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Research Paper

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ABSTRACT: In this paper, we identify the contribution of the information, communications, and technology sector to the economic growth of the United States. For the years 1997-2002, we find the sector contributed 19% of measurable economic gross output growth, or more than 582 billion 2013 dollars. For the period 2002-2007, we find the sector contributed 9.3% of gross output growth, or more than 340 billion 2013 dollars. These contributions to economic growth are above the level of economic activity that would have occurred had economic factors remained constant. The ICT sector also contributed substantially to the economic growth of many American industries.

I. Introduction

How much has the Internet—or more broadly, the information, communications, and technology sector—contributed to the American economy? In this paper, we apply economic techniques to measure the contribution of the information, communications, and technology sector to economic information consistent with the National Income and Product Accounts from the Department of Commerce's Bureau of Economic Analysis.

Understanding the economic contribution of the information, communications, and technology sector is important. Every generation has an iconic technology, one that changes the ways individuals work, live, and view the world. Ancient civilizations, among other achievements, tamed animals, developed agriculture, introduced written languages, mastered metallurgy, and harnessed mechanical power. More recent generations deployed the railroad, built telephone networks, manufactured automobiles, flew airplanes, and saved lives with new medicines and practices. Our generation has many new technologies, but none more iconic than the Internet.

It is difficult to find anyone who does not believe that it contributes substantially to economic growth. Our federal government policy has been shaped by a view that the Internet, and more recent broadband, are worthy of special governmental protection and encouragement of investment. In 1998, Congress passed and President Clinton signed the Internet Tax Freedom Act which, among actions, banned taxation on Internet access and "multiple or discriminatory taxes on electronic commerce."[1] The Act has been periodically renewed.

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[1] Internet Freedom Act, P.L. 105-277, Title XI, at http://www.gpo.gov/fdsys/pkg/PLAW-105publ277/pdf/PLAW-105publ277.pdf.

The federal view that the Internet was to be promoted was not limited to tax policy. In Section 706 of the Telecommunications Act of 1996, Congress wrote: "The [Federal Communications] Commission and each State commission with regulatory jurisdiction over telecommunications services shall encourage the deployment on a reasonable and timely basis of advanced telecommunications capability [the Internet] to all Americans…"[2] In the depths of the recent economic recession, Congress passed the American Recovery and Reinvestment Act of 2009 which, among other activities, authorized $4.7 billion to establish the Broadband Technology Opportunities Program.[3]

American government leaders of both parties adopted the view that the Internet was important for economic growth beginning in the early 1990s. Before the International Telecommunications Union in 1994, Vice President Al Gore stated that vast economic growth was available through the Internet or through the Global Information Infrastructure (GII) of which the Internet was an important part:

> The global economy also will be driven by the growth of the Information Age. Hundreds of billions of dollars can be added to world growth if we commit to the GII [global information infrastructure, which included the Internet]. I fervently hope this conference will take full advantage of this potential for economic growth, and not deny any country or community its right to participate in this growth.[4]

Jack Kemp, a former vice presidential candidate, wrote in 2000:

> If this is the course we choose, the Internet will transform our economy, expand our personal freedoms and generate economic opportunity for every American while strengthening state and local treasuries.[5]

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[2] 47 U.S.C. Section 1302.
[3] See http://www.ntia.doc.gov/legacy/recovery/index.html.
[4] Al Gore, speech to the International Telecommunications Union, March 21, 1994, at http://vlib.iue.it/history/internet/algorespeech.html (accessed April 21, 2014).
[5] See http://www.caltax.org/MEMBER/digest/mar2000/mar00-2.htm.

The positive governmental economic view of the Internet continues today. President Obama's White House website posits the Internet and related technologies not merely as a cause of economic growth, but as *essential* for economic growth:

> President Obama recognizes that technology is an essential ingredient of economic growth and job creation. Ensuring America has 21st century digital infrastructure—such as high-speed broadband Internet access, fourth-generation (4G) wireless networks, new health care information technology and a modernized electrical grid—is critical to our long-term prosperity and competitiveness.[6]

From the early 1990s through today, it is difficult to find a politician of any background who would not claim that the Internet was an important component, even cause, of economic growth. Investments in Internet-related capital have been widely viewed as having a disproportionate effect on economic activity. Reed Hundt, former chairman of the Federal Communications Commission, asserted in 2014:

> The [tech] boom accounted for about one-third of all economic growth in the decade of the 1990s. About one trillion dollars of private capital was poured into America's networks, creating vast fortunes, destroying some other wealth, producing huge productivity gains, and making America permanently better off. As a result of this investment, the ICT sector created about two million net new jobs in that halcyon era of full employment.[7]

Mr. Hundt's testimony was not disputed at the Congressional hearing. The stylized facts that the Internet and the high technology sector contributed substantially to the American economy are widely circulated. Investments in broadband and the Internet are, according to both political and popular wisdom, key drivers to economic growth.

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[6] See http://www.whitehouse.gov/issues/technology.

[7] Testimony of R.E. Hundt before the Subcommittee on Communications and Technology, House Energy and Commerce Committee, January 15, 2014. See http://democrats.energycommerce.house.gov/sites/default/files/documents/Testimony-Hundt-CT-Comm-Act-Update-FCC-Chairmen-2014-1-15.pdf.

But exactly how much have the Internet and related sectors contributed to American economic growth? Surprisingly, despite 20 years of government focus on the Internet and related services, the federal government has no official measures of the contributions of the Internet to economic growth. Moreover, the past 20 years have seen unusually slow economic growth in the American economy.

In this paper, we use techniques to identify the contribution of the broader information, communications, and technology sector to the American economy, and to industries within it, consistent with federal national income and product accounts. Given data availability, we focus on the period 1997-2007. We begin in Section II by examining traditional approaches to measuring economic growth with total factor productivity indexes. In Section III, we then expand this approach to account for the information, communications, and technology based on indexes that we have developed. In Section IV we apply our measurement techniques to specific industries.

II. Total factor productivity with quantity indexes: the traditional approach

Economists often employ the KLEMS database maintained by the Bureau of Economic Analysis for studies examining growth in the American economy as well as sources of productivity advances.[8] The KLEMS quantity indexes can be viewed as

[8] The Bureau of Economic Analysis ("BEA") has maintained for many years a database, consistent with national income and product accounts, that allocates the inputs in the American economy into five categories: capital (K), labor (L), energy (E), materials (M), and services (S). The database is often referred to as "KLEMS." BEA provides annual quantity and price indexes and expenditure shares associated with KLEMS. Many economic studies are based on KLEMS. See for example: Susan Fleck, et al., "A Prototype BEA/BLS Industry ‐ Level Production Account for the United States," http://www.bls.gov/mfp/bea_bls_industry_product_account.pdf (November 2012). The KLEMS database can be found at http://bea.gov/industry/gdpbyind_data.htm.

factors in a production function of American gross economic output.[9] Presumably, if all factors remain constant, gross output and GDP in the American economy will remain constant. As factors increase, gross output and GDP should increase. Economists have noticed in these measurements a consistent residual, or greater increase in gross output and GDP than increases in inputs. This residual is often labeled as the quantity-side total factor productivity (TFP), roughly a concept of how much more efficiently our economy uses factors of production over time. See Appendix A for a further description of the mathematical foundation of total factor productivity.

American economic growth: 1997-2002

In Table 1, we present a total factor productivity decomposition with KLEMS quantity indexes of the real growth of the United States' gross output between 1997 and 2002.

