What Explains the Post-2004 U.S. Productivity Slowdown?

Alexander Murray [1]
Centre for the Study of Living Standards

Abstract

Economic theory and history show that labour productivity growth is the main driver of rising living standards, so changes in the trend rate of productivity growth have profound implications for a society's future prosperity. The average annual rate of business sector labour productivity growth in the United States declined by 1.9 percentage points between the 1995-2004 period and the 2004-2015 period, from 3.2 per cent to 1.3 per cent. This article summarizes the state of knowledge on the causes of the post-2004 slowdown in U.S. productivity growth. Official growth accounting estimates indicate that 60-65 per cent of the labour productivity decline is accounted for by a decline in total factor productivity growth, while 30-35 per cent is accounted for by a decline in the rate of capital deepening. Three industries account for over 80 per cent of the aggregate labour productivity decline: manufacturing, wholesale trade, and retail trade. The aggregate productivity slowdown is traceable to a decline in the productivity contributions arising from industries that produce or intensively use information and communication technology (ICT) products.

Business sector labour productivity growth in the United States averaged 3.22 per cent per year over the 1995-2004 period, then declined to 1.33 per cent per year over the 2004-2015 period.[2] (From 2010 to 2015, U.S. labour productivity grew by just 0.57 per cent per year.) Economic theory and history show that labour productivity growth is the main driver of rising living standards, so the 1.89 percentage-point decline in the trend rate of productivity growth after 2004 has profound implications for the future prosperity of the United States.[3] Had labour productivity maintained its 1995-2004 pace, U.S. business sector real output would have been some

1 The author was an economist at the Centre for the Study of Living Standards (CSLS) when this research was conducted. He is currently an economist in the Economic Studies and Policy Analysis Division at Finance Canada. This article is an abridged version of Murray (2017). The CSLS thanks Innovation, Science and Economic Development Canada for financial support for this research. The author thanks Patrick Alexander, Martin Baily, John G. Fernald, Robert Gordon, Dale Jorgenson, Andrew Sharpe, Jianmin Tang and two anonymous referees for comments. The views expressed in this paper are those of the author and do not reflect the views of Finance Canada. Email: alexander.murray@canada.ca

2 Labour productivity is defined as real output per hour worked.

3 Productivity growth makes rising material living standards for the average person possible, but it does not guarantee it. Indeed, in recent decades median real wage growth in many OECD countries (including Canada and the United States) has failed to keep pace with labour productivity growth. Uguccioni and Sharpe (2016) study this puzzle for OECD countries.

$2.9 trillion higher in 2015 (in 2009 dollars); the cumulative loss of real output due to slower productivity growth over the 2005-2015 period was $13.8 trillion.

What explains the U.S. productivity slowdown in the mid-2000s?[4] In this article, we address this question by contributing original data analysis and by reviewing the research literature. We find that the trend rate of U.S. productivity growth (whether measured using labour productivity or total factor productivity) declined around 2004. About 60-65 per cent of the labour productivity decline is accounted for by a decline in total factor productivity growth, while 30-35 per cent is accounted for by a decline in the rate of capital deepening (i.e. growth of capital per hour worked). Three industries, collectively representing 28 per cent of business-sector hours worked in 2015, account for over 80 per cent of the aggregate labour productivity decline: manufacturing, wholesale trade, and retail trade.

The aggregate productivity slowdown is traceable to a decline in the productivity contributions arising from industries that produce or intensively use information and communication technology (ICT) products. The decline in the productivity contribution of ICT was driven by some combination of a) slower technological progress in ICT and b) a reduction in business dynamism in the 'high tech' sector (mainly industries producing ICT goods and services) resulting in a decline in the rate of resource reallocation from less-productive to more-productive firms.

The article is structured as follows. In the first main section, we discuss sources of data on U.S. productivity and review aggregate U.S. productivity trends over the 1987-2015 period. In Section 2, we decompose U.S. labour productivity growth into its industry sources. In Section 3, we decompose it into its proximate growth accounting sources: total factor productivity growth, capital deepening, and labour quality growth. In Section 4, we review research on possible explanations for the slowdown. Section 5 discusses implications for Canada and concludes.

Data Sources and Aggregate Trends in U.S. Productivity

In this section, we discuss sources of data on U.S. productivity and review the recent U.S. productivity performance. It is well-established that U.S. productivity growth experienced a structural shift toward a slower growth path in 2004.[5] We provide a descriptive illustration of this using a variety of measures of labour productivity and total factor productivity (TFP) for the U.S. business sector, private business sector, and total economy.

Data[6]

Our main source of U.S. productivity data is the Bureau of Labor Statistics (BLS). Two BLS programs provide productivity estimates: the Labor Productivity and Costs program and the Multifactor Productivity

4 This article focuses on the United States, but productivity growth has slowed in recent years across the OECD. Cette *et al.* (2016) find that the explanations for the slowdown are somewhat different in the United States than elsewhere; the U.S. slowdown is attributable to developments in the production and use of ICT, while unfavorable resource reallocation (driven in part by low real interest rates) has contributed to the slowdown in Europe.

5 A short review of the literature providing statistical evidence for this claim is presented in Murray (2017), Appendix B

6 An online database associated with this article contains URLs for the specific source data files on the web sites of the BLS, the BEA, and the San Francisco Federal Reserve. The database is available online at URL: http:// www.csls.ca/reports/USslowdown_database.xlsx.

program.[7] The Labor Productivity and Costs program provides estimates of labour productivity for the U.S. business sector; the Multifactor Productivity program provides estimates of labour productivity and total factor productivity (TFP) for the private business sector and for the total economy.[8]

We augment the official BLS data with estimates from two additional sources. The first is the growth accounting database maintained by John Fernald at the Federal Reserve Bank of San Francisco. It is described in Fernald (2014b). Fernald's estimates are based mainly on disaggregated industry data from the BLS and the Bureau of Economic Analysis (BEA), augmented with data from other sources in some cases. We include it in this article because it allows us to examine the influence of variable factor utilization on productivity growth rates.

For our industry decomposition, we use labour productivity estimates for private industries constructed by CSLS researchers using hours data from the BLS and output data from the BEA's GDP by Industry database. This approach allowed for the construction of labour productivity estimates in both levels and growth rates for a broad set of industries up to 2015.

Recent U.S. Productivity Performance

Table 1 summarizes measures of aggregate productivity growth in the United States over the 1987-2015 period. Consider first the labour productivity growth measures in the left panel of the table. According to the official BLS measure of labour productivity in the U.S. business sector, labour productivity grew at 2.0 per cent per year over the 1987-2015 period. The alternative measures for the business sector and the private business sector yield the same 2.0 per cent compound annual growth rate for the 1987-2015 period. The total economy measure grew somewhat more slowly, at 1.7 per cent per year. This is not surprising; the total economy measure includes government, non-profit and household sector activities that exhibit low productivity growth relative to the business sector. The private industries measure excludes government activities (both general government and government-owned enterprises) and the imputed rental value of owner-occupied housing. Its growth was similar to that of the total economy measure over the full 1987-2015 period.[9]

The full-period average growth rates mask substantial variation across sub-periods.

7 Multifactor productivity (or MFP) is another name for total factor productivity (or TFP). MFP is the term used by the BLS. We use TFP throughout this article.

8 The total economy encompasses all paid activity in the economy, whether undertaken by the government or by the private sector. The business sector is the total economy minus general government, the output of household workers and nonprofits, the gross housing product of owner-occupied dwellings and the rental value of nonprofit institutional real estate. The private business sector is the business sector minus government enterprises.

9 The main conceptual difference between the business sector and private industries is that the former includes government enterprises and excludes the nonprofit sector and the output of household workers. Empirically, most of the discrepancy between the BLS's business sector labour productivity measure and our private industries measure (based on BEA and BLS data) over the 1987-2015 period is traceable to a difference in the growth rates of the implicit deflators used to transform nominal output into real output. The BLS's business sector price deflator grew by 1.84 per cent per year over the period, while our private industries price deflator grew by 2.04 per cent per year.

10 The cut-off dates for the main sub-periods are chosen to reflect structural breaks in trend productivity growth in the U.S. economy. An alternative approach would be to choose business cycle peaks, so as to minimize the influence of business cycle factors on comparisons across sub-periods. Since we are primarily interested in trend productivity, we opted to use estimated structural break dates for trend productivity

Table 1: Measures of Productivity Growth, United States, Compound Annual Growth Rates, 1987-2015

	Labour Productivity					Total Factor Productivity			
	Business Sector (BLS)	Business Sector (Fernald)	Private Business Sector (BLS)	Private Industries (BEA and BLS)	Total Economy[a] (BLS)	Private Business Sector (BLS)	Business Sector, Unadjusted (Fernald)	Business Sector, Utilization-adjusted (Fernald)	Total Economy[a] (BLS)
1987-2015	2.00	2.05	2.01	1.75	1.74	0.93	0.93	0.96	0.76
1987-1995	1.55	1.51	1.61	1.37	1.41	0.60	0.46	0.47	0.57
1995-2004	3.22	3.32	3.27	2.94	2.65	1.75	1.83	2.04	1.34
2004-2015	1.33	1.41	1.27	1.07	1.20	0.51	0.54	0.44	0.39
2004-2008	1.33	1.21	1.33	1.11	1.28	0.27	0.04	-0.01	0.22
2008-2015	1.33	1.53	1.23	1.04	1.14	0.66	0.83	0.71	0.50
2008-2010	3.25	3.37	3.36	2.97	2.43	1.36	1.22	1.45	0.46
2010-2015	0.57	0.80	0.40	0.28	0.51	0.38	0.68	0.41	0.52

Sources: Series labelled 'BLS' are drawn directly from BLS sources. Series labelled 'Fernald' are taken from the growth accounting database of John Fernald, described in Fernald (2014b). Fernald's series were constructed using data from the BLS and BEA. Series labelled 'BEA and BLS' were constructed by CSLS researchers using BEA output data and BLS hours data. For links to the source data, see Tables 1-5 in the database accompanying this article: http://www.csls.ca/reports/USslowdown_database.xlsx. Note a. Series for the Total Economy end in 2014 rather than 2015.

