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David M. Byrne and Carol A. Corrado

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Prices for Communications Equipment: Rewriting the Record

by

David M. Byrne* and Carol A. Corrado**

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**The Conference Board, New York, and Georgetown University Center for Business and Public Policy, Washington, D.C.

Abstract

Communication equipment plays as large a role in high-tech investment as computers, yet prices for communication equipment have not been studied as extensively as prices for computers and electronic components. Prices for satellites, cell phones, and the ground stations for these systems—important components of a nation's communications infrastructure—are difficult to locate in official statistics. This paper develops new price measures for 14 types of communications equipment from 1963 to 2009. Indexes for some (e.g., cellular phone systems) experience declines of 15-20 percent per year, similar to the decline in quality-adjusted prices for computers, and suggest that advances in wireless communications technology have been very rapid. All told, our price index for domestic production falls 4.8 percent per year on average over the time period we study and 9.8 percent per year on average since 1985—nearly 10 percentage points faster than the official U.S. producer price index introduced in that year.

Keywords: Price measurement, ICT, communications technology, wireless technology, technical change, communications equipment industry.

David M. Byrne
Stop 180
Federal Reserve Board
Washington, D.C. 20551
david.m.byrne@frb.gov

Carol A. Corrado
The Conference Board
845 Third Ave.
New York, New York 10022
carol.corrado@tcb.org

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Advances in communications made possible by networked computers, innovation in radio wave technology, and advanced telephony are central to the IT revolution. When you sit at your computer and access the communications network of the Internet, your actions are powered and transmitted by a complex system of equipment. When you pick up your telephone, your voice may travel in essentially the same fashion, whereas your other phone, your cell phone, uses very different means. This paper asks whether official price measures for the varied systems and equipment that make modern communications possible are accurately capturing the underlying pace of change. This question is important because IT prices are often used to assess the ongoing pace of technological innovation (e.g., Jorgenson 2001), and in the United States, private capital spending on communication equipment often matches, or exceeds, that on computers.

Prices for communications equipment have not been examined as extensively as prices for computers and electronic components. The most recent research covered innovations in equipment used for networking computers (Doms and Forman 2005) and for transmitting voice and data over fiber optic cable (Doms 2005) during the 1990s, but communications technology has marched forward at a stunning pace since then. The explosive growth in wireless capacity and emergence of sophisticated applications on cell phones suggest it is natural to ask whether advances in communications technology, especially wireless technologies, are fully reflected in existing price measures.

The equipment and systems that power wireless networks have long been important components of the U.S. communications infrastructure—yet official producer price indexes for cellular systems and commercial satellites before 2002 and 1986, respectively, do not exist. The world's first commercial satellite was launched in the United States in 1964, and for the next 20+ years, U.S.-designed and produced commercial satellites dominated world markets. Cellular phone systems became available in the United States by the early 1980s, and the number of cellular subscribers grew by leaps and bounds after then, averaging increases of 47 percent per year before slowing in the early 2000s. Moreover, the United States was home to the world's largest cell phone plant (a Nokia plant in Fort Worth, Texas) in 1999.[1] This paper develops these missing histories, thus complementing Hausman (1999), who studied consumer prices for cell phones and cellular phone services from the industry's earliest days. Prices for cellular

[1] "Finland-based wireless telephone company benefits Fort Worth, Texas economy," Knight Ridder, May 22, 2000.

systems purchased by business and government—about two-thirds of the total market—have not been previously studied.

To complete the story of technological advances in telecom equipment, we also rewrite the record of price change for wireline equipment. We introduce new results for recent generation (IP-enabled) telephony systems and for the "local loop" transmission equipment that enables adoption of residential high-speed broadband. We also develop estimates of producer price change for "plain old telephones" from 1963 to present. Why plain old telephones? Because an official price index for this breadth of time does not exist, and we create a more accurate historical record of communication equipment prices by covering these and other terminal devices. All told, we produce and report more than one dozen new product-level price indexes that collectively span 46 years, from 1963 to 2009.[2]

1. Starting Point and Approach

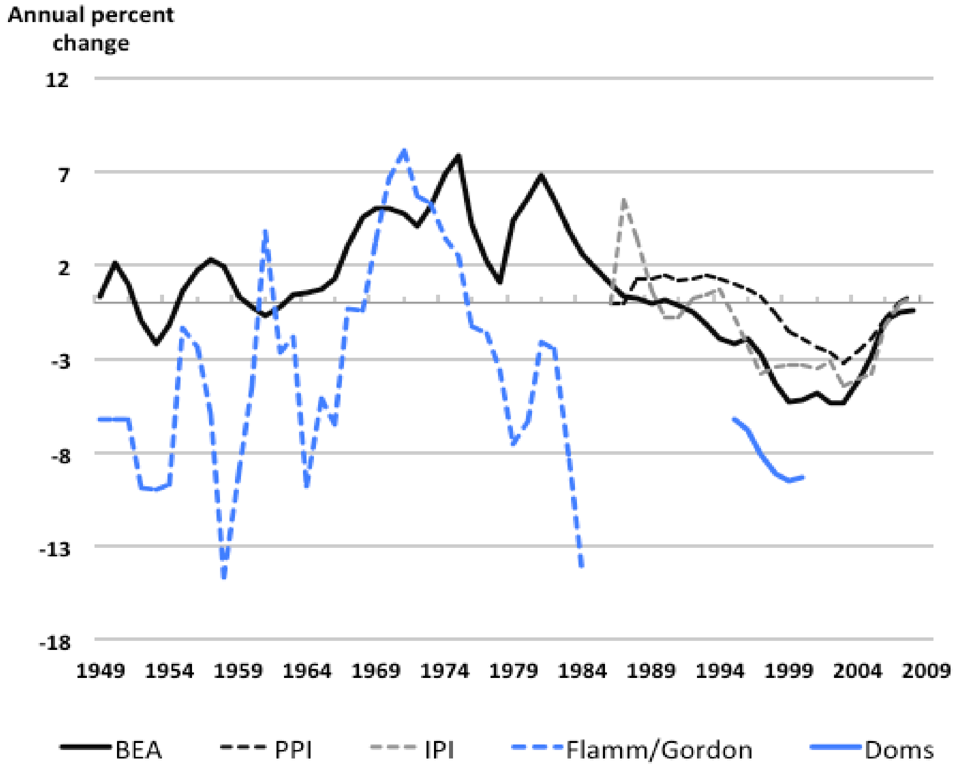
The starting point for our research is conveyed in figure 1 by the relative changes in the Bureau of Economic Analysis (BEA) investment price index for communication equipment as of May 2010 and two comparable research series (Gordon 1990, which was based on Flamm 1989, and Doms 2005). The three series differ mainly because they reflect alternative combinations of official versus research price indexes for the products of the industry. The Bureau of Labor Statistics (BLS) Producer Price Index (PPI) and Import Price Index (IPI) for the communication equipment industry and imports of telecommunications equipment, respectively, also are shown.

In the post-1985 period, most BEA investment prices are weighted averages of BLS PPIs and IPIs, but in notable cases, e.g. computers until the early 1990s, and to some degree communications equipment, research price indexes are used (Grimm, Moulton, and Wasshausen, 2005). The BEA's May 2010 price index for communication equipment investment that is shown in figure 1 incorporates Grimm's research (1996, 1997) on prices of digital circuit switches from 1985 to 1996 and the Federal Reserve's price index for data networking equipment based on Doms and Forman (2005) from 1997 on.[3] The work of Flamm/Gordon, the Federal Reserve's data networking index from its start date (1992), as well as Doms' (2005) later work that generated prices for modems, fiber optic transmission equipment and enterprise

[2] Using substantially the same methods as reported in this paper, the Federal Reserve Board extends these prices annually for use in its industrial production index. A forthcoming paper (Byrne and Corrado 2015) presents the extended measures through 2014 and analyzes long-term trends in ICT technology, ICT prices and prospects for ICT contributions to productivity change more generally.

[3] Communication from the BEA, October 1, 2009.

Figure 1. Official and Research Price Indexes for Communications Equipment, 1949 to 2008



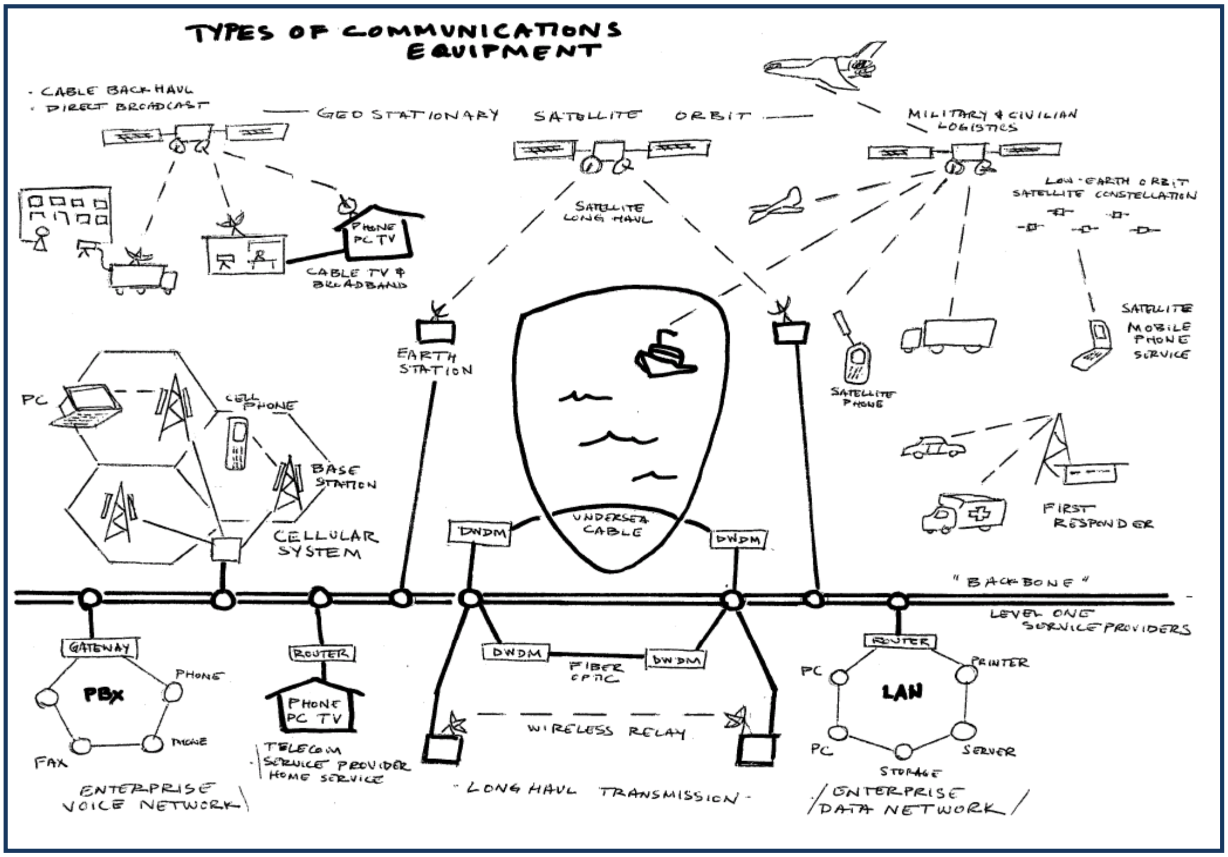
SOURCES. The Bureau of Economic Analysis (BEA) investment price index for communications equipment is as of May 2010. The Bureau of Labor Statistics (BLS) Producer Price Index (PPI) is an output price index for communications equipment manufacturing (NAICS 3342) and the Import Price Index (IPI) is for telecommunications equipment. Flamm/Gordon is the price index for telephone switching and transmission equipment in Gordon (1990), table 9.7, column 8. Doms is the "moderate" communications equipment price index shown in Doms (2005), table 9.13, line 14.

