ICT prices: What do they tell us about productivity and technology?

Carol Corrado
The Conference Board and Center for Business and Public Policy,
McDonough School of Business, Georgetown University
(Based on a paper joint with David M. Byrne, Federal Reserve Board)
`Preliminary and Not for Quotation`

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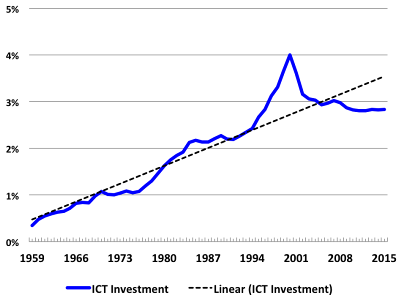
Real ICT investment spurred by rapidly falling relative prices no longer provides an extra boost to labor productivity growth.

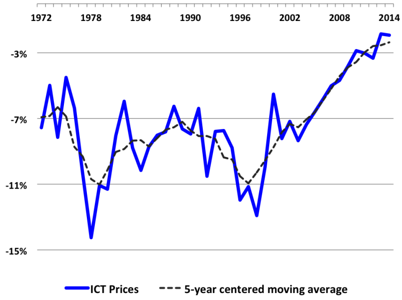
- ICT investment relative to GDP moved sideways since 2009.
- ICT price change currently shows little change, having accelerated beyond its historical range of decline (in relative terms) since 2005.

ICT Investment and Prices

Figure: **U.S. ICT Investment and Prices**



(a) Private ICT investment, percent of GDP



(b) ICT relative price change, annual rate

Source: Authors' elaboration of data from U.S. BEA. Investment for 2015 is based on partial year data. ICT price change is relative to the GDP deflator.

- Output per hour grew an estimated 1/2 percent per year from 2010 to 2015, **the weakest 5-year rate of change since 1950**.
- Both TFP and (especially) capital deepening are culprits in the slowdown
- Despite step-down in ICT capital contribution, ICT-producing industries posted sizeable contributions to TFP growth

Questions

The productivity statistics raise at least three questions:

- First, if the U.S. and other advanced economies are undergoing a digital transformation, why is ICT investment so weak?
- Second, if Internet and wireless technologies are so revolutionary, why are they not having a discernible impact on ICT prices (and labor productivity)?
- Third, with ICT services growing in importance, should we modify the standard narrative that focusses on how ICT **capital** impacts the macroeconomy?

Approach of paper

- Set out a framework for thinking about the relationships among ICT prices, technology, and productivity when ICT services, especially communication and cloud services, are increasingly important to the sector.
- Calibration requires:
  - Review the boundary of ICT investment and "ICT sector" and measure its share of income and output
  - Review trends in technology (especially communication technology) and prices and determine our best measure of price change for the sector
- Put numbers on the expected contribution of ICT to OPH growth (for the total economy) in the medium- to longer-term

Framework

Modify a model due to Oulton (2010)

- Oulton proposed an approach based on a two-sector model of an open economy where one-sector is an ICT-producing/supplying sector.
  - Approach is similar to Jorgenson-style growth accounting in which:
  - **Relative** growth of TFP in the ICT-producing sector is a key driver of growth
  - **Relative** ICT prices reflect the TFP growth differential
  - Oulton's model makes the latter explicit, as well as the fact that economies with little or no domestic ICT production also derive benefits from faster growth of TFP in the production of ICT (even if not at home) in the form of improving terms of trade.
- When Oulton's model is expanded beyond the usual ICT capital to encompass ICT services and the broader digital TED economy, the model still retains its fundamental property that relative ICT prices reflect the productivity differential between ICT producers and general business.
- The expanded model's empirical implications for the ICT contribution to growth, however, are somewhat richer.