Table 1

1997-2002, Quantity Total Factor Productivity Calculations				
Variable	v (share)	dln(*)	[v] x [dln(*)]	Percentage Contribution to Growth
QY	1	0.0811	0.0811	
QK	20.7%	0.1621	0.0336	41.4%
QL	35.0%	0.0083	0.0029	3.6%
QE	1.8%	-0.0736	-0.0013	-1.6%
QM	18.7%	-0.0306	-0.0057	-7.1%
QS	23.9%	0.1014	0.0242	29.8%
QTFP			**0.0275**	33.9%

Source: Bureau of Economic Analysis and Authors' calculations

[9] Gross output is the sum of gross domestic product (or equivalently value added from labor and capital) and the value of intermediate inputs. The intermediate inputs are energy, materials, and purchased services. See http://bea.gov/industry/gdpbyind_data.htm.

The first column of Table 1 lists the variables used in the TFP decomposition: QY is the quantity index of real gross output growth in the American economy. Between 1997 and 2002, QY grows by a total of .0811, or 8.11%, or less than 2% per year. The period 1997-2002 is marked by the recession which began in March 2001.[10]

Measures of total factor productivity allocate the growth in gross output among various factor inputs: QK is a quantity index of capital in the economy; QL is a quantity index of labor in the economy; QE is a quantity index of energy in the economy; QM is a quantity index of material inputs in the economy; QS is a quantity index of services in the economy; and QTFP is the quantity index of total factor productivity. The total factor productivity decomposition can reveal how much of the growth of the American economy is potentially attributable to factors that might be related to the Internet or the broader information, communications, and technology sector.

The second column of Table 1 shows the average expenditure share in the two time periods, 1997 and 2002, of each of the five inputs in the economy. Between 1997 and 2002, the expenditure shares range from 1.8% for energy to 35% for labor.[11]

The third column of Table 1 shows the change in the factor input index from one time period to another under the label dln(*). This value is the natural log of the index in the more recent year minus the natural log of the index in earlier year. Notice that if an input remains constant in the two time periods, dln(*) will be zero, and the factor will be treated as having not contributed to economic growth. If the quantity index for the factor decreases, dln(*) will be negative, and the contribution to economic growth will be

[10] See http://www.nber.org/cycles.html.

[11] Energy contributes to the U.S. economy both through direct consumption as well as through materials and services. This accounts for the low share for energy.

negative. If, however, the quantity index for the factor increases, dln(*) will increase, and the factor will be credited with contributing positively to economic growth. Total output in the economy grows in real terms by 0.811, or 8.11%. The quantity indexes for two of the factors, energy and materials, actually decline between 1997 and 2002. The largest increase in the quantity indexes is for capital followed by services, both of which increased more rapidly than total output.

The fourth column of Table 1 shows the contribution of the factor to economic growth between the two time periods. The quantity index for the entire economy, in dln(*) form, increases by 0.0811 between 1997 and 2002. Between 1997 and 2002, the quantity indexes for two of the factors, energy and materials, actually decline and have negative contributions to economic growth. Labor barely increases and contributes 0.0029. The largest contributions to economic growth between 1997 and 2002 are the indexes for capital and services.

Table 1 should not be interpreted to mean that energy, materials, and labor contributed little to American economic activity. These economic factors contributed substantially to economic *activity*, but these factors did not *grow* substantially over the five-year period, and they are not consequently associated with economic *growth*.

The last line in Table 1 is the residual economic growth that cannot be explained by changes in economic inputs. This residual is commonly labeled as total factor productivity, economic growth that is not attributable directly to changes in economic inputs. Between 1997 and 2002, total factor productivity in the United States increases by 0.0275, or 2.75%. Conceptually, this measure means that, if the quantity indexes for all factor inputs were exactly the same in 2002 as in 1997, one would expect that GDP would still grow by 2.75% over the five-year period.

The fifth and final column of Table 1 displays the percentage contribution to economic growth between 1997 and 2002 of each of the five economic factor inputs as well as total factor productivity. A large share, 41.4% of economic growth, is attributable to increases in capital, 29.8% is attributable to increases in services, and 33.9% is attributable to total factor productivity.

In 2013 dollars, total gross output in the American economy increases from $20.962 trillion in 1997 to $24.029 trillion in 2002, or an increase of $3.067 trillion.[12] In Table 2, we scale the quantity index of gross output change in the economy with the change in real gross output, and we allocate this increase in gross output to the changes in the five factor inputs, based on the TFP results in Table 1.[13] We find that increases in capital inputs account for approximately $1.269 trillion in economic gross output growth from 1997-2002. Increases in services lead to $914 billion in economic growth, and total factor productivity accounts for approximately $1.040 trillion in economic growth. Increases in labor account for relatively little economic growth and energy and materials actually decline.

[12] Table BEA GDP by industry VA_NAICS at http://bea.gov/industry/gdpbyind_data.htm, and Table 1.1.9, Implicit Price Deflators for Gross Domestic Product, at http://bea.gov/itable/error_NIPA.cfm.

[13] The output measure in Table 1 is an index of gross output in the economy from all factor inputs, not an index of GDP which captures only the value added in the economy from capital and labor.

Table 2

1997-2002 Contributions to economic gross output growth of changes in factor inputs in 2013 dollars		
Factor Input	Percentage Share	Contribution to Growth in Billions of 2013 Dollars
Y		3,067
QK	41.4%	$1,269
QL	3.6%	$109
QE	-1.6%	$(49)
QM	-7.1%	$(216)
QS	29.8%	$914
QTFP	33.9%	$1,040

Source: Bureau of Economic Analysis and Authors' calculations

The information, communications, and technology sector may have influenced economic growth between 1997 and 2002 through any of the factors or through total factor productivity, but the information provided in Tables 1 and 2 does not enable an identification of the economic contribution of that sector.

American economic growth: 2002-2007

In Table 3, we repeat the total factor productivity analysis in Table 1 for the time period 2002-2007. The expenditure shares between in the five years between 2002 and 2007 are remarkably similar to the shares in the prior five-year period. Total gross output increases by 0.1307, or 13.07% from 2002-2007, more than in the prior five-year period which includes a major recession from 2001-2002. This five-year growth rate corresponds to approximately 3.1% annually. The earlier period is measured from the middle of an expansion to a trough, and the latter period is measured from the trough to the peak of an expansion. The largest increases in quantity indexes are for services and capital, both of which increase more rapidly than total output. The energy quantity index continues to decline during the 2002-2007 period.

Table 3

2002-2007, Quantity Total Factor Productivity Calculations				
Variable	v (share)	dln(*)	[v] x [dln(*)]	Percentage Contribution to Economic Growth
QY	1	0.1307	0.1307	
QK	21.1%	0.1433	0.0302	23.1%
QL	34.4%	0.0672	0.0231	17.7%
QE	2.0%	-0.1268	-0.0026	-2.0%
QM	17.9%	0.0834	0.0149	11.4%
QS	24.7%	0.1839	0.0455	34.8%
QTFP			**0.0195**	14.9%

Source: Bureau of Economic Analysis and Authors' calculations

The fourth column of Table 3 shows the contribution to economic growth during the 2002-2007 period. The largest contributions are from services, capital, and labor. Total factor productivity, the residual after the economic growth contributions of other factors are calculated, is 0.0195, or 1.95%, less than in the prior five-year period.

The final column of Table 3 shows the percentage contribution to economic growth. The largest shares of contribution to economic growth are from services (34.8%), capital (23.1%), labor (17.7%), and total factor productivity (14.9%). Energy decreases in its contribution to economic growth.

Table 4, as with Table 2, shows the contribution to economic growth as measured with gross output from 2002-2007 of the five factors in billions of dollars. In $2013 dollars, the U.S. economy grows by $4.614 trillion between 2002 and 2007.[14] The largest contribution is from services with $1.607 trillion, followed by capital with $1.067 trillion and labor with $816 billion. Total factor productivity accounts for $688 billion.