The remaining rows of Table 1 present growth rates for sub-periods within the 1987-2015 period.[10] Chart 1 plots the five-year moving averages of the annual growth rates of the five labour productivity measures from the table and illustrates the pattern of accelerations and slow-downs. Business sector labour productivity grew by 1.55 per cent per year between 1987 and 1995, accelerated to 3.22 per cent per year over the 1995-2004 period, then fell back to 1.33 per cent per year post-2004.[11] Much of the labour productivity growth after 2004 occurred during a brief burst of fast growth associated with the Great Recession; over the 2008-2010 period, labour productivity grew by 3.25 per cent per year as hours worked fell much faster than real output. From 2010 to 2015, labour productivity growth has averaged 0.57 per cent per year, well below the rates observed in earlier periods.[12]

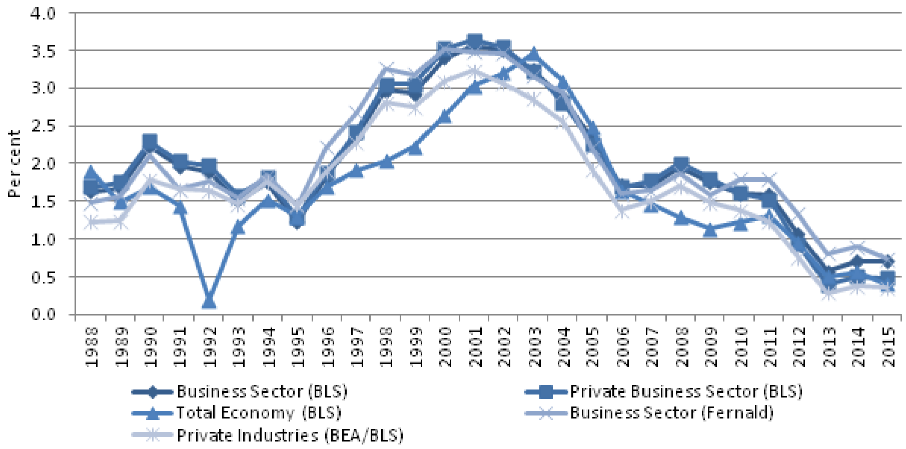
The right-hand panel of Table 1 presents measures of TFP growth. Chart 2 depicts the five-year moving averages of TFP growth implied by these TFP measures. According to the official BLS measure for the private business sector, TFP grew by 0.93 per cent per year over the 1987-2015 period. The business sector measures from Fernald's database yield an identical average growth rate for the full period. As in the case of labour productivity, TFP growth was slower in the total economy, at 0.76 per cent per

growth drawn from the econometric literature. Sprague (2017) discusses productivity growth across U.S. business cycles and shows that U.S. labour productivity growth in the current business cycle (i.e. the period since 2008) is the lowest among the ten post-war U.S. business cycles.

11 Total economy labour productivity exhibits the same pattern as the business sector measures: fast growth between 1995 and 2004, a slowdown thereafter except for the 2008-2010 period, and very slow growth since 2010. Within each sub-period, the growth rates for the total economy are smaller than those for the business sector, especially during the fast-growth periods. The measure for private industries tended to grow faster during high-growth periods and slower during low-growth periods.

12 At the time the research for this article was completed data were available only to 2015. U.S. business sector labour productivity estimates for 2016 and 2017 are now available from the BLS. According to those data, U.S. labour productivity grew by 0.1 per cent and 1.2 in 2016 and 2017 respectively, making the average growth per year, 0.65 per cent, similar to the 2010-2015 average of 0.57 per cent per year.

Chart 1: Labour Productivity Growth, Per Cent per Year (Five-Year Moving Average), United States, 1988-2015



Source: Tables 1-5 in the database, http://www.csls.ca/reports/USslowdown_database.xlsx.

year.

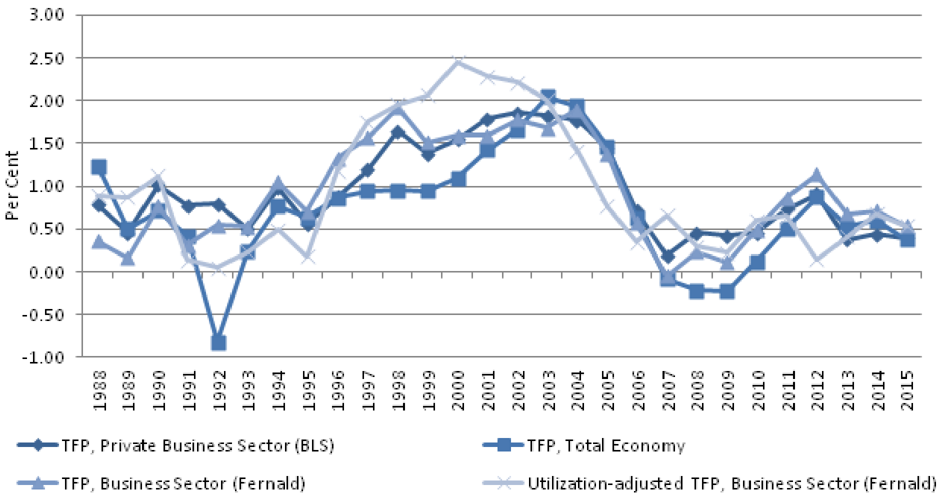
TFP growth varied across the sub-periods. Private business sector TFP grew by 0.60 per cent per year between 1987 and 1995, accelerated to 1.75 per cent per year between 1995 and 2004, then fell to 0.51 per cent per year after 2004. As in the case of labour productivity, TFP growth experienced a short-lived spike associated with the Great Recession. Our main focus in this article is on productivity growth trends, not on the relationship between productivity and business cycles.[13] In breaking down the 2004-2015 period into sub-periods, our purpose is to emphasize that since 2010 (i.e. after the end of the Great Recession) productivity growth has been especially slow for a sustained period of time.

A TFP measure commonly used in the academic literature is the utilization-adjusted measure of Fernald (2014b), which is also summarized in Table 1 and depicted in Chart 2. This measure strips out the influence of variable factor utilization (i.e. variation over time in the intensity with which labour and capital are used, conditional on total hours worked and on the total capital stock) from TFP, thereby yielding a purer indicator of technological progress.[14] Over a long span of time this should not matter because factor utilization rates tend to revert to their long-run averages. (This is true by construction under Fernald's approach.) Indeed, the utilization-adjusted and unadjusted measures for the business sector in Table 1 exhibited almost

13 That labour productivity surged during the Great Recession is not especially surprising. Capital and labour quality tend to change slowly relative to hours worked, resulting in countercyclical labour productivity growth. The spike in business-sector TFP growth during the Great Recession is perhaps more surprising. The business cycle literature does show that positive TFP shocks – especially after adjusting for variation in factor utilization – cause hours worked to decline; everything else equal, this tends to make TFP countercyclical (Basu *et al.*, 2006). See Fernald and Wang (2016) for an extensive analysis of the cyclical properties of U.S. productivity measures.

14 TFP is often regarded as a proxy for technological progress, but it is influenced by other economic forces (as well as measurement error). In addition to variation in factor utilization, these include non-constant returns to scale, static resource misallocation, and departures from perfect competition. Moreover, even leaving aside these issues, the relationship between TFP growth and technological progress is complicated and requires subtle interpretation. See Murray (2016) for a comprehensive discussion of these issues.

Chart 2: Total Factor Productivity Growth, Per Cent per Year (Five-Year Moving Average), United States, 1987-2015



Source: Bureau of Labor Statistics and Fernald (2014b).
See Tables 1-4 in the database, http://www.csls.ca/reports/USslowdown_database.xlsx.

identical growth over the full 1987-2015 period.

Nevertheless, the utilization-adjusted series is worth considering for two reasons. First, factor utilization has a non-negligible influence on TFP growth within sub-periods. During the fast-growth period of 1995-2004, in particular, the unadjusted measure appears to understate annual TFP growth by 0.2 percentage points.[15] Second, the adjustment affects the timing of the trend growth break in the mid-2000s. With the utilization-adjusted measure, TFP growth slows around 2005, more or less consistent with labour productivity. With the unadjusted business-sector measures, the turnaround appears to occur somewhat later.

Fernald also presents utilization-adjusted TFP series for the consumption sector and the investment sector separately.[16] TFP growth has consistently been far faster in the investment sector than in the consumption sector.[17] Over the full 1987-2015 period, TFP grew by 3.34 per cent per year in the investment sector and by only 0.21 per cent per year in the consumption sector.

