Accounting for Innovation in Consumer Digital Services

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Abstract

Previous work (Byrne and Corrado, 2017a,b) reassessed the link between ICT investment prices and productivity to help understand how digital technology contributes to labor productivity growth. This paper extends the analysis by considering *consumer* spending on digital durable goods as investment. When consumer digital stocks are treated as investment, their asset prices have implications for productivity, and we find mismeasurement patterns similar to those found in our earlier work on private ICT investment goods. We also consider whether and how households' increased use of its stocks of digital goods should be folded into the measurement of income from those stocks. Without considering use rates, we find that real services from consumer use of their digital stocks has increased nearly 20 percent per year since 1985. After adjusting for the increase in utilization of those stocks since 1995, real consumption of digital services is estimated to have grown 35 percent per year. The utilization adjustment is especially potent between 2005 and 2012.

Keywords: Information and Communication Technology (ICT); Digital Transformation (DX); Consumer Durables; Innovation, Productivity, Technology, and Price measurement

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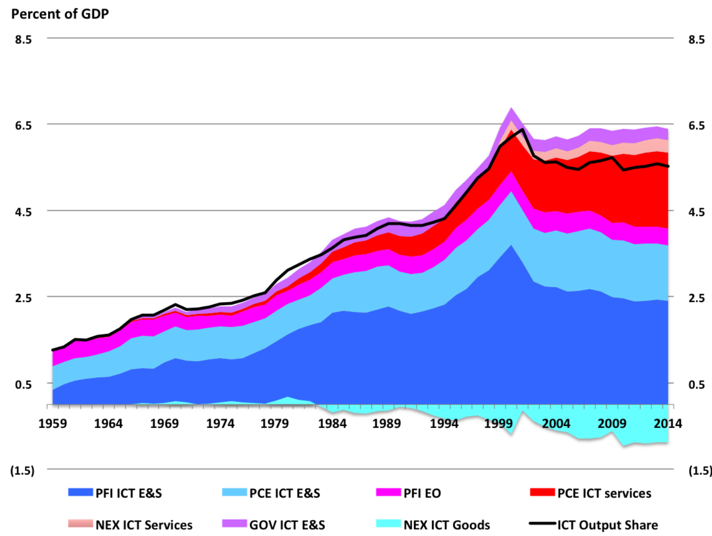
1 Introduction

This paper revisits the capitalization of consumer durables—specifically consumer digital goods—in national accounts with several goals in mind. First, the paper estimates whether accounting for the increase in stocks of household electronics during the ongoing digital transformation of the economy has an empirically relevant impact on real consumption and GDP. Second, the paper considers whether accounting for the intensity of consumer use of their digital gizmos changes the story. Third, we take steps to improve the capture of quality improvements in the digital capital services consumed by households.

The analysis in this paper, akin to the analysis in Byrne and Corrado (2017b), is based on a framework that is robust to changes in business models used for the delivery of digital content and ICT services. In the business realm, the migration of ICT operations from in-house data centers to the cloud necessitates this type of analysis (see also Byrne, Corrado, and Sichel, 2017). In the consumer realm, the constantly shifting blend of home produced and purchased services used in gaming illustrates the same point. Powerful video game consoles with advanced processing technology deliver substantial ICT services in many homes. At the same time, online games, often designed to connect players in different locations, are run from data center servers. The relative importance of these two modes is constantly changing and an accounting system designed to provide useful comparisons over time needs to be robust to the changing way in which digital services are delivered in the 21st century.

Capitalization of consumer durables requires that the implicit services provided by consumers' ownership of assets be included in GDP and total income, a procedure used for owner-occupied housing in existing national accounts and for consumer durables in aspects of the productivity literature (e.g., Jorgenson and Landefeld, 2006). The empirical importance of including imputed services flows to consumer information and communication technology (ICT), or digital, stocks is seen figure 1, which shows the relative size the digital sector of the U.S. economy in terms of what it supplies to final demand. Compare the relative size of the light versus dark blue shaded areas. Together they represent the share of total private ICT equipment and software spending in private domestic final demand—a total that is more than 50 percent larger than the spending currently capitalized as private fixed investment in ICT (the dark blue section alone). Considering that capital services tend to approximately equal investment outlays (Jorgenson, 1966), the inclusion of implicit consumer digital services in GDP is potentially consequential.

Figure 1: **ICT Final Output Share**



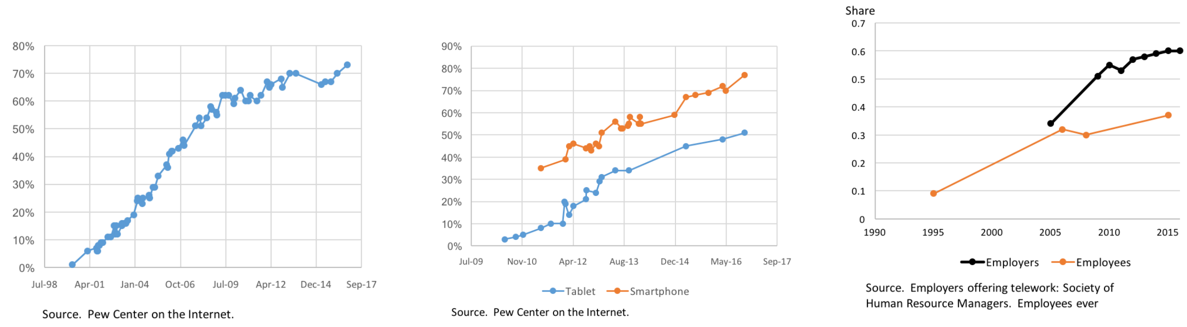
Note: E&S is equipment and software. PFI = private fixed investment. PFI ICT E&S excludes software R&D. PCE components include audio, video, and cellular equipment and exclude landline telecommunications.