Table 4

2002-2007 Contributions to economic gross output growth of changes in factor inputs in 2013 dollars		
Factor Input	Percentage Share	Contribution to Growth in Billions of 2013 Dollars
Y		4,614
QK	23.1%	$1,067
QL	17.7%	$816
QE	-2.0%	$(92)
QM	11.4%	$527
QS	34.8%	$1,607
QTFP	14.9%	$688

Source: Bureau of Economic Analysis and Authors' calculations

The information, communications, and technology sector almost certainly influenced economic growth between 2002 and 2007 through any of the factors or through total factor productivity, but the information provided in Tables 3 and 4 does not enable an identification of the economic contribution of that sector.

Total factor productivity with price indexes: the traditional approach

The same approach to total factor estimation with quantity indexes on KLEMS data can also be used with price indexes. Rather than associate gross output with a production function, we can instead associate gross output with a unit cost function for

[14] BEA GDP by industry VA_NAICS at http://bea.gov/industry/gdpbyind_data.htm, and Table 1.1.9, Implicit Price Deflators for Gross Domestic Product, at http://bea.gov/itable/error_NIPA.cfm.

national output using the KLEMS price indexes as factor prices. If all factor prices remain constant, the unit cost function for gross output is expected to remain constant. As factor prices increases, the unit cost function for gross output increases. Economists have noticed in these measurements a consistent residual, or reduction in the unit cost function over time. Economists often label this residual as price-side total factor productivity, roughly a concept of how much more efficiently our economy uses factors of production over time.

In Table 5, we present a total factor productivity decomposition with price indexes of the growth of the United States gross output between 1997 and 2002. The expenditure shares are the same as in Table 1, but the change in the price index in the third column are quite different. The log of the overall gross output price index increases by 0.0832. The price indexes for labor and energy increase even more than the price index for gross output. The price index for capital and services increases by less than the gross output price, and the price index for materials decreases.

Table 5

1997-2002, Price Total Factor Productivity Calculations				
Variable	v (share)	dln(*)	[v] x [dln(*)]	Percentage Contribution to Unit Cost Growth
PY	1	0.0832	0.0832	
PK	20.7%	0.0300	0.0062	7.5%
PL	35.0%	0.1779	0.0622	74.7%
PE	1.8%	0.1530	0.0027	3.2%
PM	18.7%	-0.0223	-0.0042	-5.0%
PS	23.9%	0.0689	0.0164	19.8%
PTFP			-0.0001	-0.2%

Source: Bureau of Economic Analysis and Authors' calculations

The overall contribution to the unit price index is shown in the fourth column. The largest contributions to price increases are from labor and services. Materials contribute to a price reduction and total factor productivity contributes to a negligible price reduction. It is difficult to translate the changes in the unit cost function directly into dollar value contributions for gross output.

We conduct a similar analysis with price indexes for the period 2002-2007 in Table 6. Gross output prices increase by 0.1836. Energy, materials, and labor increase even more; capital and services increase less. All factor prices increase substantially. There is a substantial total factor productivity change as the unit cost function does not increase as much as the price indexes for the various economic factors. The measured total factor productivity change with the unit cost function is -0.0165, or -1.65%. That is, if factor prices in 1997 and 2002 remained constant, we would expect to find unit costs of gross output to have declined by 1.65%.

Table 6

2002-2007, Price Total Factor Productivity Calculations				
Variable	v (share)	dln(*)	[v] x [dln(*)]	Percentage Contribution to Unit Cost Growth
PY	1	0.1836	0.1836	
PK	21.1%	0.1801	0.0380	20.7%
PL	34.4%	0.1925	0.0662	36.1%
PE	2.0%	0.5823	0.0119	6.5%
PM	17.9%	0.2699	0.0483	26.3%
PS	24.7%	0.1440	0.0356	19.4%
PTFP			-0.0165	-9.0%

Source: Bureau of Economic Analysis and Authors' calculations

The information, communications, and technology sector may have influenced economic growth as measured through the unit cost function between 1997 and 2002 and between 2002 and 2007 through any of the factor prices or through total factor productivity, but the information provided in Tables 5 and 6 does not enable an identification of the economic contribution of that sector.

III. Total factor productivity with quantity indexes: the contribution of ICT capital and services

The Internet and broadband services have been among the great technological innovations over the past two decades. Can we use the TFP analysis to measure the contribution of these new technologies to the American economy? If we had specific information on price and quantity indexes for the Internet consistent with the KLEMS database, we could apply this analysis directly. We are not aware of such indexes. We have, however, been able to construct price and quantity indexes for the contributions to both capital and services for the broad information, communications, and technology (ICT) sector of the economy.

The ICT sector comprises industries involved in the production of a wide-range of high-tech goods and services. For the purposes of this paper, we limit the scope of the ICT sector to a subset of capital producers and service providers. We define ICT-related capital as equipment specific to computers, communications and broadcasting, and semiconductors. ICT-related services include Internet and telecommunications, data processing and web search, software publishing, and broadcasting services, as defined by NAICS See Appendix B, Table 2 for details.

We omit certain industries traditionally considered members of ICT. For example, we omit all publishers other than those of software due to changes in these industries' definitions over our time frame 1997-2007.

Our ICT sector definition includes such industries as broadcasting which have been around much longer than the Internet. As such, our estimates for the contributions of the ICT sector to the U.S. economy will overstate the contributions of the Internet and broadband. Nonetheless, we believe that many of the major changes in the sector over the past two decades are attributable to the Internet and related new technologies such as broadband and wireless services. Table 7 shows the relative size of the ICT sector in terms of gross output of ICT-related capital and services.

Table 7

Size of ICT Sector: Millions of Current Dollars and Percentage of Gross Output			
Year	1997	2002	2007
ICT Capital (KICT)	$252 1.57%	$189 1.00%	$192 0.74%
ICT Services (SICT)	$368 2.30%	$549 2.92%	$717 2.78%
ICT Total	$620 3.88%	$738 3.92%	$910 3.53%
Gross Output Total	$15,987	$18,843	$25,802

Source: Bureau of Economic Analysis and Authors' calculations

Based in part on information from the Bureau of Economic Analysis's input-output model, which is available only in the Economic Census years, with the most recent data from 2007, we construct price and quantity indexes for ICT capital and ICT services and for non-ICT capital and non-ICT services. Our construction of the indexes is presented in Appendix B.

In Table 8, we repeat the total factor productivity analysis in Table 1 for the time period 1997-2002 but with the decomposition of capital and services into ICT and non-ICT components. As shown in the second column of Table 8, the expenditure shares for ICT capital (1.3%) and services (2.7%) are small.

Table 8

1997-2002, Quantity Total Factor Productivity Calculations with ICT decomposition				
Variable	v (share)	dln(*)	[v] x [dln(*)]	Percentage Contribution to Growth
QY	1	0.0811	0.0811	
QKICT	1.3%	0.0458	0.0006	0.7%
QKNON	19.4%	0.1573	0.0305	37.6%
QL	35.0%	0.0083	0.0029	3.6%
QE	1.8%	-0.0736	-0.0013	-1.6%
QM	18.7%	-0.0306	-0.0057	-7.1%
QSICT	2.7%	0.5528	0.0149	18.3%
QSNON	21.2%	0.0956	0.0202	24.9%
QTFP (W/ ICT DECOMP.)			0.0190	23.4%

Source: Bureau of Economic Analysis and Authors' calculations

As shown in the third column of Table 8, the quantity index for ICT capital increased only slightly over this period. The small increase may reflect partly the bursting of the dot.com bubble in 2001-2002. The quantity index for ICT services, presumably including a wide array of internet and broadband services, increased dramatically (0.5528) and much more than any other factor index.