Between the 1995-2004 and 2004-2015 periods, the rate of investment sector TFP growth declined by 2.68 percentage points (from 5.46 per cent per year to 2.78 per cent per year) and the rate of consumption sector TFP growth declined by 1.17 percentage points (from 0.91 per cent per year to -0.25 per cent per year). While the decline in the investment sector was larger, the consumption sector made a slightly larger contribution to the overall slowdown in

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15 This implies that the factor utilization rate declined over the 1995-2004 period. This decline was largely associated with the 2001 U.S. recession. Factor utilization fell 2.49 per cent (a large one-year decline) in 2001.

16 Here, the 'investment' sector refers to industries producing equipment, intellectual property and consumer durables. It does not include structures, either residential or non-residential. The 'consumption' sector encompasses all of business sector output other than those parts included in the investment sector (Fernald, 2014b). On the differing macroeconomic effects of technology growth in the investment sector and the consumption sector, see Basu *et al.* (2013).

17 For additional analysis see Murray (2017).

business sector TFP growth because of its large output share.[18] Thus, the aggregate TFP growth decline is attributable to both sectors in roughly equal proportion.

Industry Sources of U.S. Productivity Growth

We decompose aggregate U.S. labour productivity growth into two-digit NAICS industry contributions. This procedure reveals which industries have been drivers of U.S. growth and which have been hindering growth. We perform the decomposition for the 1987-1995, 1995-2004, and 2004-2015 periods and study the industry sources of the changes in trend productivity growth between periods.

Decomposition Method

There is a large body of research on methods for decomposing aggregate productivity growth into industry contributions. A comparison of some leading methods is provides by de Avillez (2012).[19] In this article, we use the CSLS decomposition (Sharpe, 2010; Sharpe and Thomson, 2010). The CSLS decomposition is a variant of a standard approach, used frequently in the literature, that decomposes aggregate labour productivity growth into industry contributions from within-sector productivity growth and labour reallocation across industries. It does not count relative price increases as part of an industry's productivity growth contribution.[20]

Define the following notation:

A_t = Aggregate labour productivity

$A_{i,t}$ = Labour productivity in industry i

$S_{Q,t}$ = Industry i share of aggregate real output

$h_{i,t}$ = Industry i share of aggregate hours worked

The CSLS decomposition expresses the relationship between aggregate labour productivity growth and industry-level labour productivity growth as follows:[21]

$$\frac{\Delta A_t}{A_{t-1}} = \sum_{i=1}^{N} [s_{Q,t}(\frac{\Delta A_{i,t}}{A_{i,t-1}}) + \Delta h_{i,t}(\frac{A_{i,t} - A_t}{A_t}) + \Delta h_{i,t}(\frac{\Delta A_{i,t} - \Delta A_t}{A_{t-1}})] = \sum_{i=1}^{N} [\mathrm{WSE}_{i,t} + \mathrm{RLE}_{i,t} + \mathrm{RGE}_{i,t}]$$

(The notation ΔX_t denotes the change $X_t - X_{t-1}$ for any variable X.) Thus, the contribution if each industry i to aggregate productivity growth is the sum of three components:

- Within-sector Effect ($WSE_{i,t}$): productivity growth within industry i raises aggregate productivity growth;
- Reallocation Level Effect ($RLE_{i,t}$): reallocation of labour into industry i increases aggregate productivity

18 The consumption sector contributed -0.88 percentage points (or 55 per cent) of the total change in TFP growth between the two periods, compared to a contribution of -0.72 percentage points (or 45 per cent) from the investment sector.

19 Important recent contributions include Tang and Wang (2004), Diewert (2015; 2016), Reinsdorf and Yuskavage (2010), Reinsdorf (2015), Calver and Murray (2016), and Baldwin and Willox (2016).

20 We have also produced results based on an alternative decomposition, the Generalized Exactly Additive Decomposition (GEAD) of Tang and Wang (2004) and Diewert (2015). This decomposition method does include relative price increases as part of an industry's productivity growth contribution. These results are in the appendix of Murray (2017).

21 See de Avillez (2012) for details of the derivation of this decomposition. The key assumption underlying it is the additivity of real output, i.e. aggregate real output equals the sum of industry-level real outputs. The BLS measures real output using chained Fisher indexes, which do not satisfy this additivity assumption. As a result, there will be a small discrepancy between aggregate productivity growth and the sum of the industry contributions generated by the CSLS decomposition. This discrepancy is evaluated quantitatively below; it turns out to be small.

growth if industry i has an above-average productivity level;

- Reallocation Growth Effect ($RGE_{i,t}$): reallocation of labour into industry i increases aggregate productivity growth if industry i has an above-average productivity growth rate.

The CSLS decomposition thus embodies the idea that the sign of an industry's reallocation effect should reflect the productivity performance of that industry *relative* to the other industries from which it is gaining (or to which it is losing) labour share. This treatment of the reallocation effects is what distinguishes the CSLS decomposition from other commonly-used decomposition methods.

We have applied this decomposition to the labour productivity measure for U.S. private industries, the aggregate growth of which was displayed in Table 1. Alternatively, the industry decomposition could have been performed using the KLEMS Multifactor Productivity Tables for manufacturing and non-manufacturing industries from the BLS. Baily and Montalbano (2016) performed an industry decomposition of U.S. TFP growth using these data (and a different decomposition method based on Domar weights). Their results on the industry sources of the mid-2000s productivity slowdown are similar to ours. We regard our analysis as complementary to theirs.

Decomposition Results

Our primary interest is the mid-2000s productivity slowdown.[22] The decomposition results are informative about the industry origins of that slowdown. Panel A of Table 2 presents the CSLS decomposition of U.S. labour productivity growth for the 1995-2004 and 2004-2015 periods separately, while Panel B presents the implied changes in industry contributions to productivity growth between the two periods.

Between the 1995-2004 and 2004-2015 periods, aggregate labour productivity growth declined by 1.87 percentage points (from 2.94 per cent to 1.07 per cent per year). Of this change, -1.84 percentage points (or 98.1 per cent of the total slowdown) was driven by the within-sector effect. Labour productivity growth slowed in eleven of the fourteen industries between the two periods. Labour reallocation across industries contributed negligibly to the productivity slowdown. Together, the reallocation level and growth effects contributed -0.04 percentage points (or 1.9 per cent) to the slowdown.

The industry total contributions to the aggregate productivity growth slowdown are depicted in Chart 3. The three industries that made the largest contributions to the slowdown were manufacturing (-0.79 percentage points), wholesale trade (-0.41 percentage points), and retail trade (-0.32 percentage points). Together, these three industries accounted for 80.5 per cent of

22 The decomposition results for U.S. labour productivity growth over the full 1987-2015 period are found in Murray (2017). The aggregate labour productivity growth of 1.76 per cent per year is entirely attributable to labour productivity growth within industries; the total within-sector effect contributed 1.90 percentage points to the overall growth rate, while inter-industry labour reallocation reduced overall growth by 0.14 percentage points (the sum of the reallocation level and growth effects). As noted earlier, the non-additivity of chained quantity indexes introduces a discrepancy between aggregate productivity growth and the sum of the total industry contributions. That discrepancy is small. For the full 1987-2015 period, the aggregate labour productivity growth rate is 1.76 per cent per year while the sum of the total industry contributions is 1.66 per cent; the discrepancy is just 0.1 percentage points. The discrepancy is similarly small within each sub-period we consider. In our tables of results, we have scaled the contributions by the ratio 1.76/1.66 so that the industries' total contributions sum to the true aggregate growth rate.

Table 2: Decomposition of U.S. Productivity Slowdown between 1995-2004 and 2004-2015, Private Industries

Panel A: Productivity Growth Decomposition by Period

	1995-2004					2004-2015				
	Labour Productivity Growth	Percentage Point Contribution				Labour Productivity Growth	Percentage Point Contribution			
		TC	WSE	RLE	RGE		TC	WSE	RLE	RGE
Private industries	2.94	2.94	3.11	-0.10	-0.06	1.07	1.07	1.27	-0.16	-0.04
Agriculture, forestry, fishing, hunting	6.20	0.10	0.07	0.03	0.00	2.58	0.03	0.03	0.00	0.00
Mining	0.02	-0.05	0.00	-0.04	0.00	1.91	0.10	0.06	0.06	-0.02
Utilities	2.15	-0.03	0.06	-0.08	0.00	-0.78	-0.02	-0.02	0.00	0.00
Construction	-0.75	-0.06	-0.07	0.01	-0.01	-1.21	-0.06	-0.09	0.03	0.00
Manufacturing	6.42	1.07	1.09	0.00	-0.02	2.09	0.28	0.35	-0.06	-0.01
Wholesale trade	6.58	0.48	0.50	-0.02	0.00	0.97	0.07	0.07	0.00	0.00
Retail trade	4.46	0.39	0.38	0.01	0.00	0.69	0.08	0.05	0.02	0.00
Transportation and warehousing	1.31	0.05	0.05	0.00	0.00	0.50	0.02	0.02	0.00	0.00
Information	5.16	0.25	0.27	0.00	-0.01	5.24	0.25	0.33	-0.07	-0.01
Other services, except government	0.36	0.02	0.02	0.00	0.00	-0.80	-0.02	-0.03	0.01	0.00
FIRE	2.78	0.45	0.39	0.06	0.00	2.36	0.31	0.34	-0.04	0.00
Professional and business services	1.73	0.27	0.27	0.01	-0.01	0.96	0.14	0.15	-0.01	0.00
AERAF	1.64	0.06	0.09	-0.03	0.00	-0.42	-0.06	-0.02	-0.04	0.00
EHSA	0.00	-0.06	0.00	-0.05	-0.01	0.27	-0.04	0.03	-0.07	0.00