NOTE. Series plotted are 3-term moving averages of annual percent changes.

telephone networking equipment are not included. The May 2010 BEA index also does not reflect the Federal Reserve's published updates to price indexes for wireless equipment that were introduced in an earlier version of this paper (Byrne and Corrado 2007).

Doms (2005) built an overall index for business and government communications equipment spending that incorporated new research price indexes for selected products and judgment about reasonable estimates for other products. The difference between the BEA and Doms series (4.5 percentage points for the period of overlap) is rather notable. The Flamm/Gordon index is for the telephone transmission and switching component that receives a 95 percent weight in the BEA investment deflator for communications equipment prior to 1983 (Gordon 1990, table A.1). Before the introduction of BLS PPIs for communications equipment

Figure 2



in December 1985, regulatory and company reports were the major source of information on prices of communication equipment. Using the available information on AT&T, Flamm (1989) constructed price indexes for telephone switching and transmission equipment that controlled for the capacity of newly installed systems. Flamm's work was famously surfaced by Gordon, who constructed a price index for communications equipment investment from 1947 to 1982/3 using the central results of Flamm's extensive research. As illustrated in figure 1, the average rate of change in the Flamm/Gordon index, like the Doms index, is well below the BEA's official measure.

Like Gordon and Doms, the research reported in this paper attempts to combine disparate sources to construct an overall price index for U.S. communications equipment production and spending. To do this we tap into an unusually wide and diverse set of data to measure price change for specific products, an approach to price measurement research Shapiro and Wilcox (1996) termed "house-to-house combat." Relative to other types of equipment, such as computers and peripherals, communications equipment contains a highly diverse set of products (e.g., routers and switches, cell phones, fax machines, satellites) and equipment systems (public switching, enterprise switching, private service provider)—see figure 2, suggesting that “room-to-room combat” is a more apt description of our process for producing price indexes for communication equipment.

In light of rapid change and innovation in communications, the primary focus of this paper is on capturing quality change in price indexes for the systems and equipment that have made the advances in communications possible.[4] As a consequence of the detailed nature of the data we use, we are able to construct constant-quality price indexes without appeal to hedonic regressions. Aizcorbe, Corrado, and Doms (2000, 2003) showed that matched-model estimates of price change yield price indexes that are essentially identical to those generated using a hedonic model *given sufficient and appropriate granularity in the underlying data*. (Grimm *et al.* (2005) and Erickson and Pakes (2007) report similar findings.) Accordingly, when data on prices and quantities are available for detailed, homogeneous items in adjacent periods, we calculate Fisher matched-model price indexes. When we only have detailed price data (again, for homogeneous items), we compute a price index from a geometric mean of price change for the individual items. When transactions-based price data are unavailable, we construct a characteristics price measure by dividing revenue (or cost) by a measure of the productive capacity of the equipment or system.[5]

The construction of a price index using a superlative aggregator decomposes the change in the average price for the product ($\Delta \ln P^{Ave}$) into a change in a constant-quality price index ($\Delta \ln P^{*}$) and a change in product quality ($\Delta \ln Q^{*}$). The decomposition implies the constant-quality price index can be expressed in terms of two components, the change in the average price of products sold less the increase in their quality:

(1) $$\Delta \ln P_t^{*} = \Delta \ln P_t^{Ave} - \Delta \ln Q_t^{*}.$$

These components of a price index have a common interpretation: average prices reflect production costs, and quality change reflects design improvements.[6] A constant-quality price

[4] Lichtenberg and Griliches (1990) argue that because long-run errors in price measurement primarily stem from “imperfectly measured changes in product quality,” this issue is central to the analysis of sources of long-run economic growth. Short-run measurement errors, not addressed in our study, such as the use of producer prices to measure investment prices, or vice-versa, may well affect analysis of cyclical economic movements or price determination.

[5] This is a form of hedonic approach implying a simple, linear hedonic function through the origin of the price-single characteristic plane (Triplett 2004).

[6] To see this, we first note that a superlative aggregator yields price and quantity indexes where the change in aggregate nominal output is the sum of the changes in the price index and the real output index. The change in nominal output is also equal to the sum of the changes in the average price and number of units sold. Algebraically,

(1a) $$\Delta \ln P_t^{*} + \Delta \ln Y_t^{*} = \Delta \ln P_t^{Ave} + \Delta \ln Units_t$$

index can fall when production economies or process improvements lower average selling prices (costs) and/or when design improvements improve quality. In our discussion of Fisher matched-model indexes below, we often refer to "average prices" or "production costs" on the one hand, and "controls" for quality on the other. "Controls" refer to characteristics—the lines along which the available price data are disaggregated (e.g., number of ports and technology type). These must be sufficiently granular to accurately capture quality change.

Another feature of our approach is the introduction of a system to classify detailed product data for communications equipment. Our ability to develop price indexes for equipment according to fixed concepts (such as "wireless" versus "wireline" equipment) over many years stems from this system, which is shown on table 1. The system is based on classifying detailed products according to the *nature*, *means*, and *function on a network*. *Nature* refers to whether communication is two-way (telecom) versus one-way (broadcast), *means* is telecom broken down in wireline and wireless, and *function on a network* refers to product types below these basic headings. This classification enables us to work with a wide variety of industry sources on prices and spending as well as exploit the rich detailed product information in the Census Bureau's Current Industrial Report (CIR) and Census of Manufactures (COM) series for the communications equipment industry. The Census publications yield data on unit values for individual products in certain cases, but their greatest utility is as a source for product-level (and some item-level) nominal time series that provide weights for superlative aggregation (Diewert 1976) of our product- and higher-level price indexes.

We populate the scheme shown in table 1 by developing 14 individual product-level price indexes for wireless and wireline telecom equipment products from about 150 item-level price indexes. Appendix table A summarizes the sources and structure for the 14 price indexes and Appendix tables B.1-B.11 show the index levels and key components used to construct them.

In the next two sections we describe the construction of our product-level price indexes. We then turn to a brief description of how we estimate values for production and spending on these products, after which we review the resulting aggregate price indexes and conclude.

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where * denotes a superlative aggregate index (i.e., P^* is a price index and Y^* is a real output index) and P^{Ave} is an average price and *Units* is output in units. Rearranging terms gives,

(1b) $$\Delta \ln P_t^* = \Delta \ln P_t^{Ave} + \Delta \ln Units_t - \Delta \ln Y_t^* .$$

The change in product quality is the difference between the change in real output and the change in units sold, i.e.,

(2) $$\Delta \ln Q_t^* = \Delta \ln Y_t^* - \Delta \ln Units_t .$$

Substitution of (2) into (1b) yields the expression given in the text. Note from (2) that quality change can also be seen as mix shifts in the composition of varieties sold.

Table 1. Communications Equipment: Major Categories and Product-level Components

1.	***Two-way (Telecom):***
2.	***Wireless*** [1]
3.	Cellular systems
4.	* Cell phones
5.	* Cellular networking
6.	* Satellites
7.	* Other radio station
8.	***Wireline***
9.	* Data networking
10.	Telephone switching
11.	* Enterprise
12.	* Central office
13.	Transmission [2]
14.	* Fiber optic long-haul
15.	* Other long-haul
16.	* Local loop
17.	Terminals
18.	* Telephones
19.	Other (*modems, *fax machines, *messaging)
20.	***One-way (Broadcast/other):***
21.	Broadcast, studio and related
22.	Traffic control, intercom, alarm systems

* Denotes product-level classification.

1. Wireless computer networking equipment is included in data networking equipment.
2. Microwave transmission is included in radio station equipment.

2. New Results for Wireless (Radio Station) Product Prices

Radio stations, broadly defined, consist of one or more wireless transmitters or receivers and accessory equipment (International Telecommunications Union (ITU) 2012). The selected radio station equipment discussed here is used for two-way telecommunications between locations on earth and in space.[7] We build product-level price indexes for four types of wireless equipment: cell phones (a kind of mobile station), cellular network equipment (a kind of fixed station), satellites, and other radio station equipment.

2.1. Cellular Systems

Cellular systems are distinguished from other wireless systems in that they are "a network of small geographic areas called cells, a base station transmitter in each, cell traffic controlled by a central switch, and frequencies reused by different cells" (Farley 2005, p. 23). Business spending on cellular systems consists of service provider investments in cellular network infrastructure (base station and switching equipment) and service provider purchases of cell phones for resale to participants in cellular networks.

2.1.1. Cellular phones. The early years of cellular phones suffer from a paucity of detailed data. Hausman (1999) studied the emergence of markets for cellular phones and reported that cell phone prices were about $3,000 when first produced in significant quantities in 1983 but fell to about $200 by the late 1990s.[8] These quotes imply that prices for cell phones dropped more than 15 percent annually *without adjustment for quality*. In addition, Gordon (1990, p. 406) cites an article that reports the price of low-end cell phones fell 23 percent per year from 1983 to 1987.[9] Information from the Telecommunications Industry Association (TIA) is broadly consistent with these sources. They report "average manufacturer" prices were $800 in 1987 and $203 by 1996—a 14.1 percent drop at an annual rate.

Our own examination of articles describing early mobile phone models reveals rapid price declines and extraordinary innovation.[10] The first widely available handheld portable cellular phone, the Motorola DynaTAC 8000x, weighed 28 ounces, was 13 inches long, and had a retail price of $3,995 in 1983 (cf. Hausman's figure of $3,000). In June 1991, this model was advertised for $179, implying an average annual price decline—controlling for quality by comparing identical models—of 32 percent.[11] The second major Motorola design, the MicroTAC, was introduced in 1989, weighed 12 ounces, and fit in a shirt pocket.