Model and assumptions

- There are two production sectors in the economy, an ICT/TED sector (subscript T) and a general business sector (subscript N)
- The relative ICT/TED price $p = P_T/P_N$
- Production assumptions:
  - The T sector supplies both final demand and intermediate use.
  - Net of own use, the N sector supplies final demand only.
  - The sector production functions are identical except for Hicksian shifters, A_N and A_T and $\Delta lnA_T > \Delta lnA_N$

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Define some ratios:

$\overline{v}_{K_T}$ = ICT/TED capital income share;
$\overline{v}_L$ = labor share;
$\overline{w}_T$ = ICT/TED sector domestic output share; and
$\overline{s}_T^N$ = ICT business services relative to total output.

Model solution

- Relative ICT/TED price change equals relative sector TFP change

$$\Delta ln\, p = \Delta ln A_N - \Delta ln A_T < 0$$

- The ICT/TED sector contribution to growth in output per hour =

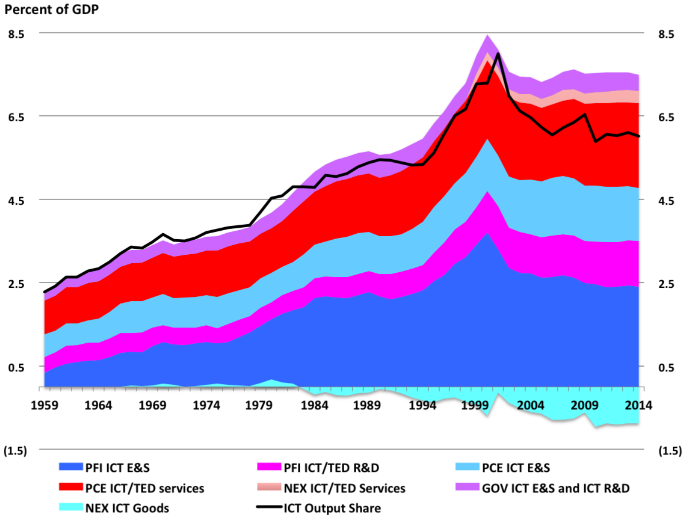
$$\underbrace{\frac{\overline{v}_{K_T} + \overline{s}_T^N}{\overline{v}_L}(-\Delta ln\, p)}_{\text{Investment (use) and Diffusion (productivity) effects}} \quad + \quad \underbrace{\overline{w}_T(-\Delta ln\, p)}_{\text{Production effect}} \quad .$$

Model implication

- Real output per hour in the N sector grows less than real output per hour in the T sector—implying that real ICT/TED services output grows faster than other services in real terms
  - ICT/TED marketed services are **flows of capital services** in this model
  - Their relative price thus comes from a user cost expression that transforms the volume of capital employed in producing the service to a value for its services (a flow), i.e., the ICT/TED relative price will decline just as relative ICT capital asset prices decline
  - Services consumed will also include those generated by "terminal" capital equipment employed with the purchased services—e.g., services from the stock of cell phones + purchased telecom service contracts

Calibration

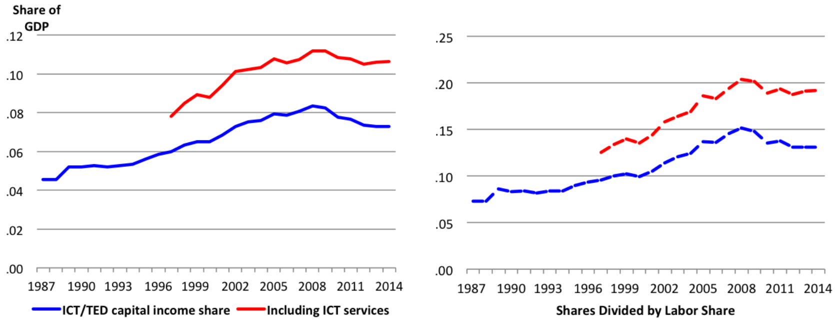
Output share ($\overline{w}_T$) trends down a tad



ICT/TED output share by final demand component, 1959 to 2014

ICT business services share ($\overline{s}_T^N$) has been growing since 2007

...enough to offset a slight downward trend in the ICT capital income share ($\overline{v}_K^T$)



ICT services and capital income shares, 1987 to 2014

Note: Capital income includes ICT E&S, ICT R&D, and Entertainment originals. ICT services include intermediate purchases of commodities supplied by NAICS 5112, 513, 514, and 5415 (BEA codes).

