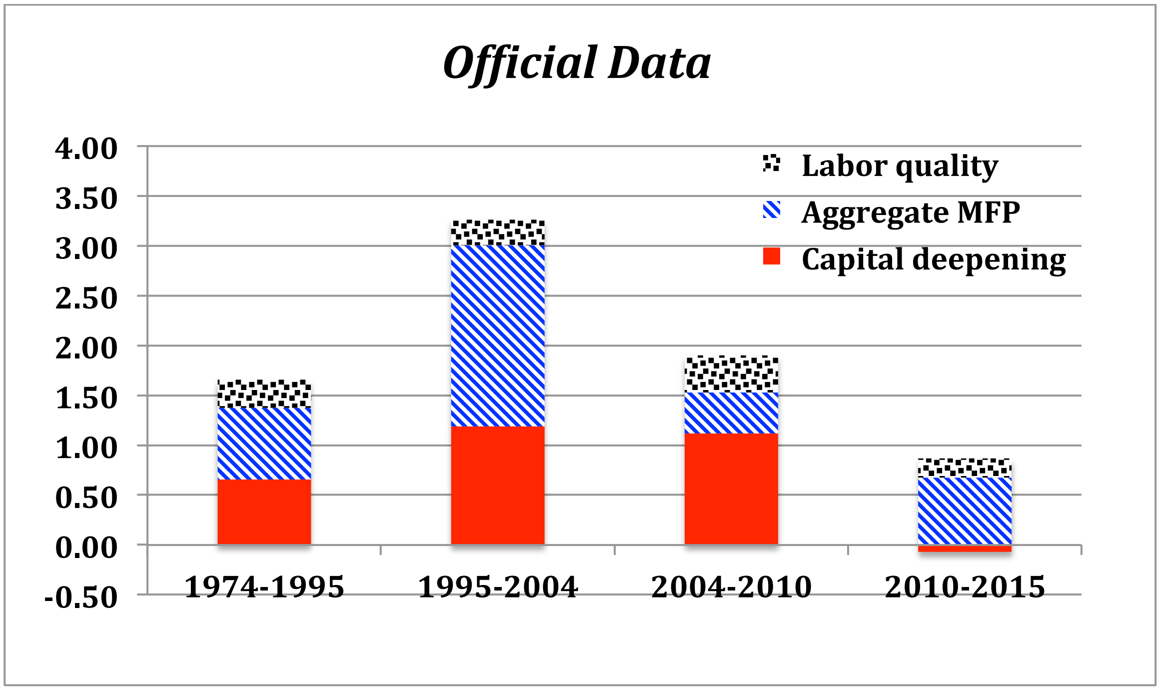
Note: The steady-state growth rates are derived from a multi-sector Solow growth model. The values using official prices and the alternative research prices differ only in the price series used for computing equipment, communications equipment, software, and semiconductors. The actual and the steady-state growth rates use Fernald's definition of business sector output.

Table 4B
Actual and Steady-State Labor Productivity Growth Rates (percent)

	Actual 2010-2015	**Steady-state based on current underlying trends**
Official prices	.8	1.5
MFP growth	.7	.7
Capital deepening	-.1	.8
Labor quality growth	.2	.1
Alternative research prices	1.0	2.2
MFP growth	.7	.8
Capital deepening	.2	1.3
Labor quality growth	.2	.1

Note: The values for the "current" steady-state are based on the authors' assessment of current underlying trends for MFP growth rates in each sector. The values using official prices and the alternative research prices differ only in the price series used for computing equipment, communications equipment, software, and semiconductors. Components may not sum to total due to rounding. The actual and steady-state figures use Fernald's definition of business sector output.

Figure 1
Decomposition of Labor Productivity Growth with *Official* and
Alternative Research Prices
1974-2015