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[7] Broadcast radio station equipment is included in "other communications equipment" (see section 4). Equipment for industrial, scientific and medical applications of radio-frequency energy are not considered communications equipment (NAICS 3342).

[8] We only have Hausman's prices for 1983 and 1997; prices for intervening years are no longer available (personal communication, Jerry Hausman, April 2007.)

[9] *Business Week, September 21, 1987, p. 90.*

[10] On DynaTAC, see "Motorola Celebrates 20th Anniversary of Mobile Phone," *MobileTech News*, March 6, 2003. (http://www.mobiletechnews.com /info/2003/03/06/154908.html, accessed August 28, 2015) On MicroTAC, see "All About/Cellular Telephones; A Gadget That May Soon Become the Latest Necessity," *The New York Times*, January 28, 1990. (http://www.nytimes.com/1990/01/28/business/all-about-cellular-telephones-a-gadget-that-may-soon-become-the-latest-necessity.html, last accessed August 28,2015).

[11] *Central Park Electronics* price for DynaTAC with service contract advertised in *New York Times*, June 30, 1991.

Although this examination of prominent cell phone models suggests quality-adjusted price declines exceeded the rate of average price decline, absent more comprehensive information on phone prices and characteristics in this early period, we refrain from quantifying the extent of any bias in the early average price data.[12] On the one hand, phones went from the size of a brick to the size of a wallet during this period and failure to account for this quality change may lead average prices to overstate inflation. On the other hand, the composition of demand may well have shifted toward the low end as cell phones became common equipment in the business world leading average prices to fall faster than quality-adjusted prices.

After 1996, the rate of decline in the *average price* of cell phones slowed (falling just 6 percent annually) and reversed sign after 2004 (increasing 3.9 percent per year). The intense innovation in wireless systems and vast expansion of network capacity during this period suggests that quality-adjusted prices behaved differently, however. Fortunately, we can address this concern with more comprehensive data on cell phones available beginning in the mid-1990s. We use data from Gartner for six functional classes of cellular mobile phones to construct a Fisher matched-model price index that *declined 16.5 percent annually from 1994 to 2007*—a strikingly different trajectory than the pattern of change in average cell phone prices although the rate of decline in the quality-adjusted index also slows after 2004.[13]

In the mid-2000s, a wave of innovation led to the emergence of smartphones—devices with powerful operating systems that allow multi-tasking and installation of third-party applications. While smartphone market share surged from 4 percent in 2003 to 25 percent in 2007, smartphone *average prices* fell only 4.6 percent per year from 2004 to 2007, suggesting further controls for quality are needed. However, because the data from Gartner data combine smartphones into a single functional category (with additional detail by transmission type) the overall cell phone price index, which moves down only 5.9 percent during this period, may fall short of fully accounting for quality. A hedonic study of the Japanese cell phone market (Watanabe, *et al.* 2010) using data on 22 cell phone characteristics supports this intuition—quality-adjusted prices in Japan were estimated to have fallen 13.9 percent per year from 2004 to mid-2007 (annual average basis).[14] Unfortunately, comparable data are not available for the U.S. market for this period.

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[12] In forthcoming work, we use extensive data from specific cell phone advertisements to build a quality-adjusted cell phone price index for the 1987 to 1994 period.

[13] The Gartner data are U.S. revenues and average wholesale prices from 1995 on and North American revenue and prices for 1994/5. Further detail according to transmission type (GSM, CDMA, etc.) is available from 1994 to 2002, bringing the total number of cell phone types used in the analysis for those years to 19. Controlling for transmission type has a small impact on price change (1-1/2 percentage points per year), and we adjust the post-2002 Gartner index by this amount to control for continued effects as various 3G technologies were rolled out.

[14] Calculated from results shown in tables 4 and 5 of Watanabe *et al.* 2010. 2007Q2 is the last time period in this study.

Subsequently, many observers argue that the price dynamics *within* the smartphone segment changed upon the introduction of Apple's iPhone in mid-2007 and that the pace at which powerful, flexible operating systems were incorporated in cell phones picked up further.[15] While we do not have prices for new cell phones to explore this proposition (because phones are typically sold bundled with a service contract), we can examine model-level dynamics using available prices from the market for used cell phones. This high-frequency data on specific models allows us to control for quality using a matched-model index. That being said, used asset price change reflects economic depreciation (the change in the price of an asset as it ages, holding time constant) as well as pure price change. If we are willing to assume a depreciation rate, we can get a handle on price change for new models by examining price dynamics in used markets.

We obtained price lists for specific models of cell phones from Phoneraiser, a fundraising organization that buys used phones for delivery to refurbishers serving large markets in other countries. From year-end 2005 to year-end 2009, prices for an average of 500 models per year are available. We construct geometric mean of model price changes grouped by major phone manufacturers (accounting for 85 to 90 percent of the market) and weight the company indexes by annual market share, yielding a price index that fell an annual average of 43 percent from 2006 to 2009.[16] To account for rapid obsolescence, we use an aggressive annual depreciation rate of 33 percent (BEA's depreciation rate for an asset with a service life of 5 years) yielding a cell phone price index that falls 15.5 percent per year.

To combine these myriad sources to construct a cell phone price index for all periods we begin with the TIA average price for 1987 to 1994, which we extend back to 1983 using Hausman's price quote (with support from Gordon 1990 and our analysis of cell phone advertisements). From 1994 to 2006, we use the matched-model index built from Gartner data and from that point forward we employ the depreciation-adjusted used price index. All told, we estimate that prices of cell phones declined 18.5 percent per year from 1983 to 2009. The price index and components used to construct it are shown in Appendix table B.1.

2.1.2. Cellular networking equipment. Cellular phones connect to the wireline network through "base stations," the typically oblong, white devices attached to structures of all kinds in densely populated areas. These consist of transceivers that exchange signals with user handsets, switches that direct traffic to and from the wireline network, and other supporting electronics. We

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[15] Articles in PCWorld on May 9, 2007 ("Motorola CEO ready to take on iPhone") and October 18, 2007 ("Nokia CEO 'Paranoid' about iPhone Competition") are examples of reports on the actions taken by others to combat the threat from the Apple product line.

[16] We truncate model price series when phones appear to have stabilized at scrap prices (unchanged prices at a level below 2 dollars for one year).

develop a cellular infrastructure equipment price index using data on the revenues and average prices of 5 distinct cellular network components for each major transmission standard (GSM, CDMA, etc.) from Dell'Oro Group for 2000 to 2009. We extend this index back to 1993 using similar data from Gartner.[17] The resulting matched-model Fisher price index declines at a 16.8 percent average annual rate from 1993 to 2009 and is shown in Appendix table B.2.

Production of cellular networking equipment effectively began in 1983, but we do not have data to directly calculate prices of cellular networking equipment before 1993. We estimate that the value of production remained less than $500 million until 1988, but grew by a factor of 14 between then and 1993. For these early years, we extend back the index using the closest BLS PPI, for "communications systems and equipment (except broadcast)," adjusted by the average difference with our Dell'Oro/Gartner research index.[18]

2.2. Satellites

Prices paid for satellites generally are not usually disclosed.[19] However, we are able to construct a price per unit of capacity. We employ a database containing technical specifications for every communication satellite launched from the inception of the industry to 2006.[20] We assign each satellite to domestic or foreign manufacturing based on the business location of the primary manufacturing contractor and also classify the satellite as one of two types: "bent-pipe" and other. Bent-pipe satellites mainly redirect signals—usually telephone calls or backhaul of cable television programming—to distant locations. Other satellites deliver more complex services, such as Internet, television and mobile phone access in sparsely populated areas. We focus on the capacity of bent-pipe satellites and argue for using their unit capacity cost as a proxy for prices in the industry as a whole.

The focus of the early communications satellite industry was on bent-pipe equipment for carrying long distance telephone traffic. Innovation was intense and the number of phone circuits per satellite grew rapidly: the capacity of the typical satellite launched by Intelsat, the dominant operator in the early industry, went from 240 circuits in 1965 to 15,000 circuits in 1985 (table 2). The number of transponders per satellite, an alternate measure of capacity, grew at a similar rate, more than 20 percent on average, during this period. With the introduction of digital

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[17] Dell'Oro reports worldwide revenue and units, but it would appear that there is a global market for this equipment. The Gartner and Dell'Oro price indexes overlap from 2000 to 2005 and both fall at about a 10 percent annual rate. This occurs despite the fact that revenues in the Gartner data are for the U.S. market.

[18] The BLS produced a PPI for "cellular system equipment" from 2002 to 2006, which falls 6.7 percent (average annual rate) during that period whereas our index drops 14.1 percent.

[19] Furthermore, when data on prices of satellites are available, they tend to include launch, insurance, and leasing costs in addition to the production cost of the satellite. The costs of these services loom large in relation to production costs and have their own market dynamics (especially insurance).

[20] *The Satellite Encyclopedia*, v0.77.001.

circuit multiplication (DCME) in 1989 (Intelsat 6), the number of phone circuits available per transponder increased by an order of magnitude. Other generations of satellites introduced advances such as frequency reuse (Intelsat 4A), orthogonal polarization (Intelsat 5), cross-strapping (Intelsat 7), and expansion to frequencies beyond the traditional C-band (Intelsat 5)—all of which increased effective capacity per transponder as well.

Table 2.
Technical Specifications for Major Intelsat Geostationary Satellites

Intelsat Series	Launch Dates	No. in series	Design life	Mass at launch (kg)	DC Power (W, BOL)	Transponders (36 MHz Equiv.)	Phone circuits
Intelsat 1	1965	1	2	68	45	1	240
Intelsat 2	1967	4	3	162	83	3	240
Intelsat 3	1968-71	8	5	293	160	13	1,500
Intelsat 4	1971-75	8	7	1,415	600	12	4,000
Intelsat 4A	1975-78	6	7	1,515	700	20	6,000
Intelsat 5	1980-84	15	7	1,900	1,800	53	12,000
Intelsat 5A	1985-89	6	9	ND	1,800	69	15,000
Intelsat 6	1989-91	10	10	2,560	2,600	77	120,000
Intelsat 7	1993-96	9	10	3,750	3,968	129	90,000
Intelsat 8	1997-98	6	10	3,400	6,400	79	112,500
Intelsat 9	2001-03	7	13	4,750	8,000	122	*195,200*

NOTE. Phone circuit figure for Intelsat 9 is authors' estimate. ND denotes not disclosed.
Source. *The Satellite Encyclopedia*, v0.77.001.