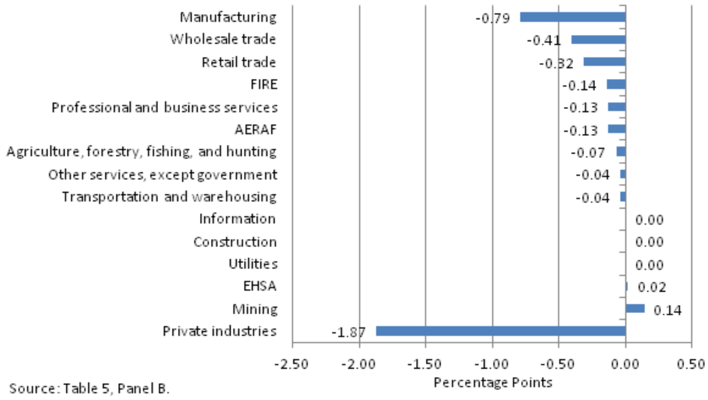
Panel B: Industry Contributions to Productivity Slowdown between 1995-2004 and 2004-2015

	Change in Labour Productivity Growth	Percentage Point Contributions				Per Cent Total Change			
		TC	WSE	RLSE	RGE	TC	WSE	RLSE	RGE
Private industries	-1.87	-1.87	-1.84	-0.06	0.02	100.0	98.1	3.0	-1.1
Agriculture, forestry, fishing, hunting	-3.62	-0.07	-0.04	-0.03	0.00	3.7	2.0	1.7	0.0
Mining	1.89	0.14	0.06	0.10	-0.01	-7.7	-3.0	-5.4	0.7
Utilities	-2.93	0.00	-0.08	0.08	0.00	-0.2	4.2	-4.4	0.0
Construction	-0.45	0.00	-0.02	0.02	0.00	-0.2	1.1	-1.1	-0.1
Manufacturing	-4.33	-0.79	-0.74	-0.06	0.01	42.0	39.3	3.2	-0.6
Wholesale trade	-5.61	-0.41	-0.43	0.02	0.00	21.7	23.0	-1.1	-0.2
Retail trade	-3.77	-0.32	-0.33	0.01	0.00	16.9	17.4	-0.5	0.0
Transportation and warehousing	-0.81	-0.04	-0.03	0.00	0.00	1.9	1.6	0.2	0.1
Information	0.09	0.00	0.06	-0.07	0.01	-0.1	-3.3	3.5	-0.3
Other services, except government	-1.16	-0.04	-0.04	0.01	0.00	1.9	2.3	-0.4	0.0
FIRE	-0.43	-0.14	-0.05	-0.09	0.00	7.5	2.6	4.9	0.0
Professional and business services	-0.77	-0.13	-0.12	-0.02	0.01	7.0	6.4	0.9	-0.3
AERAF	-2.06	-0.13	-0.11	-0.01	0.00	6.7	6.1	0.6	0.0
EHSA	0.27	0.02	0.03	-0.01	0.00	-1.1	-1.6	0.7	-0.2

Notes:

1. TC = Total contribution; WSE = within-sector effect; RLE = reallocation level effect; RGE = reallocation growth effect.
2. FIRE = Finance, insurance, real estate, rental and leasing; AERAF = Arts, entertainment, recreation, accommodation, and food services; EHSA = Educational services, health care and social assistance.

Chart 3: Total Contributions to the U.S. Labour Productivity Slowdown between 1995-2004 and 2004-2015, Percentage Points, Private Industries



Source: Table 5, Panel B.
Note: FIRE = Finance, insurance, real estate, rental and leasing; AERAF = Arts, entertainment, recreation, accommodation and food services; EHSA = Educational services, health care and social assistance.

the total slowdown. The contributions of manufacturing, wholesale trade and retail trade to the aggregate slowdown were driven almost entirely by within-sector productivity growth slowdowns in those industries.

While three industries account for 80 per cent (or four fifths) of the aggregate slowdown, nine of the fourteen industries contributed to it. In that sense, the slowdown has been broad-based. The only industry that contributed non-negligibly in the direction of faster productivity growth in the 2004-2015 period relative to the 1995-2004 period was mining. Its 0.14 percentage-point positive contribution was driven by a substantial increase in within-industry productivity growth and by a positive reallocation level effect as the industry (which has an above average productivity level) increased its hours share.

Growth Accounting

The previous section examined industry contributions to aggregate productivity growth. An alternative perspective is provided by the growth accounting framework, which decomposes aggregate labour productivity growth into contributions from the following proximate sources:[23]

- **Labour composition**: growth of the quality of the economy's labour input;
- **Capital deepening**: growth of the ratio of physical capital services to labour hours;
- **Total factor productivity (TFP)**: the residual part of labour productivity growth unexplained by the other two components.

Table 3 presents growth accounting results for the U.S. private business sector and total economy, based on the BLS measures of labour productivity from Table 1. For the private business sector (Panel A of the table), labour productivity growth over the full 1987-2015 period (2.01 per cent per year) was driven mainly by contributions

23 For any variable X, let ΔX denote the logarithmic first-difference of X (which is approximately equal to the per cent growth rate of X). Following standard procedures, labour productivity growth $\Delta(y-h)$(i.e. the log first-difference of the output-hours ratio) can be expressed as

$$\Delta(y-h) = \Delta a + \alpha\Delta(k-h) + (1-\alpha)\Delta q$$

where Δa is TFP growth, $\Delta(k-h)$ is capital deepening (i.e. growth of the capital-hours ratio), Δq is labour quality growth, and α is the share of capital costs in nominal value added.

Table 3: Sources of Labour Productivity Growth, Private Business Sector and Total Economy, United States, 1987-2015

Panel A. Private Business Sector

	Labour Productivity	Average Capital Share	Contributions (Percentage Points)		
			Total Factor Productivity	Capital Deepening	Labour Quality
1987-2015	2.01	0.35	0.93	0.80	0.28
1987-1995	1.61	0.33	0.60	0.63	0.37
1995-2004	3.27	0.33	1.73	1.24	0.25
2004-2015	1.27	0.37	0.51	0.52	0.25
2004-2008	1.33	0.36	0.27	0.81	0.23
2008-2010	3.36	0.37	1.33	1.58	0.44
2010-2015	0.40	0.38	0.37	-0.15	0.18
Percentage-point Change, 1995-2004 to 2004-2015	-2.00	0.04	-1.22	-0.72	0.00
Per cent of Total Change, 1995-2004 to 2004-2015	100.0	–	61.0	35.9	0.1

Panel B. Total Economy

	Labour Productivity	Average Capital Share	Contributions (Percentage Points)		
			Total Factor Productivity	Capital Deepening	Labour Quality
1987-2014	1.74	0.38	0.75	0.73	0.26
1987-1995	1.41	0.35	0.57	0.50	0.34
1995-2004	2.65	0.35	1.33	1.04	0.25
2004-2014	1.20	0.42	0.39	0.60	0.20
2004-2008	1.28	0.41	0.21	0.84	0.21
2008-2010	2.43	0.44	0.45	1.62	0.31
2010-2014	0.51	0.43	0.52	-0.16	0.13
Percentage-point Change, 1995-2004 to 2004-2015	-1.45	0.07	-0.94	-0.44	-0.06
Per cent of Total Change, 1995-2004 to 2004-2015	100.0	–	64.9	30.1	3.9

Source: Bureau of Labor Statistics, Multifactor Productivity Program.

Notes: Labour productivity growth rates are compound annual growth rates. The contribution of capital deepening is the growth rate of the capital-hours ratio multiplied by the average capital share for the period. The contribution of labour quality is the growth rate of labour composition multiplied by one minus the average capital share for the period. The time periods for the average capital shares end one year earlier than the date indicated (e.g. the average is computed over 1995-2003 instead of 1995-2004) to avoid double counting cut-off years. The sum of the contributions may differ slightly from labour productivity growth due to rounding.

from TFP growth (0.93 percentage points) and capital deepening (0.80 percentage points), with growth of labour quality contributing 0.28 percentage points per year.

The bottom two rows of Panel A shows the changes in labour productivity growth and in the contributions of the three components between the 1995-2004 period and the 2004-2015 period. The 2.0 percentage-point slowdown in labour productivity growth is attributable to a 1.22 percentage-point decline in TFP growth and a -0.72 percentage-point contribution from capital deepening. Labour quality growth held steady between the two periods (although it exhibited substantial variation within the post-2004 period, as shown in the table).

Panel B of Table 3 displays the growth accounting results for the total economy. Productivity growth and its components tended to be smaller in the total economy than in the private business sector, but the relative magnitudes of the contributions from TFP, capital deepening and labour quality are similar to those in Panel A. Over the full 1987-2015 period, TFP growth and capital deepening contributed 0.75 and 0.73 percentage points, respectively, to labour productivity growth in the total economy. The contribution of labour quality growth, at 0.26 percentage points, was comparatively small but certainly not negligible.

Again, we are primarily interested in the sources of the slowdown post-2004. The 1.45 percentage-point slowdown in labour productivity growth between 1995-2004 and 2004-2015 was the result of a -0.94 percentage-point contribution from slower TFP growth and a -0.44 percentage-point contribution from slower capital deepening. The contribution of labour quality growth was -0.06 percentage points. At 1.45 percentage points, the slowdown in the total economy was smaller than the slowdown in the business sector (2.0 percentage points).