Source: Byrne and Corrado (2017b) based on data from BEA.

An equally fundamental reason for capitalizing consumer digital goods is that the sector provides an extra kick to productivity growth because of its relatively fast rate of productivity growth. For this reason, Byrne and Corrado (2017a) put ICT investment prices, which should reflect these productivity improvements, under the microscope and found substantial mismeasurement. Their final results were based on more than a dozen newly developed ICT product-level price indexes for items currently capitalized as private investment in the U.S. national accounts. In this paper we draw upon that work and revisit the methods BEA uses for its price indexes for consumer digital goods.

A theme of the analysis in the paper is that during this period of digital transformation, it is important to distinguish between consumption versus consumer outlays when thinking about real digital services and productivity trends. As suggested by the indicators shown in figure 2, the intensity with which households *use* their digital capital has increased sharply since 2000. Home broadband access, almost unknown in 2000, is now used by three-quarters of American adults; the use of mobile devices providing internet access nearly anywhere at any time shot up just as broadband penetration gains began to slow; and an increasing number of adults, for good or ill, tax their home network with work activity. And, these indicators only begin to tell the story. The examples of rising *quality* delivered per unit of time spent connected are obvious: on-demand streaming of a seemingly endless library of video on nearly any device with a screen, high-quality video and still photography on your phone, seemingly intelligent navigation applications that thread us through traffic and entice us into the approaching coffee shop with coupons, etc. Accounting for utilization of household digital capital

Figure 2: **Indicators of Consumer Digital Capital Use**



(a) Broadband Use (b) Mobile Device Use (c) Prevalence of Telework

use is a difficult task, and a major challenge in any effort to capitalize household digital goods and impute a service flow to their use.

The roadmap of this paper is as follows. First we set out a framework for thinking about (a) how capitalization of consumer digital goods impacts measured GDP and productivity, and (b) how household utilization of stocks fits into the picture, including their impact on payments for digital access services. Then we set out our empirical approach and present our results. We find that real consumer digital capital services grows nearly 20 percent per year without a utilization adjustment and contributes about 0.2 percentage points to real GDP growth. This result is based on a price deflator for consumer digital goods investment that falls 5 percentage points faster than the deflator used in the existing national accounts.

Our bottom line on the utilization adjustment is that growth in real *consumption* of digital capital services is even faster, about 35 percent per year. Because the share of services in expanded GDP initially is lower with the utilization adjustment, the contribution of our estimate of real digital capital services consumption rises over the 15 years since 2000. From 2010 to 2015, growth in real digital capital services consumption contributes 1/4 percentage point to the growth in real GDP expanded to include it.

2 Framework

This paper uses a simple model to assess the productivity implications of extending the GDP asset boundary to include household ICT capital and the consequent consumption of household-produced digital services. The model we use is from (Byrne and Corrado, 2017b), who modified a model originally due to Oulton (2012) to include intermediate ICT services to account for the growth and popularity of business use of the cloud platform. The Byrne-Corrado-Oulton model, reviewed below, is fundamentally unchanged when household production and use of digital capital are incorporated.

Total final demand Y consists of investment (I) and consumption (C) produced in two sectors of the economy. The two producing sectors are: a general business sector excluding ICT producers (denoted by the subscript O), and an ICT sector (denoted by the subscript T) that consolidates business and household production of ICT goods and services. Each sector produces investment goods and services for final use. Thus we have

$$Y = C + I = Y_T + Y_O \;\; ; \quad Y_T = C_T + I_T \; ; \quad Y_O = C_O + I_O \; ; \tag{1}$$

and

$$PY = P_T Y_T + P_O Y_O \; ; \quad \overline{w}_T = \frac{P_T Y_T}{PY} \;\; . \tag{2}$$

where P is the price level, P_T and P_O are sector prices, and $\overline{w}_T$ represents the relative size of the ICT sector in total final demand in nominal terms.

The model assumes there is faster technical progress in the ICT sector. Denoting the rate of growth in the Hicksian shifter (A_i) in the sectoral production functions (not shown) as μ_i, this assumption is expressed as $\mu_T > \mu_O$. A major simplifying assumption is then employed to solve the model, namely, that the sectoral production functions exhibit constant returns and differ only by their A_i terms. This implies factor shares and input quantities are the same in both sectors.

Model solution. Log differentiation of the model's factor payments equations yields the result shown by Oulton (2012) that relative ICT price change equals (the negative of) relative ICT sector TFP growth. Defining the relative ICT price as $p = P_T/P_O$, this result is expressed as a steady-state rate of change in relative prices $\dot{p}$ given by

$$\dot{p} = \mu_O - \mu_T < 0 \;\; . \tag{3}$$

The model's steady-state solution for the contribution of ICT to the growth in GDP per hour ($O\dot{P}H$) is thus the same as in Byrne and Corrado (2017b) and is given by

$$\text{(4)} \qquad \text{Contribution of ICT sector to } O\dot{P}H \;= \;\underbrace{\frac{\overline{v}_{K_T} + \overline{\zeta}^{O}_{T}}{\overline{v}_L}(-\dot{p})}_{\text{Investment (use) and productivity (diffusion) effects}} \quad + \quad \underbrace{\overline{w}_T(-\dot{p})}_{\text{Production effect}} \;.$$

where $\overline{v}_{K^T}$ and $\overline{v}_L$ are the shares of ICT capital and labor in total income, respectively, and $\overline{\zeta}^{N}_{T}$ is ICT business services purchased by sector N relative to total income in the economy. For the derivation of this solution, see the appendix in Byrne and Corrado (2017b) available *here*.[1]

Asset boundary. The extension of the asset boundary of GDP to include household spending on ICT equipment and software gives rise to changes in national accounts. Note first that when *final* expenditures on long-lived outlays previously counted as consumption are reclassified as capital spending, the expenditure reclassification, by itself, does not change GDP. But there is a second move in which a new final expenditure category containing the imputed services to the newly classified capital good is created—and this adds to GDP. As in capital services used by producers, the imputed service flow is a gross rental payment (Jorgenson, 1963), i.e., the service flow is a gross rate of return (i.e., including capital consumption) multiplied by the value of the newly capitalized net stocks.