For each bent-pipe satellite in the database (regardless of manufacturer), we multiply bandwidth (measured in transponders) by the ratio of phone circuits to transponders for the concurrent Intelsat generation to obtain an estimate of satellite capacity. The *value* of bent-pipe satellite production is estimated from the total communications satellite production reported in the Census Bureau's Current Industrial Report (CIR) multiplied by the bent-pipe *share* of total production available in a database provided by Futron Corporation. Dividing the estimated value of production of bent- pipe satellites by the previously described capacity measure yields an index of the *unit cost of new bent-pipe capacity*, which declines about 15 percent per year on average over the entire history of the industry.[21]

Although telephone and television traffic and bent-pipe satellites dominated the early industry, beginning in the late1980s, rapid declines in the price of long-haul fiber optic transmission pushed satellite operators into other areas: Nearly all satellites launched in 1987

[21] In practice, we take a three-year forward moving average of launched units to smooth our capacity series, which is far more volatile than revenue. We suspect that units, which are recorded at time of *launch*, are not synchronized with production values for this reason. According to the Futron Corporation, the typical life cycle from contract to launch was about 2-1/2 years in the late 1990s.

were in the bent pipe class, but about half of satellites launched in 1997 were bent-pipe satellites. The capacity of these other types of satellites to perform their diverse activities depends in a complicated way on additional technical features beyond bandwidth, most notably power.[22] Table 2 shows that trends in power and bandwidth since the mid-1990s are roughly the same, however. We therefore assume that the capacity cost trends in the bent-pipe segment are a reasonable proxy for all satellites; accordingly, the value of production for all satellites is deflated by the unit cost of bent-pipe capacity index.[23]

All told, our price index for satellites falls 14.7 percent per year from 1963 to 2009 and is shown in Appendix table B.3. This contrasts starkly with the BLS producer price index for "space satellite communication and related equipment" published from 1986 to 2000, which edged down 0.6 percent per year.

2.3. Other Radio Station Equipment

The remaining types of wireless equipment and systems are a highly heterogeneous grouping that includes fixed stations (other than cellular base stations), mobile stations (other than cell phones), and the earth stations that communicate with satellites. An example of a fixed station is the microwave transmitters that handle transmission over long distances and uneven terrain, and to "backhaul" data from cellular towers to the core wireline network. A mobile station example is the legacy non-cellular mobile radio systems used by first responders which usually consist of a centrally located antenna and multiple remotely operated radio wave receivers (e.g. mounted on cars). The first such system was introduced in 1946. In addition to equipment for radiocommunication between individuals, this basket includes radiodetermination equipment, such as navigational, telemetry, and meteorological equipment, and even devices to control equipment from a distance using radio wave communication (telecommand).[24]

Besides Flamm's telephone transmission equipment index, which included microwave equipment, research and data in this area are very scarce. Gordon (1990) notes one report indicating satellite earth station prices fell 54 percent per year from 1975 to 1978.[25] Our own analysis of detailed quarterly information from the NPD Group on GPS navigation equipment yielded a price index that fell 12.2 percent per year, on average, from 2002 to 2006. A BLS PPI for radio station type equipment, available for a few years in the early 2000s, shows little change.

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[22] Conversation with Andrea Maleter, Futron Corp., September 21, 2006.

[23] An alternative approach employing the PPI containing satellite systems for the non-bent-pipe portion yields a satellite price index which falls 11.5 percent per year rather than 15 percent from 1987 to 2005. Because this PPI also contains cellular and other wireless systems (including cell phones), we conclude that our bent-pipe price index is a closer match.

[24] Manufacturing of navigational *instruments* (e.g. for measurement of speed, pitch and yaw) is found in NAICS 3345.

[25] Cooper, R. B., Jr., "Get the Johnny Carson show before it's bleeped." *TV Guide*, October 21, 1978, pp. 33-36.

Owing the paucity of direct information, we use proxies for our price index for radio station equipment.[26] For the early period, Flamm's telephone transmission index is used.[27] The average rate of change in this index is then used from 1978 to 1985; thereafter, a hybrid index that combines the PPI for the broad aggregate, "communications systems and equipment (except broadcast)," which includes microwave equipment and space satellites, and our price index for cellular base station equipment is used. (Cellular base station equipment is, of course, also a radio-wave product whose function on a network is similar to non-cellular types of base station equipment.) This results in a price index that declines 7.4 percent per year from 1985 to 2009.

3. New Results for Wireline Product Prices

Wireline products have experienced dramatic change as well, both with the spread of the Internet and use of fiber optics and multiplexing technologies. We compile six switching and transmission equipment price indexes and five terminal equipment price indexes that, together with the Flamm/Gordon work discussed earlier, collectively span the 1947 to 2009 period. Our new series and our updating significantly expand the scope and number of products previously included in research price indexes for wireline communications equipment.

3.1. Data Networking Equipment

As the Internet grew in popularity in the 1990s, spending on computer networking equipment expanded dramatically. Doms and Forman (2005) developed prices for the routers and switches used by network service providers and in the local area networks (LAN) within offices and homes. Since the completion of the Doms and Forman study, the number of marketed networking equipment products has increased significantly.[28] Some of the new devices handle wireless traffic (WLAN), while others are customized for storage area networks (SAN) or are specialized for network security or application acceleration.

The Doms-Forman price index, when originally implemented by the Federal Reserve (see Corrado 2001, p. 8), spanned the years 1992 to 2000. Reflecting ongoing research by the authors of this paper, the Federal Reserve updates this index each year, and the results are published in

[26] We concur with Gordon (2006) that "attempting to generalize cautiously from related goods or practical reasoning" when direct observation of the relevant prices is unavailable is preferable to assuming zero bias in existing measures.

[27] In discussing the technological history of transmission, Flamm (1989) comments "the expansion of network capacity was dominated … by microwave radio from the late 1950s to the late 1970s," and data presented in his paper shows that approximately 60 percent of transmission, by voice circuit miles, was still carried by microwave radio in 1980. The last two years of the index are not used because developments in phone networks dominate changes for these years.

[28] For example Cisco's 2009 catalog exceeds 300 pages with more than 200 *types* of products, whereas the 1998 catalog contained 45 types of products.

its regular report on the annual revision to industrial production and capacity utilization (Corrado 2003; Bayard and Morin 2004; Bayard and Gilbert 2006; Gilbert and Bayard 2005, 2008; Gilbert and Otoo 2007; Hall 2009).[29] The current Byrne-Corrado/Federal Reserve index consists mainly of *quarterly* data and covers LAN, WAN, WLAN, SAN, and network security types of equipment. The data are from Dell'Oro and Gartner.[30] Fisher matched-model price indexes are constructed using Dell'Oro data for Ethernet switches (11 items), wireless networking equipment (19 items), and storage area networking equipment (16 items). For dedicated security devices (VPN/firewall equipment), we use data from Gartner (3 items), and for routers, we use data from Dell'Oro (15 items, with further controls for technology, 2001-2009), augmented by similar Gartner data for 2000-2001.[31] The extended price index for data networking equipment falls 11.6 percent per year from 2000 to 2009, after having fallen 15.9 percent annually from 1992 to 2000.[32]

The value of production and spending before 1992 is very small. Nonetheless, we still need a price index from the dawn of this industry in 1986. Because early data networking devices were essentially special purpose computers, the BEA's computer and peripheral equipment price index is used. All told, our price index for data networking declines 12.9 percent per year, on average, from 1986 to 2009 and 13.5 percent per year from 1995 on. These rates are 10.5 percentage points faster than the closest matching producer price index from the BLS (Appendix table B.4).

3.2. Enterprise Voice Networking Equipment

Besides computers, the terminal equipment used in the business sector (telephones, answering and fax machines, etc.) is connected by networking equipment, and here, too, systems have undergone rapid change in recent years. Private branch exchange (PBX) systems relying on time-division multiplexing (TDM) and key telephone systems (KTS) have been supplanted by voice-over-internet-protocol (VoIP) PBX systems, which have much of the flexible programming capability found on computer networks. Indeed, the backbone of these systems is

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[29] Three other quarterly-frequency indexes are published regularly by the Federal Reserve: enterprise and home voice equipment; transmission, local loop, and legacy central office equipment; and wireless (cellular) networking equipment. (See http://www.federalreserve.gov/releases/g17/download.htm.)

[30] Data on application acceleration devices are not available.

[31] Within data networking product categories, observations are distinguished by function and technological generation, and in most cases within these subgroups are calculated on a per-port basis. (See Appendix A.)

[32] Note that the original Federal Reserve index was a bias-adjusted index of Gartner's then available data for LAN equipment. The source of the adjustment was Doms and Forman (2005), who estimated hedonic regressions using detailed item price data from Cisco catalogs. The matched-model indexes against which the hedonic results were gauged used relatively coarse price and quantity data. Because we currently have much more detailed, quarterly data on Ethernet switches and routers, we do not adjust our Fisher matched-model results. In addition, we have no basis for adjusting the new WLAN, SAN, and network security components.

typically a server with specialized software and additional electronic components.

Our price index for enterprise voice equipment including VoIP is developed from detailed product data from two sources. First, we update the annual Gartner data used by Doms (2005). His data were from 1994 to 2000 and included prices and quantities of PBX/KTS systems categorized in six groups according to the number of lines handled by the system. In our more recent data, systems are further categorized by stage of technology representing the transition from traditional PBX lines to IP-based lines and extend to the year 2004. Aggregating the full dataset yields a price index that falls 4.7 percent (annual rate) from 1994 to 2004. Prices of lines employing IP technology have fallen at a faster rate than prices for traditional PBX lines (about 2 percentage points more per year, on average), and thus the rate of decline for this category accelerates a bit in more recent years as the IP-based market has grown.

Our second source is quarterly data from Dell'Oro for revenue and price per line for six system types further distinguished by analog/digital or IP lines from 2001 to 2009; with this source, we also are able to include replacement IP phones. A Fisher matched-model price index using these data falls at a somewhat faster rate than the index derived from the less detailed annual data for the period for which the two indexes overlap. Our final index links the Dell'Oro-based index from its earliest availability to the Gartner-based index back to 1994 and falls 4.5 percent per year; see Appendix table B.5. Before 1994, we use the price index for central office switching equipment, discussed in section 3.3.1 below.

3.3. Public Telephone Switching and Transmission

During the build out of the public switched telephone network (PSTN) in the 1950s and 1960s investment in telephone equipment grew rapidly. Flamm (1989) and Gordon (1990) assembled evidence suggesting that quality-adjusted prices for central office switches and transmission equipment fell dramatically during the 1950s and early 1960s but that commercialization of leading-edge wireline technology languished for an extensive period after then.[33] The Flamm/Gordon indexes are available through the early 1980s.