These results indicate that a large decline in TFP growth was the most important proximate driver of the post-2004 labour productivity slowdown. Slower capital deepening also made a substantial contribution to the slowdown. It is particularly noteworthy that the rate of capital deepening has been negative since 2010; hours worked are recovering from the Great Recession, but capital investment has remained sluggish. Hall (2014) points to the failure of the U.S. capital stock to rebound as a major lasting effect of the recession. Note, however, that the contribution of capital deepening to productivity growth was already well below its 1995-2004 level (though not its 1987-1995 level) over the 2004-2008 period, before the recession.

Explanations for the U.S. Productivity Slowdown

Why did U.S. productivity growth decline in the mid-2000s and why has it remained low since then? In this section, we discuss a number of potential explanations for the slowdown. The discussion is based on a review of the research literature on the question, together with the empirical results from the previous sections of this article. We organize the discussion in terms of three broad categories of explanation: mismeasurement, supply-side explanations, and demand-side explanations.

Measurement Issues

Why did measured productivity growth decline in the mid-2000s? One possible answer is that the measured slowdown is the result of measurement error and not a reflection of any real economic phenomena. This explanation the mismeasurement hypothesis has been advanced by several authors in both the popular press and the academic literature.[24]

Measuring Output in the Digital Economy

Technological changes have occurred throughout the post-2004 period in areas such as robotics (e.g. autonomous vehicles, drones), communication equipment (e.g. smart phones), digital platforms (e.g. Uber, Airbnb), and data analytics (e.g. artificial intelligence, 'big data'). Official output statistics may fail to capture some of the output arising from these innovative technologies and business models, due either to conceptual or compilation challenges. Mokyr (2014: 88) makes this point forcefully:

> "[Economists] are trained to look at aggregate statistics like GDP per capita and its derivatives such as factor productivity. These measures were designed for a steel-and-wheat economy, not one in which information and data are the most dynamic sector. Many of the new goods and services are expensive to design, but once they work, they can be copied at very low or zero cost. That means they tend to contribute little to measured output even if their impact on consumer welfare is very large. ... The aggregative statistics miss much of what is interesting."

If these measurement problems have become more severe since 2004 as the use of these technologies has expanded, the result could be a decline in the pace of measured real output growth, and hence measured productivity growth. The decline would be illusory; it would reflect a statistical failure rather than a true slowdown in growth.

Ahmad and Schreyer (2016) provide a comprehensive discussion of the conceptual and practical challenges to GDP and productivity measurement posed by the digital economy.[25] They identify the following key output measurement challenges:

- **Rising importance of peer-to-peer transactions:** New technology has facilitated the matching of consumers with non-business service providers (e.g. homeowners letting their owner-occupied homes via Airbnb). How can the value added of the providers be measured?
- **'De-marketization' of production:** Digital technology has shifted some activities from the market sector to the household production sector (e.g. online banking, online flight booking and check-in, etc.). Should these activities be included in GDP?
- **Free products and services:** Many digital services are provided to users at zero or near-zero prices, which complicates their inclusion in national accounts. Such services may be financed by advertising revenues, may be traded for users' behavioural data, or may represent an investment in the

24 For discussions of the mismeasurement hypothesis in the popular press, see Ito (2013), Feldstein (2015), Smith (2015) and Aeppel (2015).

25 The digital economy refers to the matching of service providers with end users via intermediating digital platforms. Two characteristics distinguish the digital economy from the 'traditional' economy. First, digital platforms are characterized by powerful network effects, which tend to encourage market concentration. Second, digital technologies tend to reduce barriers to entry, and this tends to increase market contestability by new entrants.

provider's brand. Different methods of measuring the value of these 'payments' have different implications for output measurement.

- **Price vs. quality changes:** Digital technology has exacerbated problems in separating price changes from quality changes. Specific challenges include increasing product or service customization, non-volume-based pricing models (e.g. fee-for-access rather than price-per-unit pricing), and substitution of new services for old ones (e.g. substituting Airbnb for hotel rooms).

The first three challenges pertain to the measurement of current-dollar output in the digital economy, while the fourth pertains to the measurement of prices and hence of real output volumes.[26]

Much of the output from peer-to-peer transactions may already be captured in GDP (e.g. in the imputed rental value of owner-occupied housing, which assumes full-time occupancy), and in principle the records of the intermediaries could be used to capture the rest. The activities that have moved from the market sector to the non-market sector arguably should not be counted in GDP; this is a long-standing issue in national accounts measurement. Ahmad and Schreyer (2016) argue that the latter two issues – free products and, especially, price versus quality measurement – are the challenges for which further research efforts are most warranted.

That said, they suggest that the size of the digital economy may (so far) be too small for these issues to have affected output growth or productivity growth to a significant degree. It is therefore unlikely that these measurement issues can explain away the post-2004 productivity slowdown.

Recent quantitative research supports that conclusion. Syverson (2016) shows that even the largest estimates of the unmeasured value added associated with digital technology account for, at most, a third of the $2.9 trillion reduction in U.S. output in 2015 due to the productivity slowdown. He also finds that the tendency of measured U.S. nominal GDI to exceed measured nominal GDP – a pattern consistent with some output being produced and given away for free or at steep discounts, as is often the case in the digital economy – began in 1998, well before the U.S. productivity slowdown, and did not get worse after 2004.

Byrne *et al.* (2016) argue that the value of 'free' digital services to consumers is largely non-market and ought not to be included in market sector output or productivity measures. If they nevertheless include it (using estimates of the unmeasured value of 'free' digital services based on the opportunity cost of the time users spend using them), they find that business sector labour productivity growth would be about 0.3 percentage-points higher over the 2002-2011 period, with slightly larger effects after 2005 than before. Since business sector labour productivity growth slowed by about 2 percentage points after 2004, most of the slowdown remains unexplained even after this adjustment.

Mismeasurement of Information and Communication Technology (ICT)

The U.S. productivity boom of 1995-2004 coincided with an acceleration in the rate

26 Aside from these output measurement issues, an important implication of the rising digital economy for productivity measurement is the blurring of the line between consumer durables and productive capital. Is an Uber driver's car a consumer durable or a part of the capital stock of the transportation sector?

of decline of prices for ICT investment. After 2004, the prices of ICT goods and services fell more slowly than before and the contribution of ICT production to productivity growth declined. Some research has suggested that the official price indexes for ICT investment understate the rate of decline of ICT prices in recent years (Byrne and Corrado, 2015 and 2017; Byrne and Pinto, 2015; Byrne *et al.*, 2015). If this measurement problem became worse around 2004 for some reason, it might explain some part of the decline in measured productivity growth.

Byrne *et al.* (2015) find that this is not the case; that is, while there is substantial error in the measurement of ICT price indexes, the measurement problems did not become worse after 2004. They correct for the mismeasurement of ICT prices using new price indexes and find that the correction actually exacerbates the post-2004 productivity growth decline rather than explaining it away. ICT prices were mismeasured well before the slowdown, and since U.S. production of these products has declined, the impact of their mismeasurement on U.S. productivity was larger during the 1990s than it has been post-2004.

Syverson (2016) also provides evidence against the view that ICT mismeasurement explains the measured productivity growth slowdown. First, many countries experienced a productivity slowdown in the 2000s and the size of the slowdown is uncorrelated with the intensity with which countries consume or produce ICT products. The same is true across U.S. states (Cardarelli and Lusinyan, 2015). Second, the true output growth of ICT-producing industries would have to have been some 500 per cent greater than their measured output growth since 2004. This is an implausible degree of mismeasurement.

International Profit Shifting

Another potential source of error in productivity measurement arises from a failure to properly account for the economic activity of U.S. multinational enterprises (MNEs) that engage in significant offshore profit shifting (usually for tax purposes). Using a variety of tax planning strategies, MNEs are able to book profits in low-tax jurisdictions even though the productive activity that gave rise to those profits occurred in other jurisdictions.[27] This leads to an understatement of GDP in the high-tax jurisdiction and an overstatement of GDP in the low-tax jurisdiction. For example, suppose a U.S.-based MNE develops new intellectual property that is used in production abroad. The flow of payments for the services of this intellectual property should be accounted for in U.S. value added as part of net exports. But if the U.S. MNE legally transfers ownership of the intellectual property to a subsidiary in a relatively low-tax jurisdiction (and manages to ‘underprice’ it in the transfer), that value added will be attributed to that jurisdiction rather than to the United States.[28]

If the extent of international profit shifting was greater in the post-2004 period than in earlier times, then it could explain

27 One such strategy is to underprice the services of intangible capital developed in the United States and used by foreign subsidiaries. Another is to arrange for loans from subsidiaries in low-tax jurisdictions to subsidiaries in high-tax jurisdictions, thereby shifting profits to the low-tax jurisdiction.