The fourth column of Table 8 shows the calculation of contribution to economic growth of gross output. Overall economic growth is 0.0811 or 8.11% between 1997 and 2002. The contribution of labor, energy, and materials, which we did not decompose, are exactly the same as in Table 1. The ICT decomposition of capital appears to make little difference. The economic contribution of ICT capital is negligible and the economic contribution of non-ICT capital is 0.0305, slightly less than the contribution of all capital found in Table 1.

The dramatic change in Table 8 is in the contribution of services, both ICT and non-ICT. Non-ICT services contribute 0.0202 to economic growth and ICT services contribute 0.0149, for a combined contribution of 0.0351. In Table 1, services only account for 0.0242 gross output growth. This increase in the measured contribution of services leads to a decline in the measured contribution of TFP, which falls to 0.019. Taken together, the ICT indexes account for 19% of economic gross output growth between 1997 and 2002. Total factor productivity growth accounts for 23.4% of gross output growth and may include some effects of the ICT sector as well.

In Table 9, we allocate this increase in economic gross output between 1997 and 2002 to the changes in the seven factor inputs, based on the TFP results in Table 8. We find that increases in ICT capital accounted for little economic growth from 1997-2002. Increases in ICT services led to $561 billion in economic growth and total factor productivity accounted for approximately $718 billion in economic growth. The contributions of labor, energy, and materials are the same as reported in Table 2. Table 9 reveals that the ICT sector contributed approximately 19%, or more than $580 billion in 2013 dollars, of the economic growth of the United States between 1997 and 2002. This growth is above the constant level of economic activity had factor inputs, including ICT services and capital, remained constant. It is possible that the ICT sector may account for some of the $718 billion in economic growth attributable to total factor productivity as well.

Table 9

1997-2002 Contributions to economic gross output growth of changes in factor inputs with ICT decomposition		
Factor Input	Percentage Share	Contribution to Growth in Billions of 2013 Dollars
Y		3,067
QKICT	0.7%	$21
QKNON	37.6%	$1,153
QL	3.6%	$109
QE	-1.6%	($49)
QM	-7.1%	($216)
QSICT	18.3%	$561
QSNON	24.9%	$764
QTFP	23.4%	$718

Source: Bureau of Economic Analysis and Authors' calculations

Table 10 shows the quantity index TFP analysis for 2002-2007 with the ICT decomposition of capital and services. The expenditure shares for ICT capital, 0.9%, and ICT services, 2.9%, are both small.

Table 10

2002-2007, Quantity Total Factor Productivity Calculations with ICT decomposition				
2002-2007, Quantity Side -- With ICT Decomp.				
Variable	v (share)	dln(*)	[v] x [dln(*)]	Percentage Contribution to Growth
QY	1	0.1307	0.1307	
QKICT	0.9%	0.2794	0.0025	1.9%
QKNON	20.2%	0.1439	0.0291	22.3%
QL	34.4%	0.0672	0.0231	17.7%
QE	2.0%	-0.1268	-0.0026	-2.0%
QM	17.9%	0.0834	0.0149	11.4%
QSICT	2.9%	0.3348	0.0097	7.4%
QSNON	21.8%	0.1757	0.0384	29.4%
QTFP (W/ ICT DECOMP.)			0.0156	11.9%

Source: Bureau of Economic Analysis and Authors' calculations

The quantity index for gross output grows 0.1307 between 2002 and 2007. With the exception of labor, energy, and materials, all of the economic factors grow more rapidly than 0.1307. The most rapid growth is for ICT services and ICT capital.

The fourth column of Table 10 shows the contributions to economic growth for each of the factors. For labor, energy, and materials, the contributions are the same as reported in Table 3. The major change in the allocation of contribution of economic growth is for services. In Table 10, the combined ICT and non-ICT services account for 0.0481 while in Table 3, combine services account for only 0.0455 growth. The difference, approximately 0.0016, is much less than the difference in quantity TFP which is only 0.0156 in Table 10.

The final column of Table 10 shows the percentage contribution to economic gross output growth between 2002 and 2007. Non-ICT services and non-ICT capital are the two largest components of economic growth followed by labor. The ICT sector contributed approximately 9.3% of gross output economic growth between 2002 and 2007, less than during the 1997-2002 period.

Table 11 presents the contributions of the various factors to economic growth based on an increase in real gross output of $4.614 trillion in 2013 dollars between 2002 and 2007. The contribution of ICT capital and services, 9.3% of gross output or $340 billion, is substantial but not as large as in the prior five-year period, and smaller than the contributions of other factor inputs. This growth is above the constant level of economic activity had all factor inputs, including ICT services and capital, remained constant. Total factor productivity accounts for $435 billion of economic gross output growth, some of which may be from the ICT sector.

Table 11

2002-2007 Contributions to economic gross output growth of changes in factor inputs with ICT decomposition		
Factor Input	Percentage Share	Contribution to Growth in Billions of 2013 Dollars
Y		4,614
QKICT	1.9%	$69
QKNON	22.3%	$815
QL	17.7%	$647
QE	-2.0%	($73)
QM	11.4%	$417
QSICT	7.4%	$271
QSNON	29.4%	$1,075
QTFP	11.9%	$435

Source: Bureau of Economic Analysis and Authors' calculations

IV. Application of TFP decomposition for ICT capital and services for specific industries

Using industry level data as described in Appendix B, we calculate the contribution of the ICT sector and TFP to economic growth for the periods 1997-2002 and 2002-2007. Tables 12 and 13 show the contributions of ICT Capital, ICT Services, and TFP to growth in industry gross output for 1997-2002 and 2002-2007, respectively.

As expected, because the data are disaggregated by industry we observe less consistent measures of the contribution of the ICT sector. For example, in some industries the change in the quantity index of ICT capital or services may decline over a five-year period, leading to decline in the measured contribution of ICT to economic growth. In other industries, measurement problems may yield puzzling results. Still, certain patterns emerge:

1. During the period 1997-2002, the following industries had more than 10% of economic growth attributable directly to the ICT sector: administrative and waste management services, construction, education services, information, management of companies and enterprises, manufacturing, other services except government, and transportation and warehousing. These industries account for eight out of the 18 industries for which sufficient information is available to measure the contribution of the ICT sector.
2. During the period 2002-2007, the ICT sector contributed more than 10% of gross output growth in only five industries: educational services,

information, management of companies and enterprises, other services except government, and state and local government.

3. Total factor productivity accounted for more than 10% of gross output growth between 1997 and 2002 in seven industries, but also accounted for substantial losses in gross output in several other industries.

4. Total factor productivity accounted for more than 10% of gross output growth between 2002 and 2007 in eight industries but also accounted for substantial losses in gross output in several other industries.