3.3.1. Central office switching. Digital circuit switch prices were later studied by Grimm (1996, 1997) and Currie (2005), who assembled data on the equipment bought by large telephone

[33] Flamm and Gordon emphasize the relatively slow rate of diffusion of electronic technology in the telephone industry compared with the computer industry in their analysis. They observe that, although the technology of switching was no longer electromechanical after 1965, the actual transition to electronic switches did not begin in earnest until the introduction of *digital* systems in the mid- to late-1970s, which drastically lowered costs. Flamm also notes that the transition from copper wire and/or microwave relay to *fiber optic* cable for long-haul transmission did not really take hold until the 1980s although the technology was available much earlier.

companies based on their filings to the FCC. Although the approach and results of these studies are similar, we refer to the one by Currie because its dataset is more comprehensive and includes more years.

Using hedonic techniques, Currie estimated quality-adjusted price change for digital circuit switching equipment from 1980 through the late 1990s and found that, after rising in the early 1980s, prices dropped 7 percent annually from 1985 to 1995. We use these results to update the Flamm/Gordon price index for central office equipment. Following Grimm, we employ a smoothed version of an adjacent-years index, and the resulting measure covers the years 1982 to 1996.[34]

To extend coverage, we develop a Fisher price index based on U.S. sales and unit costs per line provided by Gartner for three types of PSTN switching equipment (digital local line, ISDN B-channel, and trunk) from 1993 to 2002. This index falls 8.7 percent per year, on average, but falls markedly faster in 2001 and 2002. We extend the Flamm/Gordon/Currie central office equipment results to 2002 using this index. Production of and spending on these trailing-edge switches has nearly vanished since 2002, but we do need a price index, and we employ the average rate of decline in the Gartner-based index through 2009.[35] The final index and components are shown in Appendix table B.6.

3.3.2. Long-haul transmission equipment. Flamm's price index for transmission equipment is based on the incremental costs of new capacity added to the network, and, as reported by Gordon, the index is available from 1952 to 1980. Similar to prices for switches for this period, the price index for transmission equipment experiences a reversal of an earlier dramatic downtrend between 1969 and 1978, but then begins to fall again in the final two years. Gordon extended the Flamm index for transmission equipment to 1984 using a price index for switching equipment

Modern long-distance signal transmission is mainly performed by fiber optic equipment, which dramatically lowers the cost of transmission compared with electrical-only systems.[36] For some applications, other types of long-haul transmission equipment are used. Prior to the

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[34] Specifically, a weighted average of three years of relative prices is used, with weights of 0.6 on the current year, 0.3 on the previous year, and 0.1 on two years prior. Currie's results for 1997 and 1998 are not used because his sample for those years is extremely thin.

[35] A Gartner analyst specializing in this market estimated that the line cost for this technology was about $35 in 2006. This figure would imply a unit cost decline of 22 percent per year.

[36] A fiber optic circuit is a path for data transmission in which light acts as the information carrier. Depending upon fiber type, the distance-bandwidth product of fiber is tens to thousands of times larger than that of electrical transmission, but an electro-optic modulator and an opto-electric demodulator are required to convert electrical signals into light and back again at the transmit and receive ends of the link, respectively. (See "http://encyclopedia2.thefreedictionary.com/Fiber-optic+circuit" accessed May 24, 2011.)

emergence of fiber optic systems, copper wire systems were the most common wireline approach and some copper systems remain in use.[37]

The transition to fiber optic cable for long-haul transmission began in the 1980s, but authoritative data on spending (as well as prices) for fiber optic vs. other long-haul transmission equipment is unavailable. Flamm reports that spending on fiber optics came to represent a substantial share of total new investment in transmission equipment by the mid-1980s (from 6 percent in 1978 to between 40 and 50 percent from 1984 to 1988), while our own estimates for the mid-1980s are somewhat lower (about 30 percent). On the price side, the earliest estimates are those by Doms (2005), who found that prices of fiber optic equipment fell more than 12 percent per year from 1994 to 2001. Using data for the more recent period from the Dell'Oro Group, we find that prices fell at a similar rate from 2001 to 2009, namely, 12.2 percent per year.

We construct price indexes for both fiber optic and other (primarily copper wire) types of long-haul transmission equipment as follows: Each series begins with Flamm's transmission equipment price index, but different data are used to extend the two series beyond 1990. For the fiber optic index, we use the results of Doms' research extended to 2009 based on the Dell'Oro Group data. Following Gordon, we bridge this index to the end of the Flamm index using a price index for central office equipment. The price index for other long-haul transmission equipment follows the same pattern (Flamm, central office) until 1990, after which it is based on a weighted average of the Flamm central office index (one-third weight) and BLS PPIs (two-thirds weight).[38] The indexes are shown in Appendix table B.7.

3.3.3. Local loop transmission equipment. The transmission equipment on the "local loops" connecting customer premises to central offices has not been the subject of recent price studies. This component was included in the work of Flamm and Gordon, but to our knowledge the subject has remained unexamined since then. This component of the public network deserves significant attention, however, as service providers have been actively working to solve the "last mile" problem—the lack of high-speed transmission in the local loop—in recent years.

Besides equipment used to manage recent efforts to put fiber "in the loop," local loop equipment also includes equipment designed to boost signals and extend the coverage of central offices, to introduce multiplexing and carry multiple signals on the same twisted pair copper wire, and to allow for various wireless "last mile" solutions. We build a spending-weighted Fisher index of unit costs for 12 different kinds of local loop equipment and find that it falls at an average rate of 16.4 percent per year from 1993 to 2009; the index is based on quarterly data

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[37] Microwave systems were discussed previously as part of radio station equipment.
[38] The PPIs covering transmission equipment start in 1990.

from Dell'Oro beginning in 1998 and extended back to 1993 with annual data from Gartner. We extend the index back using the same approach as used for long-haul transmission.

3.4. Terminal Equipment

Communication usually begins or ends with equipment such as telephones and modems that serve as entry points to communications networks. In practice, a wide array of devices can serve as terminals, and we examine price trends for four device types that have rich data available for the construction of price indexes—telephone handsets, fax machines, messaging machines, and modems. The four terminal types account for a substantial share of total terminal spending, and prices for these four types can be used to represent the more esoteric types of equipment in this product class (e.g., call center equipment, teleconferencing equipment).

3.4.1. Plain old telephones. Handsets used in the so-called Plain Old Telephone System (POTS) are rather staid devices compared with the mobile devices of today, but our analysis finds that prices for telephones fell rapidly following the breakup of AT&T and that controlling for phone characteristics is quite important. We build a price index for POTS handsets using data on unit production costs from two Census Bureau publications and information on wholesale prices reported by the Telecommunications Industry Association (TIA) in its annual industry compendium. The TIA reports information gathered by the Consumer Electronic Association (CEA). We also employ more granular data from CEA and from Dell'Oro to gauge the ability of the TIA data to account for quality change.

The Census of Manufactures reported the value of production and unit output of telephones for 1963, 1967, 1972, 1974 and 1975, including detail on dial and pushbutton phones. The Current Industrial Report for communications equipment shows annual unit values from 1975 to 1987, also with separate dial and pushbutton series. An aggregate price index for telephones constructed from this information rises 3.3 percent per year from 1963 to 1987.

TIA reports average telephone prices and sales for corded and for cordless phones, with consistent data available from 1988 on. An aggregate index of these unit values is about flat from 1988 to 1991; it then falls 9 percent per year from 1991 to 2005 but shows little change thereafter.

These basic data raise several questions: What do we make of these shifts in price change for telephones? How do we determine if we have sufficient controls for quality change (with both the Census and TIA data)? How can we knit together the sources for the earlier and later periods? Consider first the period from Western Electric's introduction of the Princess phone in the 1950s to the company's cessation of production of *home* telephones in 1986:[39] The market dynamics seem to fall in two phases consistent with the findings of Flamm and Gordon for central office telephone and transmission equipment. The market of the 1950s, 1960s, and early 1970s witnessed a good bit of product innovation (the Princess phone was quickly followed by the Trimline and Touchtone phones). From 1974 to the early 1980s, a flurry of new designs was released (the Design Line phones), and cordless phones and phones with special features such as caller ID were first marketed in the early 1980s. By 1988, the first year of our sales data for cordless vs. corded phones, cordless phones were about two-thirds of total wholesale sales—and virtually all cordless telephones sold in the United States were imports.

Besides caller ID, notable improvements in telephones have occurred since the early 1980s—new frequency bands, more channels, digital signal technologies, multiple handsets and lines, improved battery life, etc.—and suggest controls beyond corded vs. cordless are needed for measuring price change. To address this concern, we appeal to the more detailed data gathered by the CEA. The CEA provides one of the most comprehensive sources for information on telephone prices, covering 14 varieties of telephones from 1998 to 2006. The dataset distinguishes phones by corded versus cordless, feature versus basic, transmission frequency, signal type, and number of lines. A Fisher matched-model price index of price change built from these data declines 17 percent per year, 8.6 percentage points faster than the index that only controls for cordless versus corded phones.

The analysis of the CEA data and the observation that unit costs began to fall sharply in the 1990s suggests that competition was lowering unit costs at the same time that product innovation rendered simple distinctions in variety insufficient to capture quality change in telephones. But the CEA index only covers the years 1998 to 2006. We have no basis for using it to adjust the Census indexes before the introduction of feature phones in the early 1980s. Nor do we believe the large bias in the TIA index relative to the CEA index (8-1/2 percentage points) is representative of all non-overlap years since the early 1980s. The market for cordless phones was developing and expanding at an especially rapid rate in the late 1990s and early 2000s (our overlap period), in part as a result from competition from cell phones.

To build a price index for telephone handsets, we start with an index based on Census unit values from 1963 to 1987 and the TIA average price information thereafter. The estimated bias in the TIA average price is applied gradually from 1981 to 1990 and in full thereafter except, of course, from 1998 to 2006, when the CEA index is used. All told, the available information suggests that telephone prices fell 4.4 percent per year from 1963 to 2009 (Appendix table B-8). The pattern of price change is notably different before and after the breakup of AT&T,

[39] Business telephones continued to be produced, however.

however. Prices rose about 4.4 percent per year to 1985, but have declined 11.9 percent per year, on average, since then.

3.4.2. Fax machines. Though highly efficient fax machines are now taken for granted, Gordon (1990, p. 406) notes "in the 1980s, the most dramatic new product innovations have been the cellular telephone and the fax machine." We find evidence that prices have indeed fallen quickly.[40] Revenue and average price information on business fax machines are available in TIA reports from 1987 to 1996 and show average prices declining 8.9 percent. Unfortunately, from 1997 onward, the only available information is for sales to the home market, which only accounted for about 25 percent of total sales in 1996, owing in part to prices for business and home markets being at very different levels. Prices in the home market fell 2.2 percentage points faster than prices for business machines in an overlap period (1990-1996) and dropped 9.4 percent per year from 1990 to 2009 as a whole.