Sources: Elaboration of BLS (capital income), and BEA (input-output) data

The P_T of the model . . .

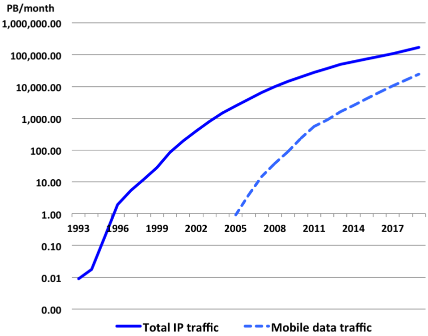
- Is not necessarily a domestic production price (because the model allows for imports). Indeed, there is no difference between import prices and domestic production prices (only differences in T outputs and N outputs) in this model
- For model calibration, it seems relevant to set aside this assumption and assume rather that
  - Relative investment and business services prices are relevant for the use and diffusion effects, whereas relative domestic output prices are relevant for the production effect
  - Relative investment prices would include the rapidly falling equipment prices, along with software, TED R&D prices, and ICT business services prices
  - Relative domestic output prices would essentially exclude the rapidly falling equipment prices but would include, in addition, consumer software and TED services (consumer telecommunications, broadcasting, internet access services)

A lot hinges on equipment and software investment prices in this model ....

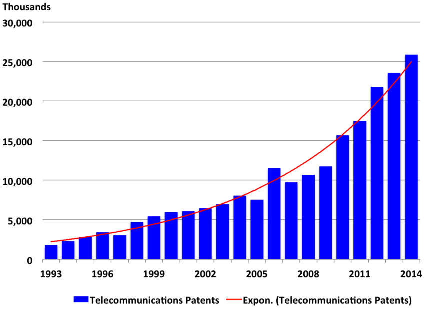
- . . . especially given its implication that prices for marketed ICT/TED services are driven by the user cost of ICT/TED capital
  - Imperfect competition might lead to deviations, however
  - Accordingly, we investigate telecom prices and are still working on the consumer price segment . . .
  - But in the important enterprise business segment, detailed data from Telegeography on enterprise services suggest prices declined 8.5 percent per year since 2006. (The implied price index for the business segment of telecom in official data is about flat.)
- ICT R&D and ICT systems design services do not fall in the category of marketable ICT/TED capital services.
  - They are dynamic components but only 9 percent of $\overline{v}_K^T + \overline{s}_T^N$ in recent years.

What's up with technology

Advances in communication capacity and wireless technology continue to be rapid



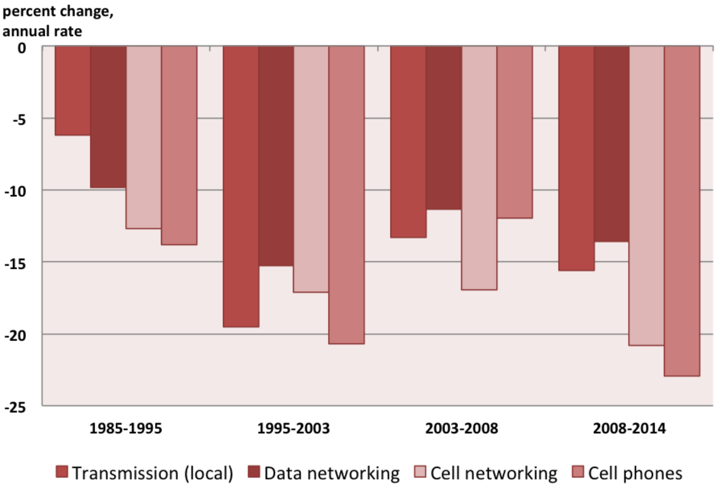
Sources: Cisco's Visual Networking Index 2014-2019 (May 2015) and Global Mobile Data Forecast Update 2014-2019 (February 2015).



Source: U.S. Patent and Trademark Office, Part I, Patent Counts by Class by Year (Sum of classes 370, 375, 379 and 455). Available at http://www.uspto.gov/web/offices/ac/ido/oeip/taf/cbcby.htm. Accessed October, 2015.