The foregoing implies the calibration of the parameters in equation (4) are affecting by extending the GDP asset boundary to include household ICT stocks. First, the production effect is unequivocally larger and reflected in $\overline{w}_T$ because of the additional services produced and consumed have been added to GDP, i.e., the ICT sector contributes a larger share to total final demand in the economy. Second, for the same reason, the use or investment effect, also becomes larger because total ICT capital now includes household stocks, and the (imputed) income generated by the additional stocks will be reflected in the overall ICT capital income share, $\overline{v}_{K^T}$.

[1] Apart from the term $\overline{\zeta}^{N}_{T}$ capturing the ICT services-using intensity of the economy, note that the solution aligns with the usual growth accounting approach in which the contribution of ICT capital to growth in output per hour is identified as flowing through two channels: ICT use and ICT production. It is typical to consider the ICT use effect as operating through services provided by producers' own investment in ICT capital, i.e., via services generated by ICT assets that producers' own themselves. In the expanded model, there is a parallel channel that operates via the contribution of nonICT producers' purchases of ICT services, e.g., purchases of computing, storage, and software services, to total factor productivity.

Imputed Income and household utilization As suggested in the introduction, households' utilization of its own ICT stocks may be an important dimension of the digital transformation story. Private industry capital income is generally understood to include a utilization effect (see Hulten, 2009, for a discussion), suggesting that the income and consumption imputed to households' use of their ICT stocks should likewise contain a utilization effect. As shown by Berndt and Fuss (1986), private industry capital utilization is proportional to the marginal product of capital and absorbed in capital income and capital services as conventionally calculated for productivity analysis, i.e., when the rate of return is calculated on an *ex post* basis following Jorgenson and Griliches (1967). When capital income is generated using an *ex ante* basis, however, a utilization effect is not "automatically" present.

As conventionally represented, e.g., when imputing rents to consumer durables in productivity analysis, the imputed value of household income and consumption is given by

$$(\overline{\rho} + \delta_T^H) * P_T^H K_T^H \tag{5}$$

i.e., as a gross rental rate $(\overline{\rho} + \delta_T^H)$ times the value of the stocks $P_T^H K_T^H$, where $\overline{\rho}$ is an *ex ante* real household discount rate and δ_T^H is a depreciation rate for household stocks of digital goods K_T^H. P_T^H is an asset price index for those stocks.

Accounting for utilization is a conceptually simple next step. Equation (5) is viewed as a capacity flow, in which case actual income and consumption is given by

$$\underbrace{u^H * (\overline{\rho} + \delta_T^H) * P_T^H}_{\text{Effective Rental Income Price}} \quad K_T^H \tag{6}$$

where $u^H < 1$ denotes the utilization of household digital stocks.

Utilization is denoted as part of the household "effective" rental price in equation 6 even though it is a productivity, or output, effect. To see this, note first that real imputed household digital services is the value from equations (5) or (6) divided by the household ICT asset price P_T^H, i.e, the asset price is the price deflator for imputed household digital services. Now assume the gross rental rate is constant, and log differentiation reveals that the rate of change of real household digital capital services with a utilization correction is given by $\dot{u}^H + \dot{K}_T^H$, i.e., changes in utilization augment actual output growth.

From the household perspective, the rate of change in the *effective* price of household digital services yielded by a unit of capital is expressed as

$$\dot{P}_T^H + \dot{\lambda} \tag{7}$$

where $\lambda = (1 - u^H)$, and the term $\dot{\lambda}$ in (7) represents the drop in underutilization of stocks. Both terms in (7) are negative, which is to say that, from the perspective of the household, increases in utilization effectively augment declines in digital goods asset prices. (The foregoing ignores relative price change and the two-sector nature of the underlying model.)

As may be seen from these equations, in terms of real services, increases in utilization may be viewed as (a) boosting the rate of growth of real digital services and (b) implying softer rates of decline in digital asset prices and/or softer investment demand. Put differently, taking the marginal productivity of the capital as given, if consumers viewed their ability or desire to utilize each unit of K_T^H as having increased (better broadband, greater access to content), they would be willing to pay a higher asset price for each new unit of K_T^H capital. In a more complex model, limitations on household time and diminishing returns ultimately dampen the demand for K_T^H (or certain types of K_T^H) for given level of demand for service as well.

Which approach—equation (5) or (6)—should be used to generate estimates of consumer digital goods services? Because changes in factor utilization are a productivity effect, it seems clear that if market prices or quantities of digital goods have been impacted by the dramatic increase in household asset use, estimated trends in real digital services and productivity may be misstated the trends in household utilization indicated by figure 2 are ignored in the estimation of consumer digital capital services.