Data from Gartner show that prices differ markedly across technologies, however. When we use prices and revenues for four types of fax machine (direct thermal, inkjet, page, and thermal transfer) from 1996 to 2006, we find that a Fisher matched-model index declines 11.7 percent, 2.0 percentage points faster than the TIA average price.[41] Unfortunately, we are not able to control for transmission speed or other technical features. For our index, we use the Gartner-based index when available and extend it using the bias-adjusted TIA price. All told, our fax price index falls 11.1 percent from 1987 to 2009.

3.4.3. Answering machines. Average prices for answering machines, as reported by TIA, fell 2.1 percent per year from 1987 to 2009. Remarkably, using data from CEA to construct a matched-model index, we find that constant-quality prices fell *18.9 percent* per year from 1998 to 2006. Detailed CEA prices for 11 device types distinguish stand-alone answering machines from those with integrated corded or cordless phone, and within the integrated cordless phone group, frequency band used and whether the signal is analog, digital, or digital spread spectrum.[42] In part, the difference between the behavior of the average price series and the price index is explained by a shift from low-cost stand-alone devices to those with integrated phones.[43] We employ the CEA index when available and extrapolate back to 1987 using our telephone index.

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[40] Gordon noted one estimate, from *Forbes* magazine, that prices fell 15 percent per year from 1985 to 1988.
[41] Following Census practice, multi-function printers with fax capability are not counted as communications equipment, but rather as computer peripherals.
[42] We follow TIA practice of classifying combination answering machine/ phone units as answering machines.
[43] This period marked a shift from cassette tape to solid-state memory and a general integration with the electronics of the attached telephone. In addition, a massive shift in demand in the 1980s surely drove costs down as well. See Wohleber (2000) for further discussion.

We apply a bias adjustment of the difference between average prices and the CEA-based index to the TIA price series for 1987 to 1997. Because the product had not fully switched to solid-state electronics in the earlier period, we phase in the bias adjustment gradually. From 2007 to 2009, we employ a price index for enterprise telephones, which embodied advances in messaging technology, built using Dell'Oro data. Our final answering machine index falls 9.5 percent per year from 1987 to 2009. The price indexes for fax and answering machines are shown in Appendix table B.9. Commercial fax machines and answering machines were in use in the early 1960s at the beginning of the period we study and first appear in our production and spending weights in 1974. We extend the fax machine and answering machine price indexes back to that date using the telephone index.

3.4.4. Modems. We use new source data to update and extend the work by Doms (2005) on analog and broadband modem prices. Doms estimated constant-quality price declines averaging 14.9 percent per year for modems overall from 1994 to 2000. We use his price index for analog modems based on highly detailed data and which falls 16.2 percent per year from 1989 to 1998. We supplement that analysis with unit values for four frequency classes of analog modems from the CIR from 1976 to 1991, yielding a Fisher matched-model price index which falls 14.4 percent per year. Before 1976 and after 1998, we extend the price index for analog modems using the BEA price index for computers.[44]

For the more recent technology, Dell'Oro provides prices for 8 types of broadband modems, including breakdowns within cable, DSL, and optical customer premises equipment. The Fisher matched-model price index we construct using these data falls 20.8 percent per year. We use industry reports on market share to construct a weight for broadband modems and aggregate the analog and broadband price indexes. All told, our price index for modems falls 15.0 percent per year from 1963 to 2009, with a significant acceleration in the mid-1990s (Appendix table B.11). These price drops, along with the marketing of internet browsing technology, contributed to a surge in computer spending at that time.

[44] The first commercial modem reportedly was marketed in 1962. The basis for using computer prices as a proxy for modem prices is as follows: Based on results due to Phister (1979), and others, Flamm (1989) concluded that costs for data communications fell by about 20 percent per year from 1955 to 1975 and attributed much of that advance to interface technology, which has more to do with computer-based electronics than with switching and transmission. Doms (2005) examined model-level prices of analog (dial-up) modems and average prices for cable modems (grouped by speed) during the 1990s and found that modem prices fell about as fast as the BEA's quality-adjusted price index for computers. This diverse evidence suggests that computer prices are a reasonable proxy for modem prices when direct price measures are unavailable.

4. Other Communication Equipment Prices

The remaining primary products for the Communications Equipment Manufacturing industry (NAICS 3342) do not conduct two-way communication, except intercom systems. The largest component of this group is FM and AM radio and television broadcast transmission equipment (including cable TV) and related equipment for both audio (microphones, amplifiers, control consoles) and video (television cameras, tape recorders, character generators) production. We have little independent information on these products, but it is likely they exploit some of the same advances in solid state circuitry and radio wave transmission that lie behind the rapid quality improvements found for the products studied in this paper. As an example, Gordon (1990) remarked the dramatic and continual evolution of television camera technology from the 1950s to the 1980s. Technology has continued to charge ahead since then with the emergence of the fully digital camera. Gordon also notes that a substantial share of the value of production for this group is transmission equipment, for which there is existing price research, discussed above.

Even though this suggests we have some basis for using our results to represent this product group, we do not pursue this avenue in this paper. Rather we employ PPIs for all remaining products of the industry. Besides radio and TV broadcasting equipment, NAICS 3342 also includes intercom systems, signals (e.g. highway, pedestrian, railway, traffic), and fire detection and alarm systems. Appendix table B.11 reports the PPI indexes needed for complete coverage of NAICS 3342.

5. Product Composition of Production and Spending

To construct aggregate prices, we need estimates of the value of production and spending for all components of the scheme in table 1. We compile production measures from 1963 to 2009 for each component by careful use of detailed data from the Census Bureau's now defunct Current Industrial Report series on telecommunications, supplemented by other sources (including the Census of Manufactures) when needed. For some products we construct spending estimates using production plus Census net trade, but often we must rely on private data sources to obtain total spending.

The results for the total and broad categories are shown in figure 3.[45] Cutting through economic downturns, the top panel in figure shows that total spending for communications equipment climbed steadily until 2000 and that production tracked domestic demand fairly

[45] Figures 3, 4, and 5 follow the list of references to this paper.

closely until 2002. Although total spending resumed an expansion path in 2003, the trajectories of the two major categories of communications equipment (shown in bottom two panels) diverge. Spending on *wireless* communications equipment continued its upward trend after 2002 whereas *wireline* demand remained at a low level. Meanwhile, the production of wireline equipment fell more than an order of magnitude between 1999 and 2009.

Cellular phones and related network equipment (figure 4, top panel) emerged as an important component of communications equipment spending in the 1990s, comprising more than one-quarter of total spending by 2009. The divergence of production and spending is dramatic for this product class, however, as offshoring of cell phone manufacturing began in earnest with the 2001 economic downturn. Indeed, the relatively large value for cell phone production in 2005 likely embodied a much lower share of domestic value added than it did just a few years earlier. Official value added statistics are not granular enough to provide data on cell phones and cell phone components, but a case study put together from press reports, "The last great American cell phone plant?" and shown in the box on the following page confirms the conjecture. The box tells the story of Nokia's manufacturing operations in Texas, which ceased in 2007 but was the world's largest cell phone manufacturing plant in 1999, *exporting* cell phones to Mexico and South America. After the tech crash and in response to changing incentives, operations went through several incarnations as the company adjusted its supply chain and moved operations abroad. Offshoring of Cisco's outsourced manufacturing reportedly is behind the near evaporation of U.S. production of data networking equipment (the middle panel) as well.[46]

By contrast, domestic production of satellites and related equipment (figure 5 top panel) has remained relatively robust. And production and spending for central office telephone switching equipment (the middle panel) has all but dried up because other products (wireless and data networking equipment) have absorbed its functions. All told, in nominal terms, overall spending on communication equipment in the United States leveled off in the 2000s following decades of expansion. Communications equipment is, of course, a key component of the capital needed to develop a communications network. Because the Internet and cellular networks expanded from next to nothing in 1985 to maturely penetrated infrastructures by 2005, a leveling in investment following a period of capacity building is to be expected until, that is, new technologies requiring new investments (4G equipment, for example) come along.

[46] Information on domestic production of data networking equipment is now only available with the publication of the Census of Manufactures every five years.

Box

The last great American cell phone plant?

1991

Nokia begins its first U.S. manufacturing operation at the Diplomacy Road/ Centreport facility in Fort Worth.

1995

Nokia begins operations at second Fort Worth plant in the Alliance industrial park.

1999

The Alliance facility produces "1 million phones every 9 days" or perhaps $5B in yearly shipments and 10 percent of world production (assuming year-round weekday operation and the TIA-reported 1999 average wholesale price of $180).

Nokia and component suppliers occupy about 1 million square feet at the facility, making it "the largest mobile phone manufacturing operation in the world." The suppliers, including makers of plastic injection molds and metalized protectants, occupy half of the space.

"If a consumer buys a Nokia phone in the United States, it came from Fort Worth."

Employment peaks at 3,500.

2001

Nokia lays off 800 workers. Diplomacy Road/Centreport manufacturing is eliminated.

Some U.S. mobile phone manufacturing moved to Mexico and Korea.

"The Alliance factory will be focused more on engineering support for the Americas and fulfillment for the U.S. market, but will continue manufacturing mobile phones."

2002

Nokia lays off 625 workers.

2005

"Nokia will transition its high-volume, final assembly processes to its other production facilities and transform the Alliance facility into a customization and logistics center." 350 workers laid off, reducing payroll to 950.

2007

Nokia ceases operations in "late spring."

At the end, "the Alliance facility focused on short lead time logistics for customers requiring three days or less turnaround."

U.S. market is completely supplied by facilities in Mexico and Brazil.

In November, Nokia sells the plant back to the developer of the industrial park.

SOURCES. Nokia company press releases and Fort Worth newspapers.

6. Results for Aggregate and Major Component Prices

Our aggregates are expressed as spending and production price indexes for total, telecom, wireless, and wireline communications equipment for which changes are shown in table 3.[47] Our main findings are that prices for communications equipment fell, on balance, over the period for which we estimate new price indexes (1963 to 2009) and that the absolute drops are especially large after 1995. In relative terms, prices for communication equipment began their steep drop in the mid-1980s, however.

The total production index (line 1, table 3) is nearly comparable in scope with the BLS PPI for the communications equipment manufacturing industry (NAICS 3342) and somewhat close to the composition and coverage of BEA's communication investment price index prior to the import penetration that took hold in the 2000s.[48] Our spending index is closer to the BEA index in this regard, but other notable differences remain, e.g., the inclusion of government and household spending in ours and of private investment in another asset type (search and detection, navigation and guidance systems and equipment) in BEA's, as well as other conceptual issues. Nonetheless we proceed with comparing our spending index to the BEA index because we have no other benchmark for the first 22 years that we study.[49]

From 1985 on, our total production index falls 9.8 percent per year, whereas the BLS PPI edges down .2 percent per year (line 32, table 3).[50] Our spending index, which begins in 1987, also drops notably during this period (9.3 percent annually) whereas, as previously shown in figure 1 and also on table 3 (line 33), the BEA's price index for private investment in communications equipment as of May 2010 drops much more modestly.[51] The relatively rapid decease in the Byrne-Corrado spending index is led by steep declines in the wireless equipment component, which falls 12.9 percent per year from 1987 to 2009.