Global IP Traffic, 1993 to 2019 (incl. forecast) and US Telecom Patents, 1993 to 2014

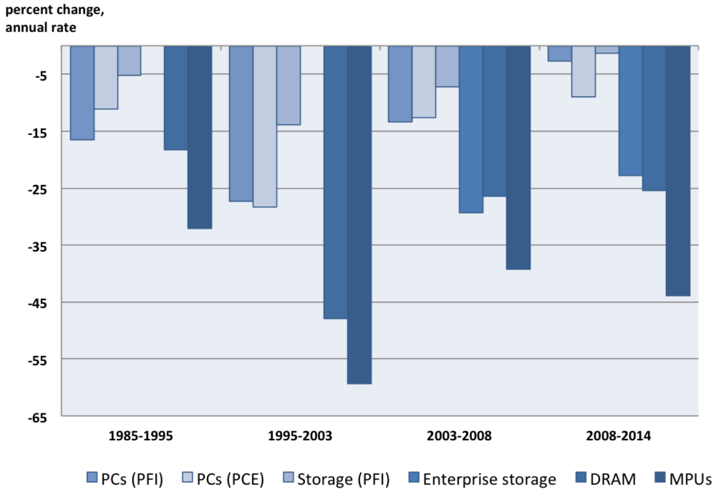
So do price declines for communication products



Price change for selected communications equipment products, 1985 to 2014 (Byrne-Corrado research price indexes)

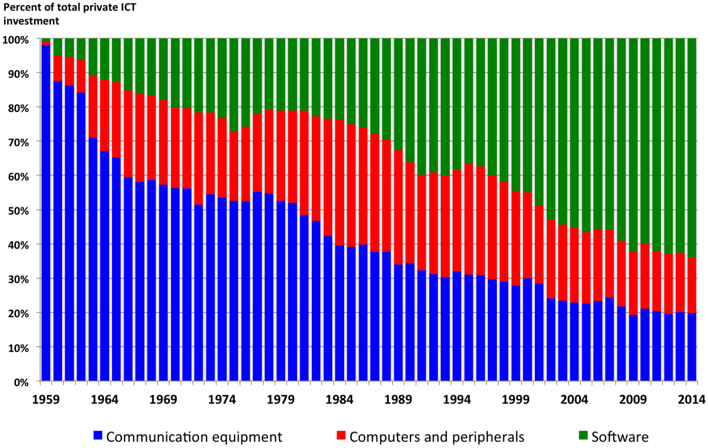
Yes, semiconductor technology did slow after 2003.....

but computer investment prices are questionable after 2007 (e.g., Byrne and Pinto 2015)



Price change for selected computer and semiconductor products, 1985 to 2014 (BEA and research price indexes, various sources)

Software, not hardware, dominates ICT investment

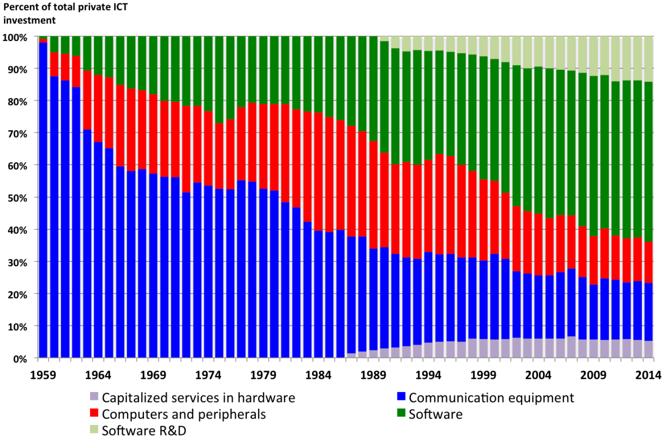


ICT investment component shares 1959 to 2014

(Source: Elaboration of BEA data)

Software investment includes software R&D and hardware investment includes capitalized services