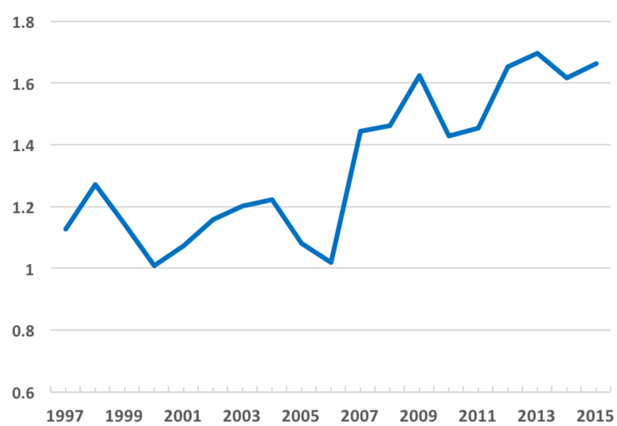
Digital access services payments and utilization. As previously indicated, private industry capital income is generally understood to include a utilization effect. Previous work that has considered how to extract a measure of network capital utilization from productivity data for network service providers is relevant in this regard (Corrado, 2011; Corrado and Jäger, 2014; see also Corrado and van Ark, 2016). The basic idea is that when an ex post approach is used to determine an industry's return in the Jorgenson (1963) user cost formula, the calculation of the ex post return exhausts the industry's observed capital income and absorbs a utilization effect. But when an ex ante approach is used to determine an industry's return, a utilization factor can be calculated so as to exhaust observed capital income.[2]

Let us then define the network services providing industry's ex post gross return as $R^N = (r+\delta^N - \pi^N)$ where r^N is determined residually, given rates for the depreciation and revaluation of the industry's capital stock δ^N and π^N. Now define the industry's ex ante gross return as $\overline{R}^N = (\overline{r} + \delta^N - \pi^N)$, where $\overline{r}$ is an ex ante nominal rate of interest. Let u^N be the network utilization rate. As shown in the appendix, this utilization rate is given by

$$u^N = \frac{R^N}{\overline{R}^N} \tag{8}$$

which suggests the relationship between the *ex post* and *ex ante* rate of return for an industry or sector is an indicator of its capital utilization.

Figure 3: **Implied Network Utilization**



Note. Ratio of ex post and ex ante gross rental rates for the combined Motion Picture, Sound Recording, Telecommunications, and Broadcasting industries (NAICS 512,515,517). Moody's AAA corporate bond rate is used in the ex ante formulation.

Source. Authors calculations using industry-level data from BEA.

Figure 3 shows the implied network utilization calculating according to equation (8). As may be seen, this measure rises sharply from about 2005 through 2013, after which it levels out. This result is

[2] As argued in Corrado (2011) for the case of network services providers, the utilization effect is absorbed in the ex post case under the assumption that the marginal productivity of the industry's aggregate net stock of capital is not particularly sensitive to composition differences in asset use, i.e., that it acts more or less as a single capital good as in Hulten (1986).

interesting for several reasons. First, it confirms the upward trend in household indicators shown previously on figure 2 and suggests there is an implicit utilization effect in consumer payments for digital access services. The measure pertains to the entire industry, i.e., including commercial and enterprise customers, and thus is not ideal for our purpose. Second, figure 3 suggests that the ex post gross rate of return in the network services industry and, by extension, its net return, is everywhere greater than the ex ante rate, which uses Moody's AAA corporate bond rate as the net rate of return. The rise in profitability implied by figure 3 likely is not unusual among private industries, but along with rising utilization, it also suggests a strengthening of business pricing power for network and video access services from about 2005 to 2013.[3] In models that introduce imperfect competition in an otherwise standard neoclassical growth framework (e.g., Rotemberg and Woodford, 1995), utilization is absorbed in a more general inefficiency wedge capturing, among other things, the ability of firms to maintain a price markup.

3 Empirical Approach

In the conventional approach to imputing service flows, to owner-occupied housing, for example, households have a more or less binary choice of renting versus owning. For digital goods, however, the service flow to households is partially mediated by the business sector and the accounting and analysis needs to carefully consider the alternative sources of supply and their utiilzation.

Sources of supply. Consider the following views of the sources of supply of consumer digital services:

1. Digital access services purchased by consumers from business

2. Consumer entertainment/online services supported by business-to-business advertising revenue

3. Consumer services yielded by consumer ownership of digital/ICT stocks

4. *Consumption* of services yielded by consumers' *use* of their own ICT stocks

5. ... plus treatment of household outlays on digital access (and business provision of free services) as *consumption*

[3] It should be noted we did not account for taxes in these calculations for this version of the paper but we doubt that would make a difference in the trajectory of the result shown in figure 3.

The first source of supply is already counted in national accounts. The second is not, but given the current scope and asset boundary of GDP, it probably should be for reasons set out in Nakamura, Samuels, and Soloveichik (2016), who also provide estimates of its value. These two sources of supply are independent, and their combined value represents the revenue from digital services delivered to the household sector.

A central contribution of this paper is to quantify the third source, the additional services yielded when consumer digital durable goods are capitalized and consumer income and consumption imputed in the standard way. The fourth and fifths views of supply are also explored, with the last seen as the most coherent in terms of capturing household *consumption*. The idea in the fifth view goes beyond making a utilization adjustment to imputed services; it also involves making a utilization adjustment to payments for digital access services.

Scope of empirics. The scope of the empirics to follow is set out in tables 1 and 2 below. Table 1, column (1), lists the product classes of digital goods that are capitalized in our analysis. As may be seen, we distinguish 14 product classes ranging from TVs, to computers and software, to cell phones. In terms of service lives, the products are grouped into two categories, those with a 9 year service life (A) and those with a 5 year service life (B). These groupings, indicated in column (2) of the table, are a (slight) simplification of the service life categories used by BEA in their fixed asset accounts, with the result that our estimated nominal net stocks (i.e., stocks at current cost) differ only slightly from those issued by BEA in its fixed asset accounts.[4]

As shown in column (3), research price indexes are developed (or adapted from) our earlier work and used to deflate investment for more than half of the product classes shown in table 1. In new moves, we use two quality-adjusted price indexes from the Japanese consumer price index and exploit Copeland (2013)'s work on consumer game software in conjunction with results from the BLS PPI.

[4]Specifically, a Hulten-Wykoff declining-balance rate of 1.65 has been used for all categories (including computers, unlike BEA), implying geometric depreciation rates for groups A and B of .1833 and .3300, respectively.