Table 12

1997-2002	ICT and TFP Contributions to Growth in Gross Output					
	QKICT		QSICT		TFP	
Industry Name	$millions	% of total growth	$millions	% of total growth	$millions	% of total growth
Accommodation and food services	$668	0.66%	$4,141	4.12%	$26,918	26.80%
Administrative and waste management services	$782	1.17%	$33,708	50.57%	$33,717	50.58%
Agriculture, forestry, fishing, and hunting	NA	NA	$580	-6.80%	NA	NA
Arts, entertainment, and recreation	-$351	-1.11%	$1,039	3.30%	-$12,813	-40.66%
Construction	$5,685	3.90%	$29,439	20.18%	-$315,095	-216.01%
Educational services	$1,613	4.81%	$3,032	9.05%	-$27,856	-83.10%
Federal government	-$1,397	-0.99%	NA	NA	NA	NA
Finance and insurance	$166	0.05%	$4,302	1.20%	$78,903	22.05%
Health care and social assistance	-$1,983	-0.73%	$6,430	2.38%	$10,723	3.97%
Information	-$2,511	-1.15%	$31,552	14.46%	-$19,274	-8.83%
Management of companies and enterprises	$14,220	34.90%	$10,531	25.84%	$13,734	33.70%
Manufacturing	$1,569	18.78%	-$493	-5.89%	-$28,270	-338.32%
Mining	NA	NA	-$1,379	-3.27%	NA	NA
Other services, except government	-$1,883	-2.51%	$11,576	15.42%	-$153,605	-204.65%
Professional, scientific, and technical services	-$4,696	-2.08%	$11,146	4.93%	-$48,820	-21.61%
Real estate and rental and leasing	-$86	-0.02%	$595	0.14%	-$42,822	-9.89%
Retail Trade	-$50	-0.04%	$935	0.78%	$12,588	10.47%
State and local government	$4,598	1.40%	-$32,743	-9.95%	-$208,834	-63.44%
Transportation and warehousing	$52,925	102.45%	$56,703	109.77%	NA	NA
Utilities	$376	0.75%	$894	1.77%	$10,273	20.38%
Wholesale trade	-$1,284	-1.05%	-$716	-0.59%	$44,914	36.74%

Table 13

2002-2007	ICT and TFP Contributions to Growth in Gross Output					
	QKICT		QSICT		TFP	
Industry Name	$millions	% of total growth	$millions	% of total growth	$millions	% of total growth
Accommodation and food services	$3	0.00%	$1,229	0.58%	$51,520	24.23%
Administrative and waste management services	$2,040	1.01%	$5,837	2.90%	$88,716	44.07%
Agriculture, forestry, fishing, and hunting	-$34	-0.03%	$660	0.62%	$52,476	49.48%
Arts, entertainment, and recreation	$185	0.31%	$1,755	2.95%	$2,949	4.96%
Construction	$129,831	39.42%	-$230,995	-70.13%	-$15,541,252	-4718.42%
Educational services	$3,683	6.60%	$4,808	8.62%	-$40,431	-72.50%
Federal government	$64,362	23.62%	NA	NA	NA	NA
Finance and insurance	$5,924	0.78%	$39,169	5.15%	-$42,363	-5.57%
Health care and social assistance	$706	0.18%	$12,876	3.26%	$4,075	1.03%
Information	$17,951	8.76%	$33,336	16.26%	$181,848	88.70%
Management of companies and enterprises	$17,783	13.52%	-$2,185	-1.66%	-$276,982	-210.62%
Manufacturing	$53,914	3.87%	$30,809	2.21%	$1,073,983	77.18%
Mining	$61	0.02%	$4,390	1.58%	-$542,402	-195.27%
Other services, except government	$28,552	31.66%	$8,051	8.93%	-$651,357	-722.16%
Professional, scientific, and technical services	$8,527	1.98%	$15,244	3.54%	$4,712	1.10%
Real estate and rental and leasing	$868	0.13%	$10,995	1.64%	$40,100	5.99%
Retail Trade	-$171	-0.06%	$8,378	2.79%	-$35,902	-11.97%
State and local government	$57,342	12.37%	$395,938	85.41%	NA	NA
Transportation and warehousing	$502	0.23%	$4,273	2.00%	$181,033	84.53%
Utilities	$13	0.02%	-$2,706	-3.11%	-$27,918	-32.09%
Wholesale trade	-$359	-0.12%	$9,509	3.11%	$106,648	34.85%

V. Conclusion

In this paper, we identify the contribution of the ICT sector to economic growth of measures of gross output in a manner consistent with the Bureau of Economic Analysis's national income and product accounts. Standard measures do not permit identification of the contribution of the ICT sector. With measures of ICT-specific services and ICT-specific capital from BEA data for the years 1997, 2002, and 2007, we can identify the specific contribution of this sector to the growth of gross output. For the years 1997-2002, we find the sector contributed 19% of measurable economic gross output growth, or more than 582 billion 2013 dollars. For the period 2002-2007, we find the sector contributed 9.3% of gross output growth, or more than 340 billion 2013 dollars. These contributions to economic growth are above the constant level of economic activity had all factor inputs, including ICT services and capital, remained constant. Total factor productivity, some of which may be attributable to the ICT sector, was in the hundreds of billions of dollars during each period. During the period 1997-2007, the ICT sector also contributed substantially to the economic growth of many industries including the information industry itself.

Appendix A: Methodology

Overview

The Bureau of Economic Analysis and Bureau of Labor Statistics estimates total factor productivity by constructing either a production or unit cost function. These functions result in a factor decomposition of gross—rather than value-added—output.[15]

Production function approach to measuring TFP

The BEA and BLS specify a national production function:

$$Y^t = a(t)f(K_t, L_t, E_t, M_t, S_t), \tag{1}$$

where
Y_t = Gross Output at time *t*,
$a(t)$ = a measure of neutral technology enhancement at time *t*,
K_t = capital at time *t*,
L_t = labor at time *t*,
E_t = energy at time *t*,
M_t = material inputs at time *t*, and
S_t = service inputs at time *t*.

The usual total factor productivity decomposition with a Divisia index is:

$$\text{dln } Y_t = \sum s^i_t * \text{dln } X^i_t + TFP_t, \tag{2}$$

where index *i* represents a factor (capital, labor, energy, materials, or services), s^i_t is the average expenditure share for factor *i* in the economy at the two-time measurement (*t* and *t*-1), and dln X^i_t is the change in factor *i* between the two time periods. The product s^i_t*dln X^i_t is the contribution of factor *i* to gross output growth. TFP^t represents the total factor productivity estimate as the change in gross output not explained by the growth of the factors. The BEA and BLS also apply this approach to individual industries by reinterpreting all variables in equations (1) and (2) to be at the industry level.

This resulting decomposition illustrates the relative importance of each factor to output growth over time, either at the national or industry level. It also provides an estimate of total factor productivity, or output growth not offset by growth in the combined inputs.

Further work has extended the framework by further dividing capital inputs into their ICT-related and not ICT-related components.[16] The decomposition allows for an estimation of ICT-related capital's contribution to output growth.

[15] Susan Fleck, Steven Rosenthal, Matthew Russell, Erich H. Strassner, and Lisa Usher. "A Prototype BEA/BLS Industry-Level Production Account for the United States." 2012. Available at: http://www.nber.org/chapters/c13005.pdf.

We now propose a method for separating purchased services into ICT and non-ICT factor groups. We modify (1) slightly as follows:

$$Y_t = a(t)f(K^{ICT}{}_t,K^{NON}{}_t,L_t,E_t,M_t,S^{ICT}{}_t,S^{NON}{}_t) \quad (3)$$

A decomposition similar to equation (2) above follows:

$$\text{dln } Y_t = \sum s_{i,t}\text{*dln } X_{i,t} + TFP_t, \quad (4)$$

with the additional decomposition of capital and services into ICT and non-ICT.

This TFP estimates from the KLEMS (2) and augmented-KLEMS (4) decompositions will differ under certain conditions. If the change in $K^{ICT}{}_t$ is the same as the change in $K^{NON}{}_t$, equation (4) collapses to equation (2) with respect to capital. Similarly, if the change in $S^{ICT}{}_t$ is the same as the change in in $S^{NON}{}_{t,}$ equation (4) collapses to equation (2) with respect to services. If, however, the changes in ICT and non-ICT inputs are not the same for either capital or services, then (4) does not collapse to (2). This implies that the growth that decomposition (2) would attribute to TFP will now be redistributed to the ICT and non-ICT inputs under (4), or vice-versa.