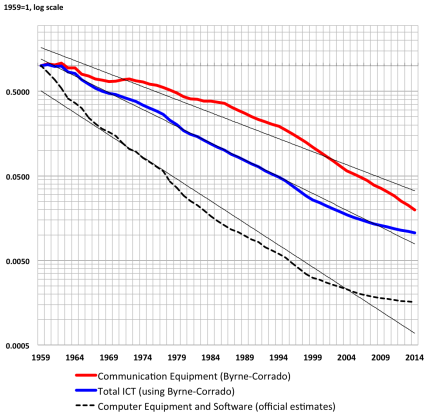
All told, computer investment currently is less than 13 percent of ICT ...
whereas communications equipment is about 18 percent.

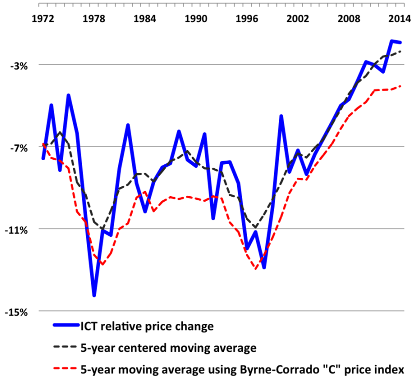


ICT investment component shares 1959 to 2014

(Source: Elaboration of BEA data)

Trends in ICT Investment Prices, with Byrne-Corrado Communications Equipment Price Index





What about computers and software?

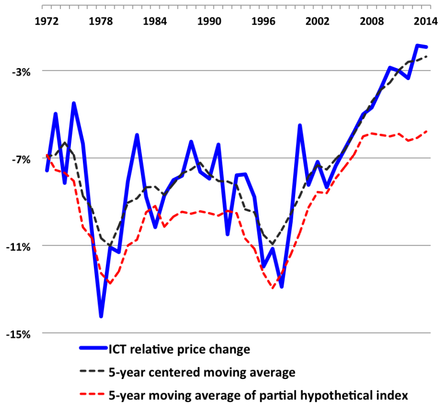
- Computer acceleration #2 likely did not happen (as per earlier discussion)
- Plausible that software did not accelerate, too.
  - Why? Reflects the introduction of networking software in the PPI in 2006
  - Index is not bias-adjusted as is computer application software

Table 3. Real ICT Prices (annual percent change)

		1987 to 1995 (1)	1995 to 2003 (2)	2003 to 2008 (3)	2008 to 2014 (4)	acceleration #1 (5)	acceleration #2 (6)
1	ICT investment	-8.7	-10.0	-6.3	-4.0	**3.7**	2.3
2	Communication equipment	-7.6	-11.6	-9.9	-10.5	**1.7**	-.7
2a	Telecom	-10.7	-15.5	-13.1	-15.0	**2.4**	-1.9
2b	Other	-3.1	-2.5	-3.6	-2.9	**-1.1**	.6
3	Computers and software	-9.2	-9.5	-5.2	-2.3	**4.3**	2.9
3a	Computers and peripherals	-13.7	-19.7	-12.4	-4.6	**7.2**	**7.8**
3b	Software	-5.3	-2.2	-2.4	-1.6	**-.2**	**.7**
	Memos:						
4	BEA ICT	-7.2	-8.5	-5.4	-2.6	**3.1**	2.8
5	BEA Comm eq	-3.2	-6.2	-6.1	-3.8	**.1**	2.3

Source: Lines 2, 2a, and 2b are based on price indexes developed in Byrne and Corrado (2014). Column 4 for lines 2a and 2b is to 2
Lines 3a and 3b are based on BEA's official price indexes.
Real prices are relative to the aggregate U.S. business output price.
Acceleration #1 is column 3 less column 2. Acceleration #2 is column 4 less column 3.