Figure 6 adds changes in a Byrne-Corrado aggregate price index to the indexes shown previously in figure 1. We believe our post-1985 results add a new dimension to the existing record of ICT investment price change. Figure 6 also shows a more recent vintage (May 2015) of BEA's communication equipment deflator. We understand that, as of the July 2011 revision

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[47] A spreadsheet with price indexes and nominal production/spending data used to create weights for the aggregates and major components shown in table 4 is available from the authors upon request.

[48] The production index shown in table 3 does not reflect prices for secondary products and miscellaneous receipts, whereas the BLS index covers these components.

[49] A more exact construction of an investment price index based on all product level indexes produced in this paper is left for later work.

[50] The change for the PPI is from 1986, the first full year for which a PPI is available.

[51] This result is not surprising in light of section 1's discussion, which noted that although BEA has incorporated selected research price indexes in its communication equipment deflator, it constructs its investment prices mainly from BLS price indexes for domestically produced and imported investment goods.

Table 3

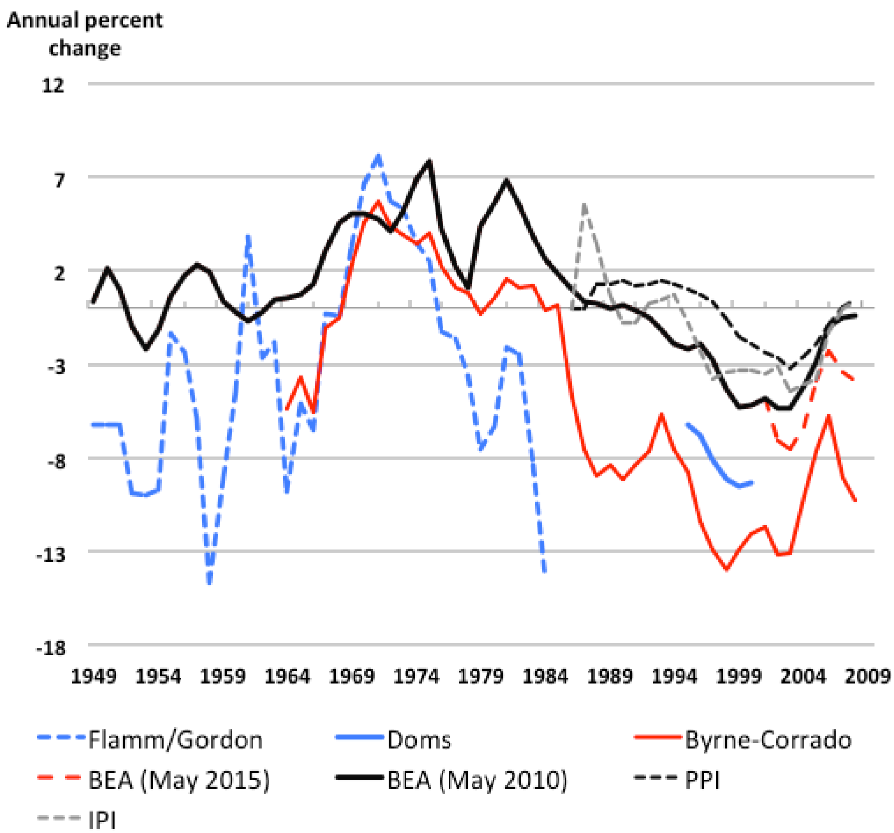
Communication Equipment Price Change

(average annual percent change)

	1963 to 2009 (1)	1963 to 1985 (2)	1985 to 2009 (3)	1985 to 1995 (4)	1995 to 2000 (5)	2000 to 2005 (6)	2005 to 2009 (7)
1. **Production (NAICS 3342)**	-4.8	1.0	-9.8	-7.8	-12.5	-11.2	-9.4
2. **Spending**			-9.3	-7.6	-11.3	-11.1	-9.3
3. **Telecom equipment (P)**	-5.7	.6	-11.1	-9.0	-13.7	-12.7	-11.1
4. **Telecom equipment (S)**			-11.3	-10.0	-13.4	-13.4	-11.0
5. **Wireline (P)**	-5.6	.4	-9.8	-7.4	-12.2	-13.3	-8.4
6. **Wireline (S)**			-10.2	-8.6	-12.3	-13.4	-8.5
7. Switching (P)	-6.2	-1.2	-9.7	-6.8	-13.4	-12.7	-8.4
8. Switching (S)			-9.4	-7.7	-11.2	-12.2	-8.8
9. ** Central Office*	-5.5	-1.2	-8.7	-6.2	-7.4	-14.5	-8.7
10. ** Enterprise Voice*	-3.3	-1.2	-4.8	-4.5	-6.0	-5.7	-2.8
11. ** Data Networking*			-12.9	-11.9	-16.7	-12.7	-10.3
12. Transmission (P)	-4.6	.7	-7.6	-4.0	-6.9	-13.8	-9.0
13. Transmission (S)			-8.2	-4.3	-7.7	-14.1	-9.9
14. ** Fiber*			-10.3	-4.8	-9.6	-19.7	-12.3
15. ** Local Loop*			-12.7	-6.2	-13.9	-22.6	-13.7
16. ** Other Line*			-4.7	-2.8	-4.3	-8.9	-4.6
17. Terminals (P)	-6.3	3.2	-14.3	-14.1	-17.0	-18.4	-6.0
18. Terminals (S)			-12.6	-12.6	-16.8	-15.3	-6.5
19. ** Telephones*	-6.0	4.3	-14.0	-10.6	-20.2	-16.1	-11.7
20. ** Fax*	-4.5	4.3	-11.6	-12.9	-14.6	-6.4	-11.0
21. ** Modem*	-14.6	-11.9	-17.8	-17.0	-19.3	-25.1	-8.1
22. ** Messaging*	-3.5	4.3	-10.2	-9.2	-14.6	-14.2	-1.7
23. **Wireless (P)**	-6.4	1.3	-12.6	-11.1	-15.9	-12.4	-12.1
24. **Wireless (S)**			-12.9	-12.3	-15.6	-13.4	-12.7
25. Cell Systems (P)			-17.8	-17.7	-18.8	-16.2	-18.5
26. Cell Systems (S)			-16.2	-17.0	-18.9	-16.7	-14.4
27. ** Cell Phone*			-17.6	-17.8	-19.3	-18.9	-13.4
28. ** Cell Networking*			-16.1	-15.3	-18.2	-13.0	-19.5
29. * Satellites	-14.4	-14.8	-14.7	-19.0	-14.6	-8.8	-10.4
30. Other Wireless	-3.8	1.9	-8.1	-7.1	-9.8	-6.7	-9.9
31. **Broadcast/other equipment (P,S)**	2.0	3.7	.6	.9	.0	.3	.9
Memos:							
32. BLS PPI (NAICS 3342)			-.2	1.2	-.6	-2.6	.1
33. BEA investment, May 2010	.8	4.0	-2.2	-.6	-3.7	-4.7	-.6
34. BEA investment, May 2015	.3	4.0	-3.0	-.6	-3.7	-6.1	-3.6

Notes--The "P" and "S" indicate aggregation of starred items using production and spending weights, respectively. Figures for spending indexes in columns 3 and 4 are calculated beginning 1987 and for the data networking index (line 11) and PPI index (line 32) beginning in 1986.

Figure 6. Price Indexes for Communications Equipment including Byrne-Corrado, 1949 to 2008



SOURCES. The Byrne-Corrado index is the production index to 1987 and the spending index thereafter. For other indexes, see sources for figure 1.
NOTE. Series plotted are 3-term moving averages of annual percent changes.

of the NIPAs, BEA began to use the Federal Reserve's price indexes for cellular networking equipment, telephone switching equipment, and wireline transmission equipment in their investment price index for communications equipment from 2002 on.[52] The Federal Reserve's price indexes are based on the research reported in this paper. The more current BEA index drops 5.1 percent per year from 2002 to 2009, whereas the earlier vintage fell 2.2 percent per year (3 percentage points less).

The utility of the research reported in this paper reflects not only the currency of its work on cellular systems, enterprise switching (VoIP), and local transmissions equipment, but also its

[52] The BEA originally introduced this change in the July 2010 revision from 2005 on. Recall that the BEA had previously introduced Federal Reserve's data networking price index.

rewriting of the entire historical record since 1963 to include satellites, terminal equipment, and the research of Flamm, Gordon, and Currie. Prior to the mid-1980s, wireless systems consisted of satellites and other radio wave equipment, and we estimate that prices for these systems edged up only 1.3 percent per year from 1963 to 1985 (line 23, column 2, table 3). Prices for these products are to our knowledge not included in official statistics for this period. We also find that prices for wireline products posted small increases prior to 1985 (.4 percent per year, line 5), with the net result that overall telecom equipment price change from 1963 to 1985 increased just .6 percentage points per year.

We break our main results into the pre- and post-1985 period because the mid-1980s are a marker for several major events in communications: the breakup of AT&T, the invention of routing technology, the emergence of fiber optics, and the introduction of commercial cell phone service. Comparing column 2 with column 4 at the product level, the impact of these events on price change was both notable and immediate in terminals, switching, transmission and wireless. By the mid-1990s, prices for *overall* telecom equipment were declining very rapidly, falling more than 13 percent annually through 2005 and more than 11 annually thereafter. This relatively consistent pace of change is all the more remarkable considering the gradual disinflation of the U.S. economy.

7. Conclusion

To complete the story of technological advances in modern communications equipment, this paper has introduced new price indexes for cellular phones and related equipment and for satellites and related equipment from the dawn of each industry. The new indexes suggest that the pace of technological innovation in the wireless area has been rapid, and that previous estimates of price change for wireless components have been a source of bias in measures of price change for communication equipment. We also examined the introduction of IP technology on prices of enterprise telephony systems since 1999 and developed new price measures for the types of local transmission equipment installed in recent years. Last, we revisited terminal equipment, which proved to have a remarkable amount of unexploited data that yielded surprisingly rapid price declines in rather staid devices like telephones and answering machines. We also obtained new results for fax machines, remarkable devices that previously received little attention, and confirmed that modem technology has continued to advance rapidly in recent years.