28 The payments would still be captured in U.S. gross national income, as part of earnings on direct foreign investment. Note that this is true even if the foreign earnings are not repatriated; the BEA accounts for U.S. foreign direct investment income at the time the earnings are earned, not when they are distributed as dividends (Bureau of Economic Analysis, 2006).

part of the measured productivity growth slowdown. Guvenen *et al.* (2017) investigate this possibility and develop adjusted measures of U.S. GDP and labour productivity to account for international profit shifting. They allocate the worldwide earnings of U.S. MNEs across countries based on measures of the amount of the company's economic activity that actually occurs in each country.[29]

They find that the effect of international profit shifting on measured U.S. GDP was small from the 1970s to the late 1990s, but became more important in the early 2000s. Their adjustments to GDP raise measured labour productivity growth by 0.1 percentage points per year over the 1994-2004 period and by 0.25 per cent per year over the 2004-2008 period. However, they found that international profit shifting did not affect productivity growth after 2008. These findings imply that the adjustments raise average productivity growth over the 2004-2015 period by about 0.09 per cent per year, which is essentially the same as the pre-2004 adjustment. Thus, accounting for international profit shifting explains none of the measured slowdown in U.S. labour productivity growth between the 1994-2004 and 2004-2015 periods. At best, it explains a small share of the slowdown in the 2004-2008 period. But productivity growth has remained low after 2008 for reasons unexplained by international profit shifting.

Conclusions Regarding Mismeasurement

While the measurement of productivity growth is subject to substantial error and uncertainty, the balance of the evidence suggests that the post-2004 slowdown in measured productivity growth is a true economic phenomenon and not an illusion driven by worsening measurement error. In the remainder of this section, we review possible supply-side and demand-side explanations for the slowdown.

Supply-side Explanations

This section discusses possible structural explanations for the decline in U.S. productivity growth in the mid-2000s. We first discuss whether the pace of technological progress has declined, due either to a decline in the rate of frontier innovation or to a decline in the rate of technology diffusion. We then discuss the role of resource reallocation across firms and across industries. Finally, we touch upon labour quality growth.

Frontier Innovation: The Exhaustion of Major Innovation Opportunities

A leading explanation of the post-2004 productivity slowdown is that it reflects the exhaustion of opportunities to enhance productivity via the adoption of new ICTs (together with the absence of any other new technology to drive fast productivity growth). This is related to a broader idea: that opportunities for fundamental, economy- and society-altering technological advances were exhausted by the early 1970s, and that aside from a transitory ICT-driven blip in the 1995-2004 period slow productivity growth since 1973 represents a permanent decline in the economy's innovative potential relative to the 1920-1970 period.

We first discuss the narrower story about the role of ICT in the 1995-2004 productivity acceleration and the subsequent slowdown. We then discuss the broader hypothesis that the pace of technological progress has slowed

29 This approach is called 'formulary apportionment.' To measure the amount of a company's economic activity that occurs in a given country, they use information on the company's labour compensation payments and sales to unaffiliated parties in that country.

more or less permanently.

Information and Communication Technology

There is a sizable literature on the sources of the 1995-2004 U.S. productivity boom and a growing one on the reasons that boom ended in 2004. The leading explanation is that the two trend breaks are tied together by a single factor: the diffusion of information and communications technology (ICT) throughout the U.S. economy. According to this explanation, an increase in the rate of technological improvement in the ICT-producing industries after 1995 led to rapid price declines in ICT and a boom in ICT investment in other sectors. That investment boom caused fast productivity growth across sectors that use ICT intensively. By 2004, the productivity gains from the adoption of ICT had all been exploited and productivity growth declined.

Rapid ICT price declines predate the mid-1990s. Before economists noticed the mid-1990s increase in trend productivity growth, there had emerged a large body of research seeking to explain the "Solow paradox" of high ICT investment and low productivity growth. When trend productivity growth increased after 1995, however, ICT became the leading explanation.[30]

The distinction between labour productivity and TFP is important in terms of the ways in which ICT diffusion shows up in productivity statistics in the late 1990s and early 2000s. The high rate of aggregate TFP growth from 1995 to 2000 was driven mainly by fast TFP growth within ICT-producing industries (especially semiconductor production). TFP growth in ICT production slowed somewhat after 2000, but until 2004 that slowdown was offset by a surge in TFP growth in industries that intensively use ICT (Jorgenson and Stiroh, 2000; Cette *et al.*, 2016). That surge reflected complementary innovations and business reorganization that ICT made possible in the intensive ICT-using industries. In terms of labour productivity, the growth increase was broad-based across both ICT-producing and intensive ICT-using industries (but not in industries that do not use much ICT) throughout the 1995-2004 period because TFP growth in ICT-producing industries led to lower relative prices for ICT goods and, hence, to capital deepening in ICT-using industries.

The ICT-based story is broadly consistent with our industry decomposition results. Wholesale trade, retail trade, and finance – three of the industries that drove the productivity slowdown after 2004 – are all ICT-intensive service industries according to Cette *et al.* (2016). The other key contributor, manufacturing, includes both ICT-producing and ICT-using industries, though it also includes some industries that are neither. The decomposition results of Cette *et al.* (2016), which focus explicitly on ICT producers and users, confirm the importance of intensive ICT-using industries in the post-2004 slowdown.

Slowdown in the Pace of Technological Progress

A view associated most closely with Robert Gordon (2016a) holds that the 1995-2004 period of fast ICT-driven productivity growth was a temporary deviation from the normal state of affairs, which is modest

30 Jorgenson (2001) decomposes aggregate U.S. productivity growth into industry contributions using the Domar approach. He finds that the ICT sector (comprising the computer, software, and communication equipment industries) accounted for 49 per cent of the TFP growth increase between 1990-1995 and 1995-1999, and 77 per cent of the labour productivity increase between those two periods. He attributes this to an increase in the rate of technological advance in the development of semiconductors after 1995.

technological innovation and moderate productivity growth. Gordon argues that the period between 1920 and 1970 represented a unique period in U.S. economic history. A set of 'great inventions' developed during the decades before 1920 (electricity, the internal combustion engine, etc.) spread throughout the economy during the 1920-1970 period and led to an explosion of productivity growth that was unprecedented in history and that is in Gordon's view unlikely ever to be repeated.

The slowdown in U.S. productivity growth in the early 1970s marked the end of this period of revolutionary technological transformation. Subsequent innovations, Gordon argues, have been 'evolutionary rather than revolutionary'; that is, they represent incremental improvements in some aspect of economic life but not fundamental transformations of the kind that occurred during the 1920-1970 period. The ICT-driven productivity boom of the 1995-2004 period was short-lived because it did not take long for the associated opportunities for productivity enhancement to be exhausted. The productivity improvements in communication and information processing associated with ICT are simply smaller and less far-reaching in their impact than were the productivity improvements associated with, say, electrification.

Some other productivity and innovation experts disagree with Gordon's pessimistic outlook for U.S. productivity growth. Syverson (2013) points out that the productivity effects of earlier general purpose technologies (e.g. electricity) occurred in waves separated by periods of slow growth, and that there is no basis for certainty that the productivity growth benefits of ICT have all been exhausted. The findings of Byrne *et al.* (2015) suggest that technological progress in ICT continues at a fast pace.[31] Brynjolfsson and McAffee (2011; 2014) and Mokyr (2014) suggest that emerging technologies such as 3-D printing, artificial intelligence and genomics could lead to heretofore unimagined societal and economic transformations.

People on both sides of this debate agree that the post-2004 productivity slowdown is traceable to a decline in the measured contribution of ICT-producing and intensive ICT-using industries to aggregate productivity growth. The debate is over how to interpret this decline. Is it a return to normal that we should expect to be permanent, as Gordon claims? Or will further waves of fast productivity growth driven by ICT occur in the future, so that the post-2004 slowdown will turn out to have been temporary? Only time can answer this question.

Technology Diffusion: Growing Gap between Frontier Firms and Laggards

The process of productivity growth occurs in two stages: technological innovation and technology *diffusion*. The Gordon view is that the pace of innovation has slowed; that is, that new ideas at the technological frontier are arriving more slowly or are less significant relative to the past. An alternative possibility is that the process of diffusion is somehow being impeded; the frontier continues to be pushed forward as in the past, but the new technologies are not being adopted as readily by businesses.

It has been known for some time that there is substantial dispersion in productivity levels across firms within the same industry (Syverson, 2004; 2011).

31 See Sichel (2016) for some challenges to Gordon's outlook, and Gordon (2016b) for a response.

Decker *et al.* (2017a) show that this dispersion has been rising over time, both in terms of TFP (for firms in the manufacturing sector) and in terms of labour productivity (for the entire U.S. private sector). Using firm-level data from 23 OECD countries including the United States, Andrews *et al.* (2015) find that the productivity gap between firms at the global productivity frontier (within an industry) and all other firms increased over the 2000s. Moreover, their econometric evidence suggests that, within countries, the productivity gap between firms at the national productivity frontier (as opposed to the global frontier) and laggard firms also increased.

If we expect best-practice technologies to diffuse through the productivity distribution from productivity leaders to the laggards, an increase in the dispersion of productivity levels may signal a problem in that diffusion process which may result in slower productivity growth. Taking a long-run perspective, Comin and Mestieri (2016) find that the diffusion of new technologies across countries has grown faster over time but that the diffusion of those technologies within countries (following initial adoption by early adopters) has slowed.

While the evidence suggests that the dispersion of firm-level productivities has been growing over time, there is no sign that this trend changed in any way around 2004. Indeed, Decker *et al.* (2017a) find that productivity dispersion in the United States has been trending upward at least since the late 1980s. It is therefore unlikely that the post-2004 productivity slowdown can be attributed to a decline in the rate of diffusion of best-practice technologies from the frontier to the laggards. That being said, problems in technology diffusion may be imposing a longer-term drag on U.S. productivity growth. This is an area that warrants further research.