Results of partial hypothetical (uses BC for communication equipment and assumptions for computers and software)



Summing up

Evaluating the model's implications for the contribution of ICT to the growth of OPH in balanced growth using $\Delta ln\, p = 5.8$ percentage points:

$$\begin{aligned}
&\text{Total contribution in percentage points} \\
&\quad = [\text{Investment (use) effect} + \text{Diffusion (productivity) effect}] \qquad (1) \\
&\qquad + \ [\text{Production effect}] \\
&\quad = [.19 * .91 * 5.8] + [.06 * .955 * 5.8] \\
&\quad = 1.3 \text{ percentage points}
\end{aligned}$$

This is very large. Consider the conventionally calculated ICT growth accounting contribution from 2000 to 2007 (.9 out of 2.1 percentage points **without** allowance for diffusion effects, or 43 percent of OPH growth) or from 1995 to 2000 (1.1 out of 2.3 percentage points, or 48 percent). But it is not so unreasonable when looking at the experience since 2007, where ICT contributed .7 out of 1.1.

Conclusions (1)

- The change in ICT investment prices likely is at the upper end of its historical range—but not way beyond it as official data show.
- The contribution of ICT to economic growth going forward is likely to be substantial because
  - The level of ICT penetration (via both capital stocks and subscription services) is high
  - Advances in internet and wireless communication technology likely will continue to be rapid.

As to price measurement,

- This paper suggested that, under certain assumptions, prices for ICT services that are forms of marketed ICT capital services (e.g., telecommunications services, cloud computing services) should move in tandem with the relative prices of the underlying ICT assets used to produce them.
- This rule-of-thumb does not apply to software asset prices—or to ICT R&D and ICT design services, either.
- New research and thinking about measuring software and other intangible asset prices is needed.

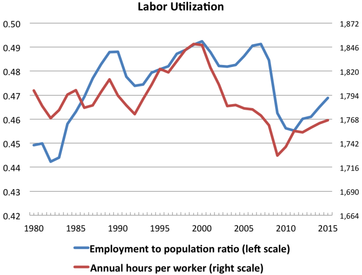
Thank you. Back-up slides.

- Output per hour grew an estimated 1/2 percent per year from 2010 to 2015, **the weakest 5-year rate of change since 1950.**

Table 1: **U.S. Labor Productivity Growth, 1980 to 2015**

Item	1980 to 1990	1990 to 2000	2000 to 2007	2007 to 2015	Memo: 2010 to 2015
	(1)	(2)	(3)	(4)	(5)
1. GDP	2.9	3.4	2.4	1.3	2.2
2. Population	1.0	1.2	.9	.8	.8
3. GDP/capita	2.0	2.2	1.5	0.5	1.4
4. Hours/capita	.6	.4	-.6	-.6	.9
5. Emp/Pop	.7	.1	.0	-.6	.6
6. Hours/worker	-.1	.3	-.6	.0	.3
7. Output per hour	1.3	1.8	2.1	1.1	.5

SOURCE: Author's elaboration of The Conference Board's Total Economy Database, May 2015.



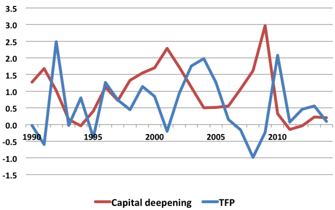
- Both TFP and (especially) capital deepening are culprits

Table 2: **Decomposition of Labor Productivity Growth, 1990 to 2014**

Item	1990 to 1995	1995 to 2000	2000 to 2007	2007 to 2014	Memo: 2010 to 2014
	(1)	(2)	(3)	(4)	(5)
1. Total GDP	2.6	4.2	2.4	1.1	2.1
2. Hours	1.3	1.9	.3	.0	1.6
3. Output per hour	1.2	2.3	2.1	1.1	.5
Contribution of:[1]					
4. Labor Composition	.2	.1	.2	.1	.1
5. ICT capital	.4	.8	.4	.4	.3
6. NonICT capital	.3	.6	.5	.3	-.3
7. TFP	.4	.7	1.0	.3	.3

SOURCE: Author's elaboration of The Conference Board's Total Economy Database, May 2015.
NOTES: Rows 1 to 3 are average annual rates of growth (percent). Rows 4 to 7 are percentage points.
1. Contributions in rows 4–7 are to growth in output per hour.

Sources of Growth in Output per Hour



Note: Capital deepening is the sum of ICT and NonICT capital contributions to the growth in output per hour.