Generally, we expect that the richer specification in (4) will explain more of the changes in Y_t than the simpler specification in (2). That is, TFP in equation (2) should be greater than TFP as measured in equation (4).[17] We can express the explanatory contribution of the IT decomposition to the measurement of TFP between equations (4) and (2) as follows:

Explanatory contribution of further ICT decomposition to TFP =
1 - TFP (equation 4) / TFP (equation 2). (5)

If TFP (equation 4) is equal to TFP (equation 2), the resulting contribution of further ICT decomposition (5) is equal to 0; there is no incremental explanatory contribution from equation (5). If, on the other hand, value in equation (5) is nonzero, then equation (5) demonstrates all changes in output from ICT.

Unit cost function approach to measuring TFP

The second approach used by the BEA/BLS to construct total factor productivity is based on the following specification of a national cost function:

$$C_t = b(t)C(Y_t, P^K{}_t, P^L{}_t, P^E{}_t, P^M{}_t, P^S{}_t), \quad (6)$$

[16] Jorgenson, Dale. "Information Technology and the U.S. Economy." 2001. Available at: http://ssrn.com/abstract=257536.
[17] This result obtains only if all factor contributions are non-negative.

where P^i_t = the price of the i^{th} factor input, for i = K,L,E,M,S.

Moreover, the cost function is assumed to be approximately homogeneous of degree one in output such that the unit cost function can be expressed as:

$$C_t / Y_t = c_t = b(t)C(P^K{}_t, P^L{}_t, P^E{}_t, P^M{}_t, P^S{}_t). \tag{7}$$

The usual total factor productivity decomposition with respect to the unit cost function with a Divisia index is:

$$\text{dln } c_t = \sum s^i{}_t * \text{dln } P^i{}_t + TFP_{c,t}. \tag{8}$$

As with the production function, we propose a different means of measuring the contribution of ICT to economic activity with the unit cost function. We modify (9) slightly by decomposing capital and services into ICT and non-ICT components as follows:

$$c^t = b(t)f(P^{KICT}{}_t, P^{KNON}{}_t, P^L{}_t, P^E{}_t, P^M{}_t, P^{SICT}{}_t, P^{SNON}{}_t), \tag{9}$$

which has the same decomposition as equation (8) above as follows:

$$\text{dln } c_t = \sum s^i{}_t * \text{dln } P^i{}_t + TFP_{c,t}. \tag{10}$$

where $s^i{}_t$ is the average expenditure share on factor i at the two time measurements in the economy and factor i is as in equation (8) with the addition of the decomposition of the price of capital and the price of services into ICT and non-ICT.

Generally, we expect that the richer specification in (10) will explain more of changes in c^t than the simpler specification in (8). That is, TFP in equation (8) should be greater than TFP as measured in equation (10). We can express the explanatory contribution of the IT decomposition to the measurement of TFP between equations (10) and (8) as follows:

$$\begin{gathered}\text{Explanatory contribution of further decomposition of ICT to TFP} = \\ 1 - \text{TFP (equation 10) / TFP (equation 8)}\end{gathered} \tag{11}$$

If TFP (equation 10) is equal to TFP (equation 8), equation (11) is equal to 0; there is no incremental explanatory contribution from equation (10). If, on the other hand, value of equation 11 is nonzero, then equation (10) helps explain some of the change in output.

Below are the results.

Table A-1: Results, Change in TFP Contribution to Growth Due To ICT Decomposition

	Annual TFP w/o Decomposition	Annual TFP w/ Decomposition	Share of ICT Decomposition in Explaining TFP
1997 - 2002			
Quantity	0.00544205	0.003775287	31%
Price	-2.63958E-05	-0.000488901	
2002 - 2007			
Quantity	0.003869788	0.003098064	20%
Price	-0.003318544	-0.002953685	11%

After decomposing capital and services inputs into their ICT and non-ICT components, we test if the contribution of TFP changes. A large change in TFP's contribution after decomposition suggests that measuring changes in ICT inputs significantly alters our understanding output growth.

On the quantity side (i.e. the production function decomposition), the ICT decomposition results in the following changes:

- 31% decrease in TFP's estimated contribution to growth from 1997 to 2002
- 20% decrease in TFP's estimated contribution to growth from 2002 to 2007

On the price side, the impact was generally smaller. From 1997 to 2002, the magnitude of the TFP contribution estimate was too small to accurately compare before and after decomposition. From 2002 to 2007, the decomposition resulted in an 11% increase in TFP's contribution (i.e. TFP's contribution became 11% less negative after decomposition).

The results agree with the stylized facts that the period of 1997-2007 saw rapid declines in ICT prices and increases in ICT production.

The positive effect on output (quantity) growth previously attributed to TFP (prior to ICT decomposition) now shifts to ICT services and capital (after ICT decomposition). Intuitively, with the generally rising demand and production of ICT services and capital from 1997 to 2007, these factors contributed positively to output (quantity) growth.

The negative effect on output (price) growth previously attributed to TFP (prior to ICT decomposition) now shifts to ICT services and capital (after ICT decomposition). Intuitively, with the falling price for ICT services and capital during the period, these factors contributed negatively to output (price) growth.

Appendix B: Sources of Data

Overview

We study the impact on economic growth of industry investment in ICT capital and expenditure on ICT services by estimating changes in total factor productivity, often called "disembodied technological change." This computation involves the decomposition of gross output growth into KLEMS input components, either at the national or industry level. TFP is estimated as residual of the decomposition. We perform the decomposition for three years (1997, 2002, and 2007) at the 2-digit NAICS industry level. In contrast to previous studies focusing on ICT capital, we introduce a measure of ICT services, which accounts for a large share of ICT's contribution to growth.

ICT Input Classification and Groupings

For the purposes of our study, we distinguish between the definitions of ICT and non-ICT input. Table B-1 presents the classification of ICT factors. Given the unclear distinction between ICT and non-ICT goods and the limitations of the data,[18] our chosen grouping is inherently subjective and imperfect. We therefore explicitly enumerate the NAICS industry codes for inputs classified as "ICT-related" in our study. These groupings allow us to construct the necessary data series for ICT capital and services for the decomposition. For example, we calculate the aggregate expenditure on ICT Capital and Services by summing across the commodity groups listed in Table B-1 using the BEA Input-Output data.

The NAICS classification of ICT Capital commodities is consistent over the three relevant years. However, the organization of ICT Services frequently changes during this period. We have carefully ensured consistency in our selection of ICT-related services. In all but two cases, we were able to maintain consistency between data releases. Data for the inputs (1) Internet Service Providers/Web Search Portals and (2) Internet Publishing/Broadcasting are missing from the 1997 Input-Output tables. We therefore only include these commodities in our ICT Services group for the 2002 and 2007 years. As such, our measurement of ICT services will underestimate the ICT service expenditures in 1997, while overestimating the increase in expenditures between 1997 and 2002.

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[18] We use the BEA Input-Output data to measure input expenditures and BLS PPI to measure input prices, both of which group inputs by NAICS definitions. We faced several complications arising from changes to the NAICS and from missing data.

First, we often lacked data on inputs at a detailed — e.g. 6-digit NAICS — level (i.e. Fiber Optic wire as opposed to other forms of Wire used for signals). As a result, we did not count inputs such as "Signal and Energy Wire" as ICT-related, because these broad categories included too many unrelated subtypes of inputs (e.g. energy wire).

Second, the NAICS codes are slow to reflect the current technologies. For example, "Internet Service Providers/Web Search Providers" did not appear as a 4-digit NAICS category until the 2002 NAICS. Furthermore, the BEA Input-Output and BLS PPI did not report data for this category until well into the 2000s. Therefore, we resort to other estimation techniques for these problematic inputs as explained.