Aggregate productivity depends on both the distribution of firm-level productivities and the relative sizes of the firms (measured in terms of input shares). Having discussed the changing productivity distribution, we now turn to the matter of resource reallocation.

Reallocation

Recent evidence suggests that the tendency of resources to be reallocated toward high-productivity firms in the United States has grown weaker in recent years and that this is tied to the productivity slowdown in the mid-2000s. We review this evidence in the first part of this section. In the second part, we discuss a different reallocation issue: the reallocation of resources across industries with different productivity levels and the so-called Baumol Effect.

Reallocation Across Firms: Declining Business Dynamism

An emerging literature documents a decline in the rate of labour reallocation across firms in recent decades.[32] Decker *et al.* (2017a; 2017b) study the relationship between labour reallocation and aggregate productivity growth and find that a rise and fall in the pace of reallocation in information industries helps to explain the 1990s U.S. productivity acceleration and the post-2004 slowdown.

Decker *et al.* (2017a) note that trends in within-industry labour reallocation differ substantially across industries. Measures of business dynamism (e.g. start-up rates, firm exit rates, cross-firm labour reallocation rates, etc.) in the aggregate U.S. economy

32 See Davis *et al.* (2007), Decker *et al.* (2014; 2016), Davis and Haltiwanger (2014), Hyatt and Spletzer (2013), Molloy *et al.* (2016) and Alon *et al.* (2017).

have been declining since (at least) the early 1980s, but the implications of changes in dynamism for aggregate productivity depend on which industries are driving the aggregate labour reallocation trends. In the 1980s and 1990s the decline in overall U.S. labour reallocation rates was being driven by the retail trade industry, and this was productivity-enhancing because it reflected the growing concentration of activity in that industry in highly productive 'big box' retailers. In the 1990s and 2000s, changing rates of labour reallocation in 'high-tech' industries (a set of ICT-related manufacturing industries) became relatively important. High-tech business dynamism declined throughout the 1980s, increased throughout the 1990s, then declined again after 2000.

On the relationship between high-tech labour reallocation and aggregate productivity growth, Decker *et al.* provide two main results. First, trends in high-tech labour reallocation were driven not by changes in the distribution of firms' productivities but by changes in firms' responsiveness to productivity shocks. The dispersion of productivity across high-tech firms rose steadily over time, but the responsiveness of firms to productivity changes (measured in terms of employment growth or equipment investment growth) increased in the 1990s and fell in the 2000s. This is what explains the pattern of labour reallocation rates in that sector.

Second, the rise and fall of labour reallocation rates in high-tech industries contributed significantly to the rise and fall of productivity growth in high-tech manufacturing. Firms' rising responsiveness to productivity shocks contributed about 0.5 percentage points to annual TFP growth in the 1990s, while declining responsiveness subtracted as much as 2.0 percentage points from TFP growth in the 2000s. The authors' econometric simulations suggest that declining labour reallocation became a drag on productivity growth in the high-tech sector around 2003, which is close to the date of the aggregate U.S. productivity slowdown.

As discussed earlier, a declining productivity growth contribution from the ICT sector has been a major driver of the aggregate productivity slowdown (Fernald, 2014a). The results of Decker *et al.* (2017a) are consistent with this view, but they suggest that the decline in the productivity contribution of the ICT sector may be the result of a decline in the efficiency of the allocation of labour across firms in the ICT sector rather than (or in addition to) a decline in technological progress in the sector. Efficiency-enhancing labour reallocation is supposed to occur as the result of a number of forces: the exit of the least productive firms from the marketplace, the entry of firms with new ideas to challenge incumbents, and the reallocation of market share toward relatively productive firms through competition. Evidently, these forces are growing less effective at channelling resources toward the most productive firms in the tech sector.

Decker *et al.* (2017b) provide further evidence in support of the view that declining allocative efficiency is part of the explanation of the post-2004 slowdown. Using measures of labour productivity and employment for firms in the U.S. business sector, they show that the positive correlation between productivity and employment share declined in the early 2000s. As a result, the positive contribution of labour reallocation to aggregate labour productivity growth fell significantly. Both a decline in reallocation among continuing firms and a decline in the contribution of net firm entry to reallocation led to slower productivity growth after the early 2000s.

These results suggest that changes in U.S.

business dynamism may play a substantial role in explaining aggregate productivity trends in recent years. That said, this line of research is still in its infancy and there remains much uncertainty about the magnitudes of the effects. Much more work needs to be done to develop more reliable quantitative estimates of the relationship between business dynamism and aggregate productivity. One important issue that the literature must address is the possibility that the changes in business dynamism, rather than (or in addition to) being causes of changing productivity growth, have themselves been caused by underlying changes in the rate of technological progress.

Reallocation Across Industries: The Baumol and Denison Effects

The previous subsection discussed the implications of labour reallocation across firms. Aggregate productivity growth is also affected by the reallocation of labour (or other inputs) across industries. For completeness, we address this now.

The idea that resource reallocation across industries may tend to cause a slowdown in aggregate productivity growth is associated with the work of William Baumol on unbalanced growth and the 'cost disease.'[33] If some industries (say, manufacturing) exhibit fast productivity growth while others (say, health services) exhibit slow productivity growth, the relative prices of the outputs of the slow-growth industries will tend to rise. Baumol thought that this would lead to an increase in the share of slow-growing industries in total output, and hence to lower aggregate productivity growth even if productivity growth rates within each industry remain unchanged over time.

On the other hand, there has been a long-run tendency for labour (and other inputs) to move from low-productivity to high-productivity uses over time. Edward Denison pointed this out in the context of the shift from agriculture to manufacturing in advanced economies in the middle of the 20th century.[34] In general, aggregate productivity growth will rise if labour is reallocated into industries with high productivity levels.

We already touched upon both these ideas in our industry decompositions of productivity growth earlier in this article. What we called the reallocation level effect and the reallocation growth effect could have been called the 'Denison effect' and the 'Baumol effect', respectively.[35]

Our industry decomposition revealed that reallocation accounted for only 0.04 percentage points (or 1.9 per cent) of the labour productivity growth slowdown between the 1995-2004 period and the 2004-2015 period (Table 2). Of this, 0.06 percentage points (or 3.0 per cent of the total slowdown) were attributable to the reallocation level effect (or the 'Denison effect'). The reallocation growth effect (or the 'Baumol effect') actually worked against the slowdown, but its impact was quantitatively negligible. The contribution of the reallocation level effect to the slowdown was driven by the FIRE, information and manufacturing industries, while mining and utilities made substantial contributions in the opposite direction (i.e.

33 See Baumol (2012) for a recent exposition of the cost disease argument. Classic references include Baumol (1967) and Baumol *et al.* (1985).

34 See Denison (1967), especially chapter 16.

35 Indeed, this is the terminology used by Nordhaus (2001) in his industry decomposition of productivity growth.

toward faster overall productivity growth) through the reallocation level effect.

Overall, our industry decomposition results make it clear that cross-industry reallocation was not a dominant driver of the slowdown.

Labour Quality Growth

Our growth accounting exercise in Section 3 revealed that change in the growth of labour quality was not a significant driver of the productivity slowdown (Table 3). Labour quality growth contributed nothing to the productivity decline in the private business sector, while in the total economy it contributed -0.06 percentage points (or 3.9 per cent of the total decline).

That being said, it is noteworthy that the contribution of labour quality growth to labour productivity growth was high during the 2008-2010 period and has been quite low since 2010. The brief surge in labour quality growth during the Great Recession may reflect the concentration of job losses among relatively low-wage workers. It remains to be seen whether the low contribution of labour quality since 2010 is a temporary effect of the recovery from that recession (as those relatively low-productivity workers return to work) or a permanent slowdown in labour quality growth (perhaps due to declining growth in educational attainment).[36] If it is the latter, then the labour productivity growth slowdown may become even worse in the coming years. The projection exercises of Bosler *et al.* (2016) and Jorgenson *et al.* (2016) suggest that slow U.S. labour quality growth is likely going forward due to a plateau in educational attainment, and a recovery of labour market participation among unskilled workers would reduce labour quality growth further.

Aggregate Demand and Productivity Growth

All the explanations discussed so far might be described as supply-side explanations. An alternative view (or perhaps a complementary one) is that, since 2008, part of the decline in productivity growth has been the endogenous result of a shortfall in aggregate demand. Theoretical models of endogenous growth provide reasons to think that demand shocks might affect TFP growth (at least temporarily) through endogenous changes in R&D spending. Empirical evidence in support of this mechanism as a driver of the productivity slowdown is limited.

The recession of 2008-2009 involved both a financial crisis and a large decline in aggregate demand in the U.S. economy. A disruption of financial markets or an aggregate demand shortfall could lead to lower TFP growth via a number of channels. Financial market disruption could lead to a reduction in resource reallocation, and hence to lower TFP due to a higher degree of misallocation.[37] Financial disruption or low demand could lead firms to reduce their investment in research and development and technology commercialization, leading to slower TFP growth (Queralto, 2015; Anzoategui *et al.*, 2015; Bianchi *et al.*, 2016). Duval *et al.* (2018) find evidence consistent with this view in a large sample of firms in OECD countries. Both lower capital investment and lower TFP growth contribute to lower labour productivity

36 Labour quality is measured using information on the relative wages of workers across age, gender and skill categories.