Table 1: **PCE durable digital goods**

	Product class	Depreciation	Source for Asset Price Index
	(1)	(2)	(3)
1.	Televisions	A	Byrne-Corrado (2017a,b)
2.	Cameras	A	Japanese CPI, cameras
3.	Photographic equip. ex. cameras	A	PCE price index
4.	Video equipment	A	Japanese CPI, video equipment
5.	Audio equipment	A	PCE price index
6.	Recording media	A	PCE price index
7.	Computers	B	Byrne-Corrado (2017a,b), reweighted for consumers
8.	Data storage equip.	B	Byrne (2015)
9.	Monitors	B	(Same as line 1)
10.	Computer peripherals	B	BEA (investment price)
11.	Misc. office equip	B	PCE price index
12.	Software and accessories	B	PPI, game software, bias-adjusted using Copeland (2013); Byrne-Corrado (2017a,b) software investment index
13.	Telephone equip. ex. cellular	A	Byrne-Corrado (2015a,b)
14.	Cell phones	B	Byrne-Corrado (2015a,b)

Notes: In column 2, A = 9 year service life, B = 5 year service life. In column (3), where multiple sources are listed, they are equally weighted. In column (3), line 4, the Japanese CPI for video equipment begins in 1990; the Japanese CPI for cameras is used for prior years.

Source (column 1): Selected products in BEA's annual PCE bridge tables, for which data are available from 1998 on; data for prior years are based on NIPA table 2.4.5U for 9 categories; Byrne and Corrado (2015a,b) for cell phone/telephone equipment ex. cellular split, and authors' estimates for computer and peripheral equipment and photographic equipment detail.

Table 2: **PCE digital access services**

		Sources:		
	Type of service	Payments	Users	Volume
	(1)	(2)	(3)	(4)
1.	Internet access	Line 283	ITU	Cisco
2a.	Cellular (conventional) telephone	Line 279, Nielsen	ITU, Nielsen	n.a.
2b.	Smartphone	Line 279, Nielsen	ITU, Nielsen	Cisco
3.	Cable and satellite TV and radio	Line 215	all households	Nielsen
4.	Video subscription	Nielsen and press reports	n.a.	n.a.

Notes: Line numbers refer to NIPA table 2.4.5U. Line 279 split between conventional cellular and smartphone based on Nielsen reports of adoption and authors' estimates. ITU is International Telecommunication Union. In column (4), Cisco is Cisco Virtual Networking Index of consumer IP traffic and mobile IP traffic, various years. Nielsen refers to reports of hours of television, including replay of recordings.

Figures 2 and 3 suggested that consumer utilization of digital access network/video services has risen sharply, but the data shown in these figures are coarse indicators. We build an explicit utilization series applicable to the consumer ICT assets shown in table 1 using data on consumer payments for digital access services shown in table 2.

Lines 1 to 3 of table 2 list the types of digital access services included in BEA's detailed PCE tables. These BEA tables also show data for landline telephone services and video media rental services, which are not included in our analysis. The latter is not included because it does not appear to include video subscription services, also known as OTT (Over-The-Top) services, covering payments for, e.g., Hulu, Netflix, and Amazon. These are shown in the table for completeness because consumer payments may be estimated from industry sources and included in our analysis.

The remaining columns of the table show sources that we use to develop a utilization measure based on the relationship between the number of users, column (3), and a volume measure of activity, column (4). The procedure we used is described more fully in the following section of the paper, but as seen in column (4), measures of data traffic are used to represent volumes for internet and smartphone services and hours are used as a volume measure for cable television services. For conventional cellular telephone service, utilization is treated as unchanged over time. In effect, the accessibility component of this service—the fact that a user is always reachable—is viewed as predominant. (Measures for video subscription services are not developed in this version of the paper.)

4 Results

We first present our central estimates (i.e, the third view as set out in the previous section). Then we present a measure of household utilization and apply this measure to our central estimates (the fourth view). In this version of the paper we do not implement the fifth view but it is a logical next step.

4.1 Real services

To generate our results, we first calculate an end-of-year (EOY) net stock of capital for each product class j using the perpetual inventory method with geometric depreciation:

$$K^H_{j,EOY} = I^H_{j,t}(1 - \frac{\delta^H_j}{2}) + (1 - \delta^H_j)K^H_{j,EOY-1} \quad (9)$$

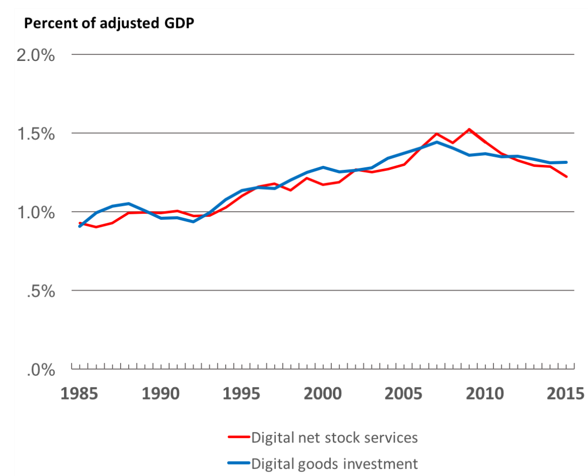
where $I^H_{j,t}$ is annual average real investment for the year t, calculated by deflating nominal spending on each product class using price indexes $P^H_{j,t}$ based on the sources listed in column (3) of table 1. We calculate a mid-period net stock $K^H_{j,t}$ by averaging adjacent EOY net stocks, which we multiply by its corresponding (annual average) price index. Summing over product classes:

$$P^H_T K^H_T = \sum_j P^H_j K^H_j \tag{10}$$

yields the value of consumer digital capital referred to in equation (5).