Table B-1: ICT Classification from BEA Input-Output Data (Using 1997, 2002, 2007 NAICS)

1997		2002		2007	
Classification	Code	Classification	Code	Classification	Code
ICT Capital					
Electronic Computer Manufacturing	334111	(Unchanged)		(Unchanged)	
Computer Storage Device Manufacturing	334112	(Unchanged)		(Unchanged)	
Computer Terminal Manufacturing	334113	Computer Terminal Manufacturing	334113, 33411A	Computer and peripheral equipment manufacturing (combined)	33411A
Other Computer Peripheral Equipment Manufacturing	334119	Other Computer Peripheral Equipment Manufacturing	334119, 33411A		
Telephone Apparatus Manufacturing	334210	(Unchanged)		(Unchanged)	
Radio and Television Broadcasting and Wireless Communications Equipment Manufacturing	334220	(Unchanged)		(Unchanged)	
Other Communications Equipment Manufacturing	334290	(Unchanged)		(Unchanged)	
Semiconductor and Related Device Manufacturing	334413	(Unchanged)		(Unchanged)	
ICT Services					
Software Publishers	511210	(Unchanged)		(Unchanged)	
Telecommunications	513300	Telecomm.	517000	Telecomm. (Reorganized)	517000
Data Processing Services	514200	Data Processing, Hosting, and Related Services	518200	Data Processing, Hosting, and Related Services	518000
No Data Available		Internet Service Providers and Web Search Portals	518100	Telecomm. (ISP nested within)	517000
No Data Available				Internet Publishing and Broadcasting and Web Search Portals	519130
No Data Available		Internet Publishing and Broadcasting	516000		

Overview of Data Requirements

1. Output and Non-ICT inputs: Expenditures, Prices, and Quantities for industry *i*, in year *t*:
   - Expenditures: $Y_{i,t}$, $K_{i,t}$, $L_{i,t}$, $E_{i,t}$, $M_{i,t}$, $S_{i,t}$
   - Prices: $P^{Y}_{i,t,}$, $P^{K}_{i.t}$, $P^{L}_{i,t}$, $P^{E}_{i.t}$, $P^{M}_{i,t}$, $P^{S}_{i,t}$
   - Quantities: $Q^{Y}_{i,t,}$, $Q^{K}_{i.t}$, $Q^{L}_{i,t}$, $Q^{E}_{i.t}$, $Q^{M}_{i,t}$, $Q^{S}_{i,t}$

2. Expenditures on ICT inputs for industry *i*, in year *t*:
   - Expenditures on ICT Capital: $K^{ICT}_{i,t}$, $K^{NON}_{i,t}$
   - Expenditures on ICT Services $S^{ICT}_{i,t}$, $S^{NON}_{i,t}$

3. Prices on ICT inputs, fixed across industries *i*, in year *t*:
   - Prices on ICT Capital $P^{KICT}_{i,t}$, $P^{KNON}_{i,t}$
   - Prices on ICT Services $P^{SICT}_{i,t}$, $P^{SNON}_{i,t}$

We assume perfect input mobility across industries, implying that different industries face the same prices for the same inputs. Thus, $P^{KICT}_{t} = P^{KICT}_{i,t}$, for all industries *i*.

4. Quantities of ICT inputs for industry *i*, in year *t*:
   - Quantities of ICT Capital $Q^{KICT}_{i,t}$, $Q^{KNON}_{i,t}$
   - Quantities of ICT Services $Q^{SICT}_{i,t}$, $Q^{SNON}_{i,t}$

Data Collection

1. **Measuring Industry-Level and Economy-Wide Expenditures, Prices, and Quantities for Output and KLEMS Inputs**

Data Needed:

- Expenditures: $Y_{i,\ t}$, $K_{i,t}$, $L_{i,t}$, $E_{i,t}$, $M_{i,t}$, $S_{i,t}$
- Prices: $P^{Y}_{i,t,}$, $P^{K}_{i.t}$, $P^{L}_{i,t}$, $P^{E}_{i.t}$, $P^{M}_{i,t}$, $P^{S}_{i,t}$
- Quantities: $Q^{Y}_{i,t,}$, $Q^{K}_{i.t}$, $Q^{L}_{i,t}$, $Q^{E}_{i.t}$, $Q^{M}_{i,t}$, $Q^{S}_{i,t}$

We extract these variables from BEA-provided data, documented in Table B-2.

Table B-2: Underlying Data Sources

Variables	Source	URL
$Y_{i,\ t}$, $E_{i,t}$, $M_{i,t}$, $S_{i,t}$, $P^{Y}_{i,t,}$, $P^{E}_{i.t}$, $P^{M}_{i,t}$, $P^{S}_{i,t}$, and $Q^{Y}_{i,t,}$, $Q^{E}_{i.t}$, $Q^{M}_{i,t}$, $Q^{S}_{i,t}$	BEA, 1998-2012 NAICS Data: "KLEMS" Release Date: November 13, 2012	No longer in circulation online.
$K_{i,t}$, $L_{i,t}$, $P^{K}_{i,t}$, $P^{L}_{i.t}$, and $Q^{K}_{i.t}$, $Q^{L}_{i,t}$	BEA, "BEA-BLS Industry-level production account.xlsx"	http://www.bea.gov/industry/xls/BEA-BLS%20Industry-level%20production%20account.xlsx

2. Measuring Industry-Level and Economy-Wide Expenditures on ICT Inputs

Measuring industry expenditures on ICT Capital (KICT) and ICT Services (SICT) using Benchmark Input-Output data:

Data Needed:

- Expenditures on ICT Capital: $K^{ICT}_{i,t}$, $K^{NON}_{i,t}$
- Expenditures on ICT Services $S^{ICT}_{i,t}$, $S^{NON}_{i,t}$

Approach:

Data Source: The Bureau of Economic Analysis's (BEA) publishes its Benchmark Input-Output (I-O) Tables in years ending with "2" and "7". The I-O Use table provides data on the amounts industries spend on various types of commodities and services.

Aggregating I-O data into industry-level expenditures on ICT Capital and Services:

To obtain each industry's expenditures on ICT goods in a given year, we sum down the columns from that year's I-O Use Table for ICT-related inputs (defined in Table 1):

$$K^{ICT}_{i,t} = \sum_{j \in ICT}(K_{i,j,t}) \text{ and } S^{ICT}_{i,t} = \sum_{j \in ICT}(S_{i,j,t}) \qquad (12)$$

where *i* denotes the given industry, *j* the input type, and *t* the time period. We sum industry *i*'s expenditures across inputs *j* relevant to ICT for given time period *t*. The same approach applies to the aggregation of the "*NON*"-ICT inputs.

Methodological Challenges:
We were able to bridge input expenditures data for about 400 industries. However, due to changes to the way industries were grouped by the NAICS, we were unable to match input-output data for about twenty industries between 1997 and 2002. The missing industries consist of mostly government and construction.

Aggregating industry-level expenditures on ICT Capital and Services into national aggregates for each period:
We simply sum over industries *i*:

$$K^{ICT}_{t} = \sum (K^{ICT}_{i,t}) \text{ and } S^{ICT}_{t} = \sum (S^{ICT}_{i,t}) \qquad (13)$$

3. Measuring ICT and Non-ICT Price Series

As aforementioned, the following price series are taken directly from BEA data (see Table 2):

- $P^{K}_{i,t,}$ $P^{S}_{i,t}$. at the industry-year level.

We need these additional data to perform the ICT decomposition of capital and services:

- Prices for ICT Capital: $P^{KICT}_{i,t}$, $P^{KNON}_{i,t}$
- Prices for ICT Services: $P^{SICT}_{i,t}$, $P^{SNON}_{i,t}$

for each industry *i* in year *t*.

We construct these ICT price series using the following approach.

Computing Economy-Wide ICT Prices

Data Source:
BLS PPI (Current and Discontinued Series) provides price series over time for commodities and services at varying degrees of detail.