37 Quantitative findings on the importance of financial market frictions for TFP are mixed. Some studies find that financial frictions have a large effect on TFP through resource misallocation (e.g. Moll, 2014; Greenwood *et al.*, 2012), while others find that the effects are small (e.g. Midrigan and Xu, 2012; Gilchrist *et al.*, 2012). Further research in this area is warranted.

growth, everything else being equal.

Reifschneider *et al.* (2015) develop an econometric model of potential output and find that the financial crisis in 2007 and 2008 was followed by a substantial decrease in U.S. potential output growth. The largest contributors to this decline were reductions in capital formation and in their estimates of trend TFP growth.[38] In an accounting analysis, Hall (2014) measures the sources of the shortfall of U.S. output in 2013 relative to its 1990-2007 trend and finds that the largest contributors were reduced capital accumulation and reduced TFP growth.[39] Reifschneider *et al.* speculate that the decline in TFP growth might be the endogenous result of demand-driven declines in R&D activity. Hall is skeptical of this view, given that "similar slowdowns [of TFP growth] over 6-year periods have been common." In a more recent study, Fernald *et al.* (2017) find that slow output growth since 2009 reflects two structural forces slow TFP growth and declining labour force participation that already existed before the Great Recession.

Blanchard *et al.* (2015) examine recoveries from 122 recessions in 23 countries. They note that, in many cases, output growth (not just the output level) remains below its pre-recession trend for a long time after the recession. While they consider the possibility that these growth slowdowns are caused by the recessions, they think it more likely that the reverse is true: the recessions were caused by the arrival of news that future growth would be slower than expected. Along similar lines, Blanchard *et al.* (2013; 2017) argue that the weakness of U.S. aggregate demand since the Great Recession is a reflection of Americans' downward revisions of expectations for future growth, not a cause of them.

The growth accounting exercises presented in Section 3 of this article revealed that a decline in the rate of capital deepening accounted for 36 per cent of the private business sector labour productivity slowdown between the 1995-2004 and 2004-2015 periods (Table 3). Indeed, the contribution of capital deepening to labour productivity growth has been negative since 2010. Low capital investment could reflect depressed aggregate demand, but it could also reflect low expectations of future productivity growth. If productivity growth is expected to be low, then expected returns to capital investment will be low as well.

The cause and effect relationship between current aggregate demand and future productivity growth is difficult to untangle. Estimated structural models such as those of Anzoategui *et al.* (2015) and Bianchi *et al.* (2016) can do so, but their results are contingent upon all the assumptions embedded in the models. Given that U.S. productivity growth remained high following the 2001 recession and then declined a few years before the 2008 recession, it seems likely that the post-2004 slowdown in trend productivity growth was not primarily a demand-driven phenomenon (Fernald, 2014b). Still, further research on the question is warranted.

Conclusion

The post-2004 U.S. productivity slowdown resulted in a decline of some

38 They did find an increase in TFP growth in 2009 and a decline thereafter, broadly consistent with the numbers in our Table 1.

39 Together, slower TFP growth and low capital deepening contributed 7.4 percentage points to the 13 per cent shortfall of U.S. output in 2013 relative to the level implied by its 1990-2007 trend. Low labour force participation and labour market slack (i.e. high unemployment and low hours worked relative to past trends) also made substantial contributions in Halls' decomposition.

$3 trillion in U.S. real output in 2015 relative to the counterfactual in which the slowdown had not occurred. In this article, we aimed to provide an overview of the current state of knowledge on the causes and descriptive characteristics of the slowdown. We summarized recent trends in U.S. productivity measures and identified the proximate sources of the slowdown in a standard growth accounting framework. We presented new findings on the industry sources of the slowdown based on the CSLS labour productivity growth decomposition. We reviewed the extensive literature aimed at explaining the slowdown.

Based on our analysis, the state of knowledge about the slowdown can be summarized in the following four points:

- The trend rate of U.S. productivity growth declined around 2004. The decline occurred in both labour productivity growth and TFP growth, and in both the business sector and the total economy.

- Labour productivity growth in the private business sector slowed by 2.0 percentage points per year after 2004. Of this decline, 60-65 per cent was accounted for by a decline in TFP growth and 30-35 per cent was accounted for by a decline in the rate of capital deepening. Changing growth of labour quality played a comparatively small role.

- Three industries collectively accounted for 80.5 per cent of the labour productivity slowdown: manufacturing (42.0 per cent), wholesale trade (21.7 per cent), and retail trade (16.9 per cent). These industries' contributions to the slowdown were driven by within-sector productivity slowdowns. Labour reallocation across industries accounted for only 1.9 per cent of the labour productivity slowdown.

- The slowdown is traceable to a decline in the productivity contributions arising from industries that produce or intensively use information and communication technology (ICT) products. The decline in the productivity contribution of ICT was driven by some combination of a) slower technological progress in ICT and b) a reduction in business dynamism in the ICT sector resulting in a decline in the rate of resource reallocation from less-productive to more-productive firms.

It is important to emphasize that the role of ICT in the slowdown does not mean that the entire slowdown is attributable to a slowdown of productivity growth in ICT-producing industries. The slowdown is also evident in industries that intensively use ICT, particularly market service industries. During the 1995-2004 period, such industries were able to raise their productivity by adopting ICT. Evidently, these gains were played out by 2004. The industry decomposition results in this article are broadly consistent with this account. In retail trade, for example, ICT made possible the rise of Big Box' retail and facilitated productivity gains in inventory and supply chain management. These gains were exhausted once these management changes had been made and all the best locations for Big Box' stores had been developed.

What implications might the U.S. productivity growth slowdown have for Canada? Over the 1987-2015 period, business sector labour productivity growth in Canada lagged that of the United States by 0.78 percentage points per year (Table 4). The gap has tended to be larger during periods of fast growth in the United States. During the 1995-2004 period (the ICT-

Table 4: Labour Productivity Growth in the United States and Canada, Business Sector, 1987-2015

	United States	Canada	Growth Gap
1987-2015	2.00	1.22	0.78
1987-1995	1.55	1.12	0.43
1995-2004	3.22	1.69	1.53
2004-2015	1.33	0.91	0.42
2004-2008	1.33	0.79	0.54
2008-2010	3.25	0.88	2.38
2010-2015	0.57	1.02	-0.45

Sources: U.S. data are from the Bureau of Labor Statistics, Labor Productivity and Costs. Canadian data are from Statistics Canada, CANSIM Table 383-0008.

driven productivity boom), U.S. labour productivity grew by 3.22 per cent per year. Canadian labour productivity grew by 1.69 per cent per year over the same period; while this was above the Canadian average for the 1987-2015 period, it was 1.53 percentage points below the U.S. growth rate an enormous gap.[40] During the slow-growth periods of 1987-1995 and 2004-2015, the gap was about 0.4 percentage points. The U.S. productivity slowdown has slowed the labour productivity divergence between the United States and Canada relative to the 1995-2004 period.

Indeed, since 2010, the gap has turned negative. U.S. labour productivity growth over the 2010-2015 period has averaged 0.57 per cent per year, the lowest rate of any extended period since 1987. In Canada, by contrast, labour productivity growth picked up after 2010 and has averaged 1.02 per cent per year over the 2010-2015 period. Thus, Canadian labour productivity growth has exceeded U.S. growth by 0.45 percentage points. In the near term, this bodes well for the growth of Canadian living standards relative to those of the United States.

In the longer term, however, a slowdown in U.S. productivity growth portends slower growth in Canada as well. The United States is at the global technological frontier in many sectors, including the important information technology sector. To the extent that the U.S. slowdown reflects a decline in the pace of technological change at the frontier, then it is almost certain that productivity growth in the countries chasing the frontier like Canada will eventually fall as well.

We conclude by suggesting some areas for future research. First, we provided industry decomposition results for labour productivity. It would be informative to perform a similar decomposition for TFP growth.[41] Second, our decomposition based on two-digit industries could be extended to a more detailed level of industry disaggregation. This would allow us to identify the sub-industries that drove the large contributions of two-digit manufacturing, retail trade, and wholesale trade to the productivity slowdown.

The industry-level results could be examined in greater detail in other ways. For example, how much of the decline

40 The gap was even larger during the 2008-2010 period, at 2.38 percentage points. This probably reflects the larger impact of the Great Recession on hours worked in the United States relative to Canada.

41 Calver and Murray (2016) show how to apply the CSLS decomposition method to TFP data. They present decomposition results for Canadian TFP growth over the 1997-2014 period.

in manufacturing is attributable to a slowdown in the rate of semiconductor price decline versus increased offshoring of ICT production?

Our growth accounting results indicated that U.S. labour quality growth spiked during the Great Recession and has been slow since 2010. We speculate that this pattern reflected cyclical changes in the skill composition of the workforce, but it would be worthwhile to examine this formally.

A topic that we did not discuss in this article and that has received little attention in the literature is the potential role of international trade in the productivity slowdown. Modern trade theory emphasizes the relationship between trade and firm-level productivity dynamics, and the Great Recession was associated with a significant slowdown in global trade. Could this have affected U.S. productivity growth?

The emerging literature using firm-level data to link aggregate productivity growth to industry-level trends in business dynamism suggests that declining labour reallocation across firms might be a key driver of the productivity slowdown. This should be a major focus of future research, since this driver of slower aggregate productivity growth might carry very different policy implications than a decline in the pace of fundamental technical progress would.

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