We calculate a gross rental rate using the depreciation rates described above and an *ex ante* net return measured using the 10-year constant maturity government bond rate and actual price change for the relevant asset type. Summing over asset types yields an estimate of consumer digital services. This series, which is in nominal terms, is shown in figure 4, where it has been plotted relative to GDP adjusted to include it. Relative to this metric, imputed services have averaged 1.3 percent of GDP for the last 20 years. Imputed services rose beginning in the early 1990s and reached a peak in 2009, after which they fell back to their relative level in 2005. The ratio of consumer digital investment to GDP has been more stable of late, averaging 1.34 percent of adjusted GDP since 2010.[5]

Figure 4: **Consumer Digital Investment and Services, 1985 to 2015**



Note. Consumer durable digital goods are listed in table 1.

Dividing the result for services shown in figure 4 by our implicit asset price index for consumer digital investment goods yields real consumer digital services according to equation (5). The results for real services and related series for the last thirty years (to 2015) are shown in table 3. There are several takeaways from these results. First, as shown on line 1, column (1), real services yielded by consumer stocks of digital goods grow robustly, averaging nearly 19 percent per year for the period

[5]The softening of investment in the last 5 years relative to the prior 5 years primarily reflects a sharp slowing in consumer outlays on computer software; consumer outlays for software grew 9.6 percent per year from 2005 to 2010 but dropped back to 3.0 percent per year from 2010 to 2015.

Table 3: **Rates of Change for PCE Digital Goods and their Services (annual rate)**

		1985 to 2015	1985 to 1995	1995 to 2005	2005 to 2015	2005 to 2010	2010 to 2015
		(1)	(2)	(3)	(4)	(5)	(6)
1.	Real services	18.7	15.1	21.8	19.2	23.8	14.7
2.	Real net stocks	18.4	15.2	20.5	19.6	21.3	17.8
3.	Real investment	19.0	15.7	22.1	19.4	21.2	17.6
4.	Nominal services	5.8	7.7	7.3	2.6	4.9	0.4
5.	Nominal investment	6.2	8.3	7.6	2.8	2.7	2.9
6.	Asset price index (real)[a]:	-12.7	-9.0	-13.6	-15.4	-16.9	-13.9
6a.	Group A assets	-9.8	-6.2	-8.6	-14.4	-15.5	-13.2
6b.	Group B assets	-19.2	-19.3	-21.6	-16.5	-18.4	-14.6
7.	Asset price index (nominal):						
7a.	Byrne-Corrado	-10.8	-6.4	-11.9	-13.9	-15.3	-12.5
7b.	BEA	-5.8	0.0	-7.8	-9.3	-10.5	-8.0
7c.	Line 7a less line 7b	-5.0	-6.4	-4.1	-4.6	-4.8	-4.5
8.	Contrib. to $\dot{\text{GDP}}$ (log ppts):						
8a.	Addition of new services[b]	.18	.11	.20	.23	.30	.15

NOTES: a. Byrne-Corrado index based on table 1 relative to the GDP deflator. b. We assume that PCE digital goods are imported and do not adjust GDP to account for the difference between the Byrne-Corrado asset price index shown on line 7a and the BEA price index shown on line 7b.

shown. From 2005 to 2010, column (5), real growth was especially robust. But growth tapered off thereafter. This tapering is partly a compositional effect, reflecting a relative slowing in the growth of consumer software, whose weight in aggregate real services is higher than it is in aggregate real investment.

Our real PCE digital asset price index is shown on line 6. As seen in columns (2), (3), and (4), price declines accelerate some over the period shown, reflecting fairly dramatic composition effects under the broad aggregate, shown on lines 6a and 6b. Price drops for the Group A assets (the AV and photo equipment) jump sharply beginning in 2005, whereas price declines for Group B assets (the computer and communications equipment) slow. All told, it seems that real prices for consumer digital assets are currently dropping about 14 (or 15) percent, about 5 percentage points faster than in BEA's national accounts.

Finally, as shown on line 8, the approach to accounting for innovation in consumer digital services set out in this paper has notable consequences for GDP growth. From 2005 to 2015 as a whole, we estimate that annual GDP growth would be nearly 1/4 percentage points higher; over the entire period analyzed, annual GDP growth is boosted by nearly 0.2 percentage point.

This GDP contribution is, of course, also the impact of capitalizing consumer digital goods on measured growth in output per hour (assuming the imputation would be included in a productivity analysis). In terms calibrating the contribution of an expanded ICT sector to output per hour growth per equation (4), the capitalization of consumer digital goods adds via two channels. First, it contributes via the "production effect" which also is the GDP contribution.[6] Second, it contributes via the investment effect which is larger by the expansion of ICT capital income. This effect also is consequential, about 1/3 of a percentage point.[7]