Table B-3: ICT Price Series – PPI Data Sources

Price Series Name	PPI Series ID
Capital (K)	
Computer and Peripheral Equipment Manufacturing	PCU33411-33411-
Communications Equipment Manufacturing	NDU3342203342201
Semiconductor and Related Device Manufacturing	PCU334413334413
Services (S)	
Software Publishers	PCU511210511210
Telecommunications	Manually Created
Data Processing, Hosting, and Related Services	Manually Created
Internet Service Providers and Web Search Portals	Manually Created

Aggregating prices series for different groups of inputs into a single price series:
We combine price series for different inputs into a single series by taking the averages of the PPI's each year, weighted by (for the case of ICT capital) each input's share of total ICT Capital expenditures.

$$P^{KICT}_{t} = \sum_{j \in ICT} w_j * P^{K}_{j,t}, \tag{14}$$

where *j* denotes input type and $w_j = K_{j,t} / K^{ICT}_{t}$ indicates the share of total ICT Capital expenditures attributable to input *j*.

We follow a similar approach to construct the ICT services price series.

Methodological Challenges:
For price series for which available data from the BLS PPI does not extend far back enough for our study, we use regression models to extrapolate the series backward.

A. Telecommunications Price Series
We combine two component price series to form the telecom price series:
- Wired Communications (NAICS 517110, 1997-2009)
- Wireless Communications (NAICS 517210, 2000-2009)

We first fill in missing values for the wireless PPI by using the following regression:

$$\ln P_{t,\mathrm{Wireless}} = \alpha + \ln X_{t,\mathrm{Wireless}} + u_t, \tag{15}$$

where P denotes the price and X the revenues for wireless telecommunications. This yields a price series for wireless telecommunications from 1997-2009.

We then take the expenditure-weighted average of the resulting series:
- Wired Communications (NAICS 517110, 1997-2009) - (PCU517110517110)
- Wireless Communications (NAICS 517210, 1997-2009) - (PCU517210517210)

We use the following data source for our weights:
- Expenditure shares – from the US Census Bureau, Statistical Abstract of the US - Information Services (1997-2009)

This resulting series of weighted averages is the telecom price series for 1997-2009.

B. Internet Service Providers and Web Search Portals Price Series
We use the BLS PPI Series for Internet Service Providers/ Web Search Portals (2005-2012) (BLS PCU5171105171106).

We use the following linear regression model to predict data for 1998-2004 using the available data from 2005-2012:

$$P_{t,ISP} = \; + Q_{t,ISP} + X_{t,ISP} + u_t, \tag{16}$$

where P is the price, Q is the Quantity, and X is the value of expenditures for "ISP/Web Search Portals." We also experimented with a log specification for the regression but ultimate chose to use the non-log specification in equation (16).

Data Sources for regression:

Q - MINTS (1990-2011) - US Backbone IP Traffic Est.
X - US Census Bureau, Annual Services Survey (1998-2012), Table 3.0.1 - revenue for employer companies

This yields the price series for Internet Service Providers for 1998-2012.

C. <u>Data Processing / Hosting / Related Services Price Series</u>
Using Current PPI for Data Processing/ Hosting/ Related Services (2001-2012), we extrapolate backwards using the following linear regression model:

$$\ln P_{t,Data} = \ +\ln X_{t,Data} + u_t. \qquad (17)$$

Data Sources for regression:

- X - US Census Bureau, Annual Services Survey (1998-2010)

This yields the price series for data processing for 1998-2010.

D. <u>Timeframe: What to use for year 1997?</u>

Our study's scope extends as far back as 1997. However, because some ICT price series were only released beginning in 1998, we use our 1998 prices to represent 1997 prices in these cases. Since ICT prices were generally in decline in the late 1990s, we expect that the 1998 prices are lower than the true 1997 prices. Therefore, our price estimates likely underestimate the actual change (decline) in prices between 1997 and 2002.

Specifically, we substitute 1998 prices in 1997 for the following price indexes:

- Internet Service Providers / Web Search Portals
- Data Processing, Hosting, and Related Services

The 1997 price index for Software Publishers is based on only one month's value (December), which was 100 (being the start of the series). Our constructed version of Telecommunications extends back to 1997 (see above discussion for details).

We were able to use 1997 PPI data for all three components of ICT capital (KICT):

- Computer and Peripheral Equipment Manufacturing
- Communications Equipment Manufacturing
- Semiconductor and Related Device Manufacturing

Computing Non-ICT Price Series at the Industry Level

We now use BEA's estimates of Capital and Service Prices ($P^{K}_{i,t}$ and $P^{S}_{i,t}$) to derive the price series for non-ICT inputs (i.e. all those types of capital and services that do not fall in the ICT baskets). These BEA data are at approximately the NAICS 3-digit industry level.

We assume that the economy-wide ICT prices computed before are faced by all industries, such that $P^{KICT}_{i,t} = P^{KICT}_{t}$ and $P^{SICT}_{i,t} = P^{SICT}_{t}$ for all industries *i*.

Given these estimates of economy-wide prices on ICT capital and services, we compute the price series for the remaining inputs classified as non-ICT, denoted by *NON*, at the 3-digit industry level. On the capital side, we assume that the industry *i*'s price for general capital (P^K_i) is an average between ICT and non-ICT capital prices, P^{KICT}_i and P^{KNON}_i, weighted by expenditures on ICT and non-ICT capital, K^{ICT}_i and K^{NON}_i:

$$P_i^K = \left(\frac{K_i^{ICT}}{K_i}\right) \quad P^{KICT} + \left(\frac{K_i^{NON}}{K_i}\right) * P^{KNON}. \tag{18}$$

Rearranged, solving for the price on non-ICT capital, yields:

$$P_i^{KNON} = \quad P_i^K \quad \frac{K_i^{ICT}}{K_i} \div * P^{KICT} \quad * \quad \frac{K_i}{K_i^{NON}} \div . \tag{19}$$

The price series on non-ICT services, P^{SNON}, is computed similarly.

Now, we have constructed price series for ICT and non-ICT Capital and Services.

4. Deriving ICT Quantity Series from the Price Series

To obtain the corresponding quantity series for each industry *i*'s ICT and non-ICT capital and services inputs, we use the following relationship between expenditures, prices, and quantities (Here, for input group *j*, which may be (1) ICT or non-ICT and (2) capital or services).

$$\frac{K_{i,j}^{t+1}}{K_{i,j}^{t}} = \frac{P_{i,j}^{t+1}}{P_{i,j}^{t}} * \frac{Q_{i,j}^{t+1}}{Q_{i,j}^{t}} = \frac{P_{i,j}^{t+1}}{100} * \frac{Q_{i,j}^{t+1}}{100}. \tag{20}$$

We select a base year *t* (in most cases, 2002), and normalize the series so that Pj, it and Qj, it are both equal to 100.

To calculate the quantity series for the other years, we simply rearrange:

$$Q_{i,j}^{t+1} = \frac{K_{i,j}^{t+1}}{K_{i,j}^{t}} * \frac{P_{i,j}^{t} * Q_{i,j}^{t}}{P_{i,j}^{t+1}} = \frac{K_{i,j}^{t+1}}{K_{i,j}^{t}} * \frac{100 * 100}{P_{i,j}^{t+1}}. \tag{21}$$

Data Collection Summary:

Expenditures	Quantity	Price	Description
Y	QY	PY	Gross Output
K	QK	PK	Capital Compensation
KICT	QKICT	PKICT	ICT Capital
KNON	QKNON	PKNON	Non-ICT Capital
L	QLI	PLI	Labor Input
E	QE	PE	Energy Input
M	QM	PM	Materials Input
S	QS	PS	Purchased Services
SICT	QSICT	PSICT	ICT Services
SNON	QSNON	PSNON	Non-ICT Services