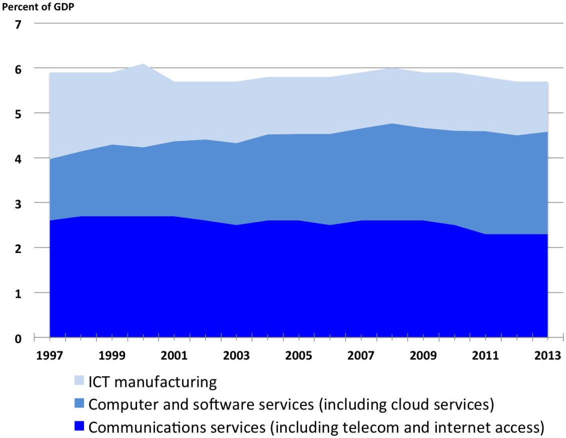
- Despite step-down in ICT capital contribution, ICT-producing industries posted sizeable contributions to TFP growth

Table 3: **ICT Industry Contributions to TFP Growth**

Item	1995 to 2000	2000 to 2007	2007 to 2014
	(1)	(2)	(3)
1. TFP[1]	.7	1.0	.3
Contribution of:[2]			
2. ICT-producing industries[3]	.3	.5	.3
2a. Manufacturing	.5	.2	.1
2b. Services	-.2	.4	.2

SOURCES: TFP growth, previous table, and author's elaboration of industry estimates reported in Rosenthal, Russell, Samuels, Strassner, and Usher (2014).
NOTES: Row 1 is average growth (in logarithms). Rows 2, 2a, and 2b are percentage points.
1. Includes reallocation effects.
2. Contributions are to growth in total factor productivity.
3. The estimates in row 2 for the last period (column 3) are to 2012.

ICT-producing sector is stable as share of total value added



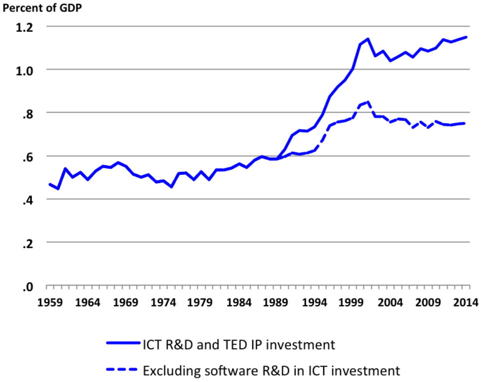
Source--Authors' elaboration of value added data issued by BEA, which includes R&D.

Value added share of US ICT-producing Industries, 1997 to 2013

Why is ICT investment so weak?

Investment in ICT R&D and TED IP remains strong

. . . which is to say, the weak ICT investment rate has not translated into a lack of interest in innovation in ICT- and TED-related products and services

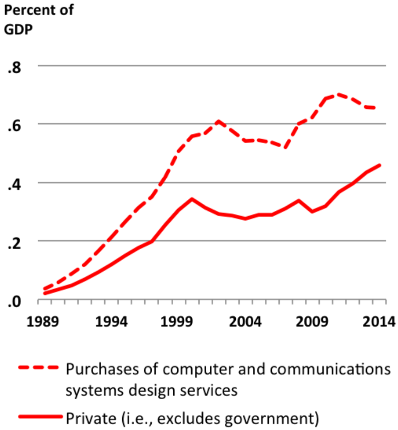


Private investment in ICT R&D and A&E originals (i.e., TED IP) as percent of GDP

The intangibles framework provides further perspective

- Spending on ICT systems design is not counted as software investment in national accounts but would be included in expanded frameworks (e.g., Corrado, Hulten, and Sichel 2005) that recognize **design** as a type of innovative property, or intangible asset.
- U.S. private investment in purchased computer and communications system design services has in fact risen very sharply relative to GDP since 2009. (This may be capturing cloud services flows, however)
- If design purchases were capitalized, ICT investment would appear more dynamic.

Purchases of ICT systems design



Source: The Conference Board's SPINTAN database (United States).