4.2 Utilization

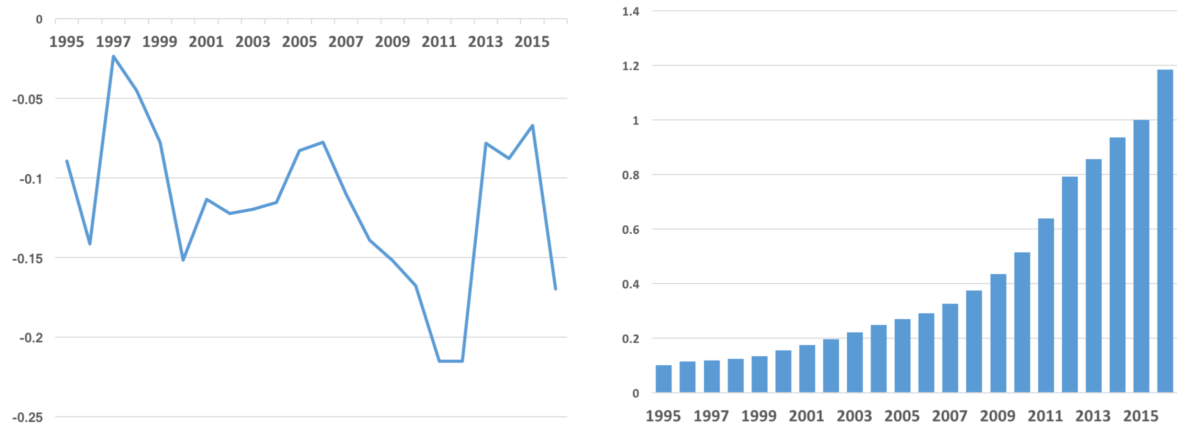
To construct an aggregate measure of utilization, we proceed first to construct $\dot{\lambda}$, the contribution of the *change* in underutilization to the effective price of real services from the ICT consumer durable stock per equation (7). $\dot{\lambda}$ is implied by the difference between the rate of change of two conceptually different "price" indexes derived from the information on digital access payments shown in in table 2. Using the nominal spending in the first column of the table, the first index is constructed by dividing these payments by the number of users whose sources are described in column (2). For the second index, we divide payments by the indicator of volume shown in column (3). The four components (internet, cable, smartphone, and conventional cellular service) of each index are aggregated using spending weights. The difference in the rates of change of the two aggregate indexes—the per user index and the volume index—is our estimate of the contribution to real service flows from changing underutilization, $\dot{\lambda}$. The results of this calculation are shown in figure 5.

As may be seen in panel (a) of figure 5, we find that the contribution of drops in underutilization to the growth of real services is substantial. The per user index indicates that the price of services *rises* at an average annual rate of 4.9 percent from 1995 to 2015. In stark contrast, the volume index *falls* at an average annual rate of 7.5 percent over this period. From about 2008 to 2012, the drops are especially large, and on balance, the contribution from the change in underutilization is 14.4 (log) percentage points per year. Panel (b) of figure 5 plots the utilization rate implied by our estimate of $\dot{\lambda}$;

[6] To see this, taking the long-term final output share of the newly capitalized services to be 1.3 percent, and the long-term relative price effect as 14 percent, we get 0.18 percentage point (.013 * 14 = .18).

[7] Referring back to the equation, taking .013 divided by the labor share in the total economy of .55, we get .0236. Multiplying this by 14 percent, we get .33 percentage point. Note that the labor share in the total economy is .556 according to BLS March 2016 Total Economy Multifactor Productivity release, and this has been scaled down slightly to account for the expansion of GDP due to the inclusion of the newly capitalized consumer digital services.

Figure 5: **Household Digital Access Services Utilization**



(a) $\dot{\lambda}$ (b) Utilization, 2015=1

it has been normalized to 1 in 2015. If this utilization rate is used to estimate services via equation (6), the change in real services growth is substantial. The utilization "wedge" adds 10.6 percentage points to the growth of real services from 1995 to 2005 and 14.2 percentage points from 2005 to 2015. All told, then, accounting for the dramatic increase in household use of digital capital stocks from 1995 on boosts our estimate of the growth in real digital services consumed to 35 percent per year.

5 Conclusion

This paper looked at the digital transformation of consumer activity through the lens of capitalization of certain consumer durable goods in national accounts. In this approach, services are imputed to investments in long-lived purchases, as is done now for owner-occupied housing. Like the selective treatment housing in national accounts, the notion is to avoid imparting a bias to GDP—in this case not because the size of the services is large (as in housing) but rather because the relatively faster productivity growth of the ICT sector provides an extra kick to overall growth, and expanding the coverage of national accounts is needed to capture the digital innovations in content delivery that have been especially fast since the advent of this century.

Given our earlier work on ICT prices (Byrne and Corrado, 2015a,b, 2017a,b), at one level our task was straightforward: We built a new price index for consumer digital investment and performed an exercise in which this investment was capitalized. These empirical results suggested that U.S. consumer digital goods investment and capital services growth has been exceptionally robust—nearly 20 percent per year. These results are based on a price deflator for consumer digital goods investment that falls 5 percentage points faster since 1985 than the deflator used in the existing national accounts. If the production boundary of these accounts were to embrace consumer digital goods as investment, the annual growth of real GDP would be nearly 0.2 percentage points faster, on balance, from 1985 on.

As stressed throughout this paper, however, the story of digital innovation and the consumer does not end with digital goods capitalization. A key point of this paper is that considering the increase in household use of digital stocks along with the capitalization of these stocks provides a more complete story of the digital transformation of consumer activity in the 21st century. Accounting for the dramatic rise in utilization boosts the estimate of real digital capital services growth developed in this paper to 35 percent per year. Because the share of services in expanded GDP initially is lower with the utilization adjustment, the contribution of our estimate of real digital capital services consumption rises over the 15 years since 2000. From 2010 to 2015, growth in real digital capital services consumption contributes 1/4 percentage point to the growth in real GDP expanded to include it.

References

Berndt, E. R. and M. A. Fuss (1986). Productivity measurement with adjustments for variations in capacity utilization and other forms of temporary equilibrium. *Journal of Econometrics 33*(1), 7–29.

Byrne, D. M. (2015). Prices for data storage equipment and the state of IT innovation. FEDS Notes (July 15), Federal Reserve Board, Washington, D.C.

Byrne, D. M. and C. A. Corrado (2015a). Prices for communications equipment: Rewriting the record. Finance and Economics Discussion Series 2015-069 (September), Board of Governors of the Federal Reserve System, Washington, D.C.

Byrne, D. M. and C. A. Corrado (2015b). Recent trends in communications equipment prices. FEDS Notes (September 29), Federal Reserve Board, Washington, D.C.