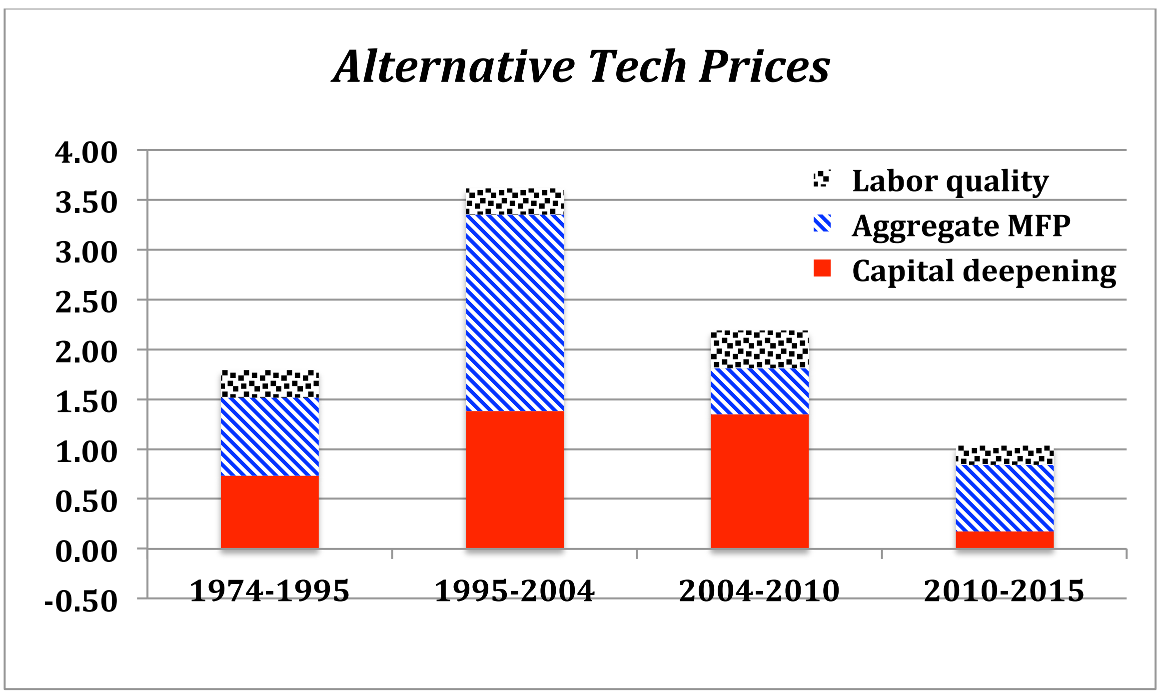


Figure 2
Total Tech Sector
MFP Growth Rates with *Official* and *Alternative Research* Prices
1974-2015, percent

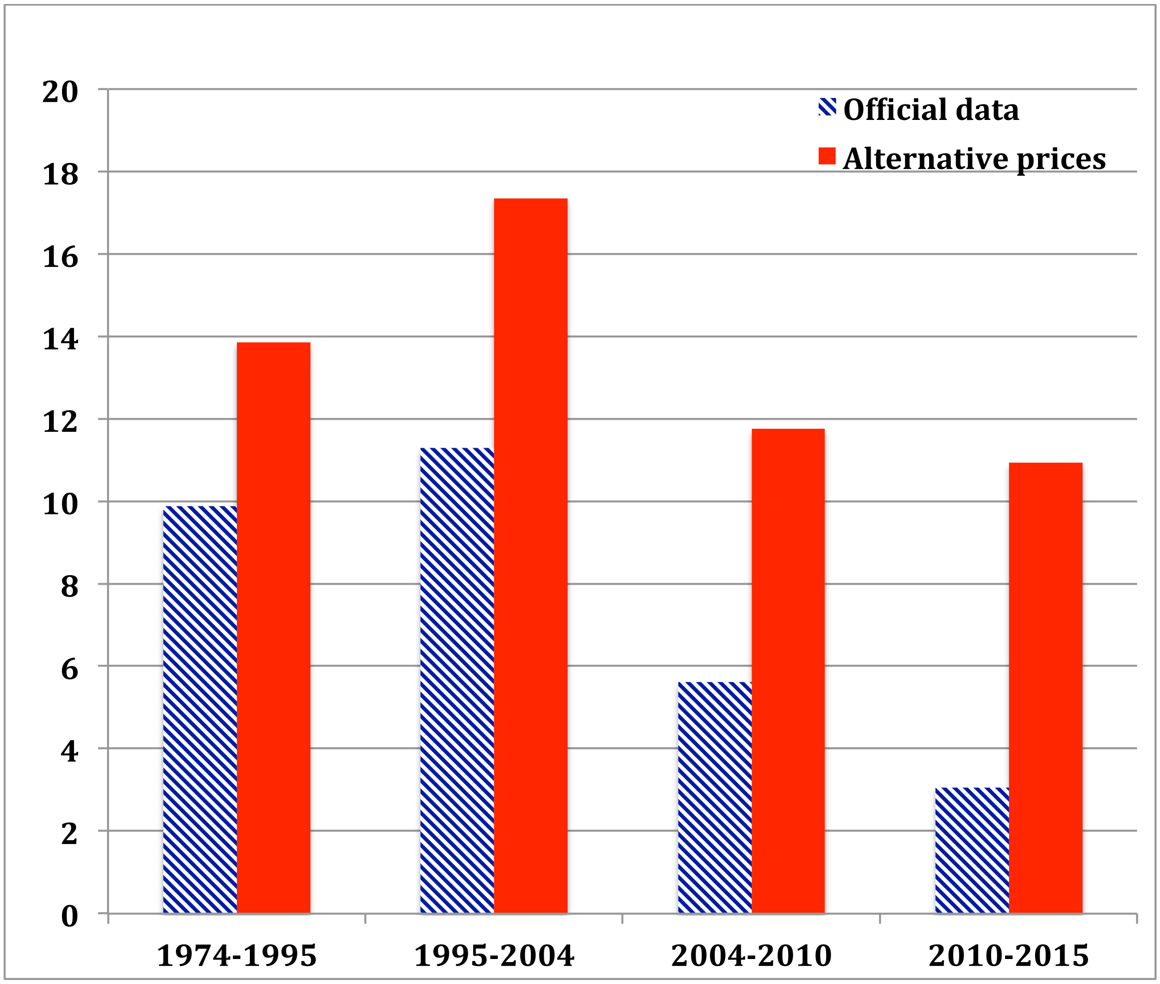


Figure 3
Computing Equipment
MFP Growth Rates with *Official* and *Alternative Research* Prices
1974-2015, percent