Byrne, D. M. and C. A. Corrado (2017a). ICT asset prices: Marshalling evidence into new measures. Finance and Economics Discussion Series 2017-016 (February), Board of Governors of the Federal Reserve System, Washington.

Byrne, D. M. and C. A. Corrado (2017b). ICT Prices and ICT Services: What do they tell us about Productivity and Technology? Finance and Economics Discussion Series 2017-015 (February), Board of Governors of the Federal Reserve System, Washington.

Copeland, A. (2013). Seasonality, consumer heterogeneity and price indexes: the case of prepackaged software. *Journal of Productivity Analysis 39*, 47–59.

Corrado, C. (2011). Communication capital, Metcalfe's law, and U.S. productivity growth. Economics Program Working Paper 11-01, The Conference Board, Inc., New York. Available at `http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2117784`.

Corrado, C. and K. Jäger (2014). Communication networks, ICT, and productivity growth in Europe. Economics Program Working Paper 14-04, The Conference Board, Inc., New York.

Corrado, C. A. and B. van Ark (2016). The Internet and productivity. In J. M. Bauer and M. Latzer (Eds.), *Handbook on the Economics of the Internet*, pp. 120–145. Northamption, Mass.: Edward Elgar Publishing, Inc.

Gordon, R. J. (1990). *The Measurement of Durable Goods Prices*. Chicago: University of Chicago Press.

Hulten, C. (1986). Productivity change, capacity utilization, and the sources of efficiency growth. *Journal of Econometrics 33*, 31–50.

Hulten, C. (2009). Growth accounting. Working paper, NBER Working Paper 15341 (September).

Hulten, C. R. and F. C. Wykoff (1981a). The estimation of economic depreciation using vintage asset prices. *Journal of Econometrics 15*, 367–396.

Hulten, C. R. and F. C. Wykoff (1981b). The measurement of economic depreciation. In C. R. Hulten (Ed.), *Depreciation, Inflation & the Taxation of Income from Capital*, pp. 81–125. The Urban Institute.

Jorgenson, D. W. (1963). Capital theory and investment behavior. *American Economic Review 53*(2), 247–259.

Jorgenson, D. W. (1966). The embodiment hypothesis. *Journal of Political Economy 74*(1), 1–17.

Jorgenson, D. W. and Z. Griliches (1967). The explanation of productivity change. *The Review of Economic Studies 34*(3), 249–283.

Jorgenson, D. W. and J. S. Landefeld (2006). Blueprint for expanded and integrated U.S. accounts: Review, assessment, and next steps. In D. W. Jorgenson, J. S. Landefeld, and W. D. Nordhaus (Eds.), *A New Architecture for the U.S. National Accounts*, Volume 66 of *NBER Studies in Income and Wealth*, pp. 13–112. Chicago: University of Chicago Press. Available at http://www.nber.org/chapters/c0133.pdf.

Nakamura, L., J. Samuels, and R. Soloveichik (2016). Valuing 'free' media in GDP, 1929–2015. Paper presented at the ASSA meetings, January 8, 2017.

Oulton, N. (2012). Long term implications of the ICT revolution: Applying the lessons of growth accounting and growth theory. *Economic Modelling 29*(5), 1722–1736.

Rotemberg, J. J. and M. Woodford (1995). Dynamic general equilibrium models with imperfectly competitive product markets. In T. F. Cooley (Ed.), *Frontiers of Business Cycle Research*, pp. 243–293. Princeton University Press.

Appendix

This appendix provides a derivation of equation (**??**) in section **??** of the main text, i.e., we set out how to extract a measure of network capital utilization from productivity data.

What follows is based on the framework set out for analyzing communication networks and network externalities in Corrado (2011), in which it is assumed there no markups due to imperfect competition or other inefficiency wedges; see also Corrado and Jäger (2014) and Corrado and van Ark (2016).

In sources-of-growth accounting, the contribution of private capital is expressed in terms of the services it provides. Let the value of the relevant private stocks be denoted as $P^I K$ where the price of each unit of capital P^I is the investment price and the real stock K is a quantity obtained via the standard perpetual inventory model. In our application, the value $P^I K$ represents the replacement value of network service provider capital in terms of its capacity to deliver digital services (i.e., including in this application, the value of the "originals" for the content the provider can diseminate). The value $P^K K$ represents the service flow provided by that capital.

The price P^K is an unobserved rental equivalence price, but which is related to the investment price by the user cost formula, $P^K = P^I(r + \delta - \pi)T$, where r is an after-tax *ex post* rate of return, δ the depreciation rate used in the perpetual inventory calculation, π is capital gains, and T is the Hall-Jorgenson tax term. The rental equivalence price is simplified by defining the gross return $R = (r + \delta - \pi)T$, so that when capital services $P^K K$ are equated with observed capital income via the residual calculation of an *ex post* after-tax rate of return r, we have

$$\textbf{observed capital income} = P^I K * R \tag{A1}$$

When capital services are computed on the basis of an *ex ante* financial rate of return $\overline{r}$, the value for capital income of network providers must be expressed differently. Defining the *ex ante* gross return $\overline{R} = (\overline{r} + \delta - \pi)T$ accordingly, network provider capital income is expressed as

$$\textbf{observed capital income} = P^I K u^N * \overline{R} \tag{A2}$$

where u^N is network capital utilization and, via Berndt-Fuss (1986), capital utilization u^N (rather than r) exhausts capital income.

Equating expressions (A1) and (A2)

$$P^I K * R = P^I K u^N * \overline{R}$$

and solving for u^N yields

$$u^N = \frac{R}{\overline{R}} \tag{A3}$$

which suggests the relationship between the *ex post* and *ex ante* rate of return for an industry or sector is an indicator of its capital utilization.