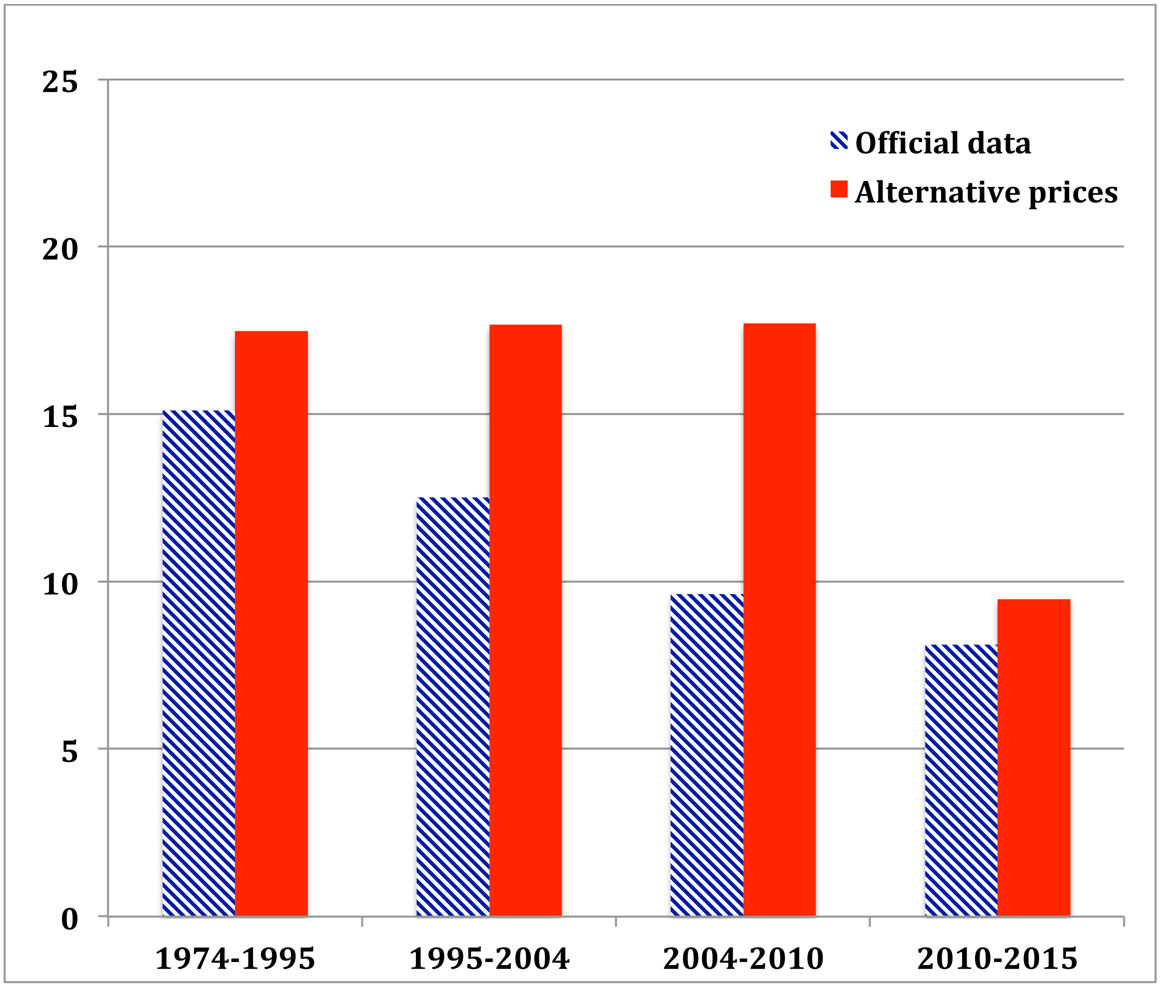


Figure 4
Communications Equipment
MFP Growth Rates with *Official* and *Alternative Research* Prices
1974-2015, percent

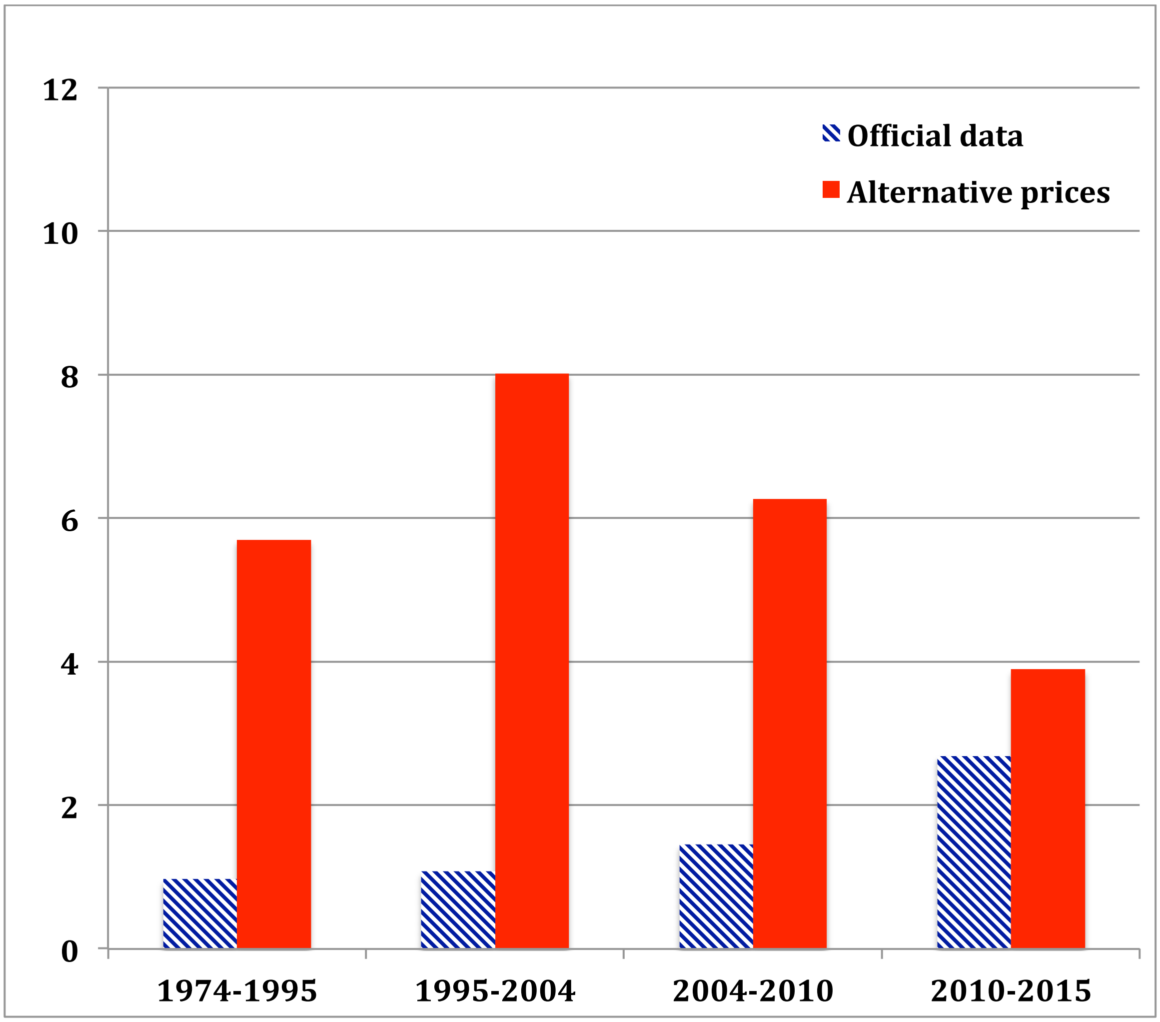


Figure 5
Software
MFP Growth Rates with *Official* and *Alternative Research* Prices
1974-2015, percent

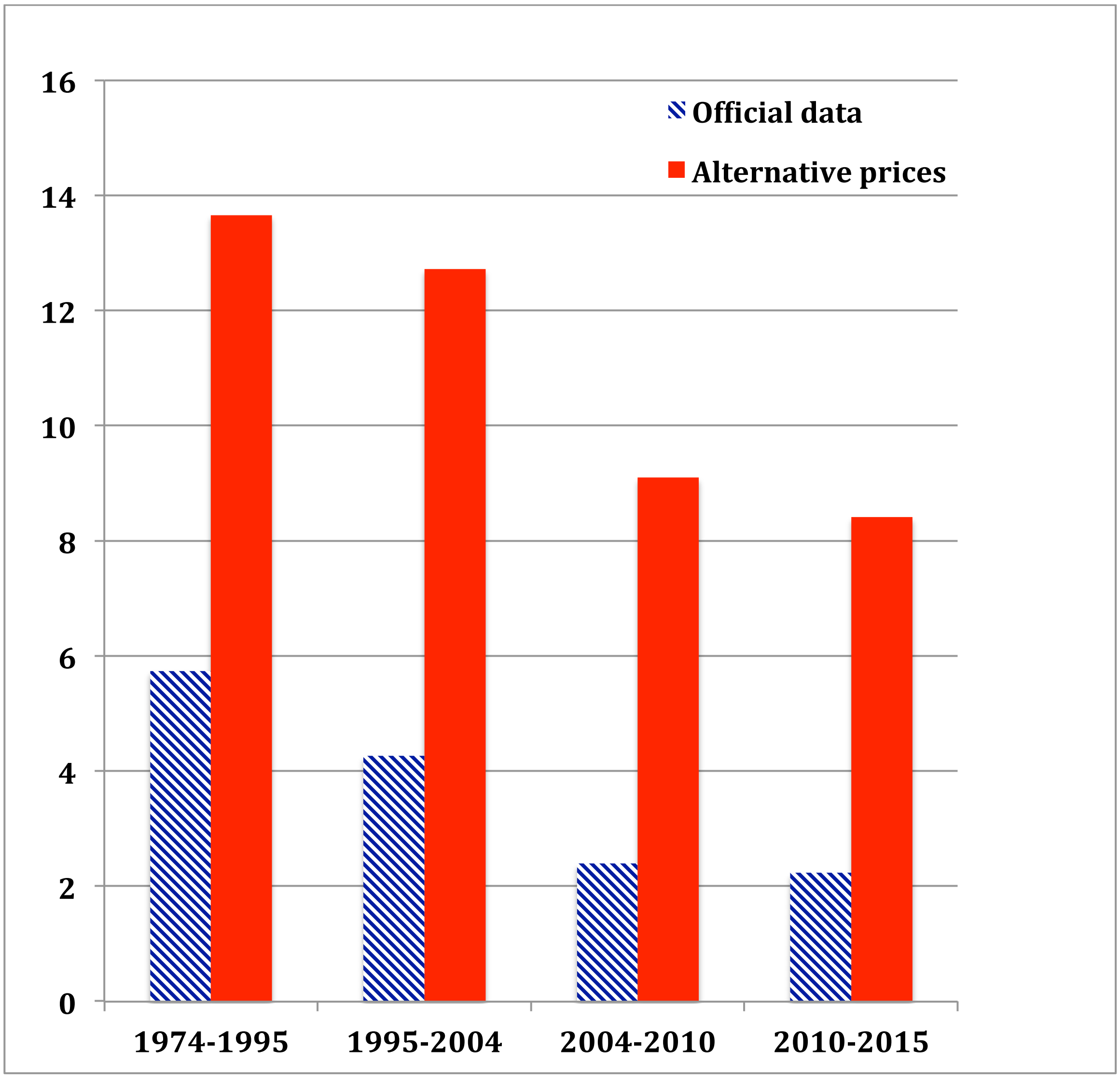


Figure 6
Semiconductors
MFP Growth Rates with *Official* and *Alternative Research* Prices
1974-2015, percent

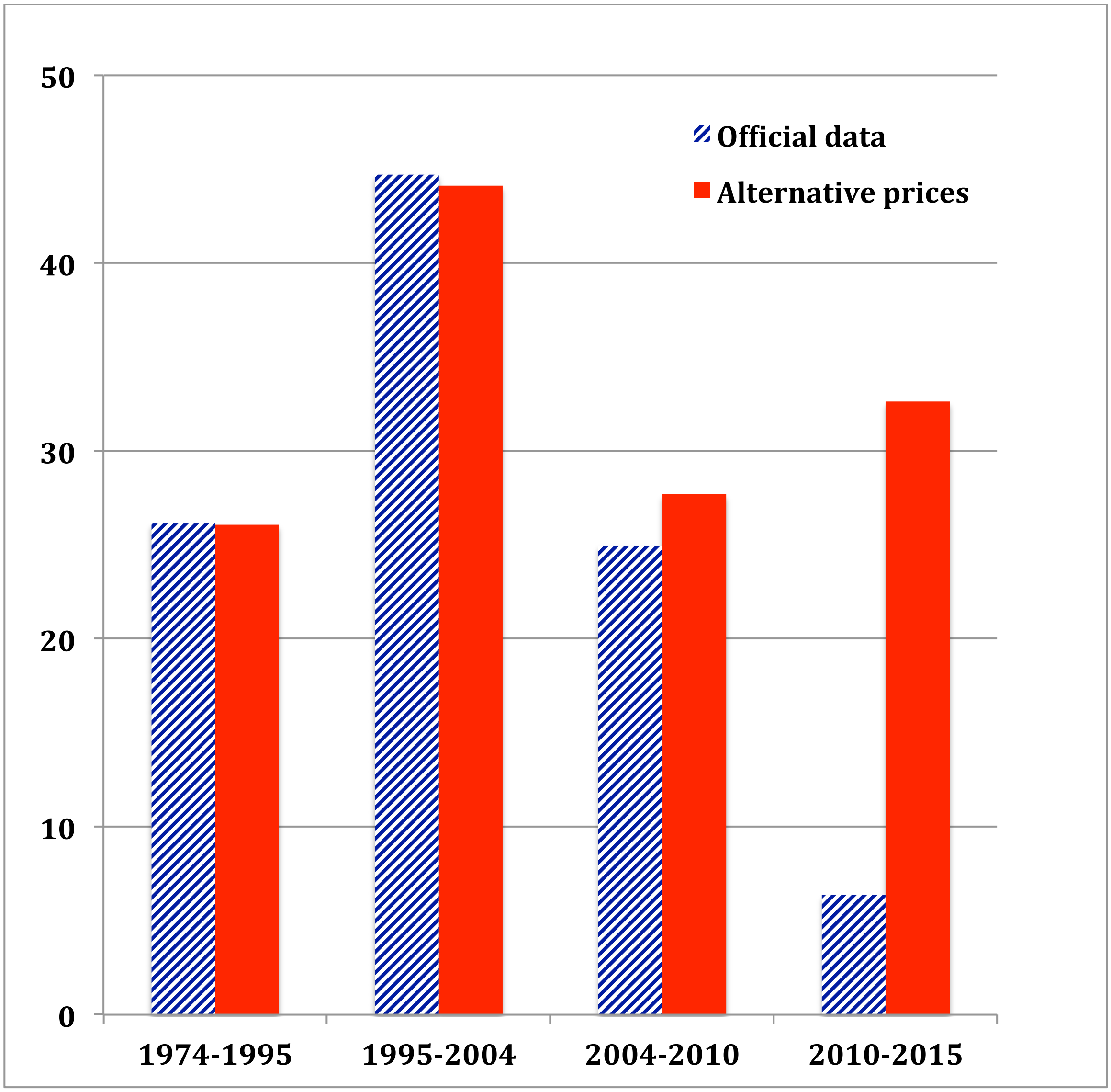


Figure 7
Other Output
MFP Growth Rates with *Official* and *Alternative Research* Prices
1974-2015, percent