Our reconsideration of price measures for communications systems that predate the IT revolution of the 1990s yielded interesting results in several ways: A major finding is that prices for communications products fell over the 46-year period we study, whereas existing estimates record a rise (see again table 3, column 1). The introduction of the new satellite price index and the incorporation of the early work of Ken Flamm are important contributors to our results for the first 22 years. Our main findings are for the period since 1985, however. Since then our aggregate telecom equipment price index falls 11 percent annually, driven by the new price index for wireless systems that drops 13 percent per year from 1995 to 2009.

All told, the rapid and consistent declines in prices for communications equipment that we estimate raise new considerations when thinking about U.S. productivity growth.[53] We take stock of the state of ICT price measurement more generally, especially in terms of prospects for productivity growth due to changes in communication technology and digitization going forward, in forthcoming work (Byrne and Corrado 2015).

[53] We previously used the new communication equipment price measures in a sources-of-growth framework to study the role of the Internet and wireless communication on the 2000-2007 productivity performance of the United States (Corrado 2011) and the 2003-2011 experiences of eight major European countries (Corrado and Jaeger 2014).

References

Aizcorbe, Ana, Carol Corrado, and Mark Doms (2000). "Constructing Price and Quantity Indexes for High Technology Goods," presented at the CRIW workshop on Price Measurement, NBER Summer Institute 2000 (July).

Aizcorbe, Ana, Carol Corrado, and Mark Doms (2003). "When do Matched-Model and Hedonic Techniques Yield Similar Measures?" Working Paper Series 2003-13. San Francisco: Federal Reserve Bank of San Francisco (June).

Bayard, Kimberly, and Norman Morin (2004). "Industrial Production and Capacity Utilization: The 2003 Annual Revision," *Federal Reserve Bulletin*, vol. 90, no. 1, pp. 32-46.

Bayard, Kim and Charles Gilbert (2006). "Industrial Production and Capacity Utilization: the 2005 Annual Revision." *Federal Reserve Bulletin*, vol. 92, pp. A39-A58

Byrne, David M. and Carol A. Corrado (2007). "Prices for Communication Equipment: Updating and Revisiting the Record." Paper presented at the 2007 NBER/CRIW workshop, Cambridge, Mass. (July 16).

Byrne, David M. and Carol A. Corrado (2015). "ICT Prices: What do they tell us about Trends in Productivity and Technology?" (forthcoming working paper).

Carol Corrado (2001). "Industrial Production and Capacity Utilization: The 2000 Annual Revision," *Federal Reserve Bulletin*, vol. 87 (March), 132–48.

Carol Corrado (2003). "Industrial Production and Capacity Utilization: The 2002 Historical and Annual Revision," *Federal Reserve Bulletin*, vol. 89 (April), 15176.

Currie, Kent A. (2005). "Hedonic Price Indices for Digital Circuit Switching Equipment: 1980-1998." Mimeo (SBC Services, Inc., August 7).

Diewert, W. E. (1976). "Exact and Superlative Index Numbers," *Journal of Econometrics* 4 (2), 115-145 (May).

Doms, Mark and Christopher Forman (2005). "Prices for Local Area Network Equipment." *Information Economics and Policy* vol. 17 (July), 365-388.

Doms, Mark (2005). "Communications Equipment: What has Happened to Prices?" In *Measuring Capital in the New Economy* C. Corrado, J. Haltiwanger, and D. Sichel, eds., 323-362. Chicago: The University of Chicago Press.

Erickson, Timothy and Ariel Pakes (2007). "An Experimental Component Index for the CPI: From Annual Computer Data to Monthly Data on Other Goods." Paper presented at the NBER Productivity Workshop, Cambridge, Mass. (March 9).

Farley, Tom (2005). "Mobile Telephone History." *Teletronikk* (3).

Flamm, Kenneth (1989). "Technological Advance and Costs: Computers versus Communications." In *Changing the Rules*: *Technological Change, International Competition, and Regulation in Communications,* R. Crandall and K. Flamm, eds. 13-61 and 371-410. Washington: The Brookings Institution.

Gilbert, Charles, and Kimberly Bayard (2005). "Industrial Production and Capacity Utilization: The 2004 Annual Revision," *Federal Reserve Bulletin*, vol. 91, no. 1, pp. 9-25

Gilbert, Charles and Maria Otoo (2007). "Industrial Production and Capacity Utilization: The 2006 Annual Revision." *Federal Reserve Bulletin*, vol. 93, pp. A17-35.

Gilbert, Charlies and Kim Bayard (2008). "Industrial Production and Capacity Utilization: The 2008 Annual Revision." *Federal Reserve Bulletin*, vol. 94, pp. A41-A60.

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

Gordon, Robert J. (2006). "The Boskin Commission Report: A Retrospective One Decade Later," NBER Working Paper 123111.

Grimm, Bruce T. (1996). "A Quality-Adjusted Price Index for Digital Telephone Switches. Mimeo (Bureau of Economic Analysis, August 28).

Grimm, Bruce T. (1997). "Quality-Adjusted Price Indexes for Digital Telephone Switches." Memorandum (Bureau of Economic Analysis, May 20).

Grimm, Bruce T., Brent R. Moulton, and David B. Wasshausen (2005). "Information-Processing Equipment and Software in the National Accounts." In *Measuring Capital in the New Economy*, C. Corrado, J. Haltiwanger, and D. Sichel, eds., 363-98. Chicago: The University of Chicago Press.

Hall, Anne (2009). "Industrial Production and Capacity Utilization: The 2009 Annual Revision." *Federal Reserve Bulletin*, vol. 95, pp. A125-A145.

Hausman, Jerry (1999). "Cellular Telephone, New Products, and the CPI." *Journal of Business & Economic Statistics* vol. 17 (April), 188-94.

Houseman, Susan, Christopher Kurz, Paul Lengermann, and Benjamin Mandel. 2011. "Offshoring Bias in U.S. Manufacturing. *Journal of Economic Perspectives*, 25(2): 111–32.

International Telecommunications Union (2012), *Radio Regulations*, (http://www.itu.int/dms_pub/itu-s/oth/02/02/S02020000244501PDFE.PDF, accessed August 20, 2015).

Jorgenson, Dale W. (2001). "Information Technology and the U.S. Economy." *American Economic Review* 90:1 (March), 1-32.

Lichtenberg, Frank R. and Zvi Griliches (1989), "Errors of Measurement in Output Deflators." *Journal of Business & Economic Statistics*, 7:1 (January), 1-9.

Phister, Montgomery Jr. (1979). *Data Processing Technology and Economics*, 2d ed. Bedford, Mass: Digital Press, and Santa Monica Publishing Co.

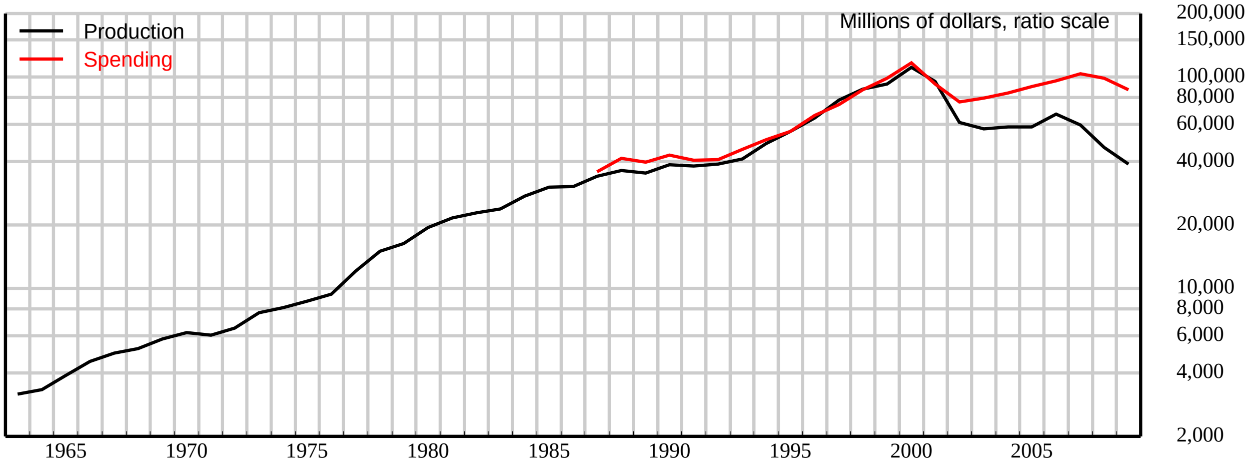
Triplett, Jack E. (2004). "Handbook on Hedonic Indexes and Quality Adjustments in Price Indexes: Special Application to Information Technology Products." STI Working Paper 2004/9. Paris, France: OECD.

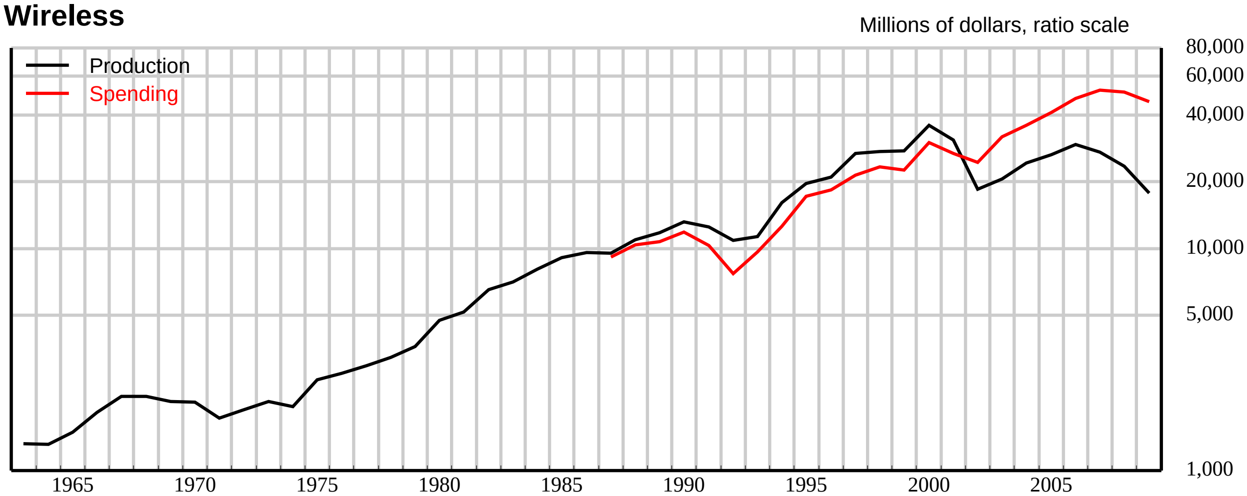
Shapiro, Matthew D. and David W. Wilcox (1996). "Mismeasurement in the Consumer Price Index: An Evaluation." In B. Bernanke and J. Rotemberg, eds., *NBER Macroeconomics Annual 1996*, 93-154. Cambridge, Mass: MIT Press.

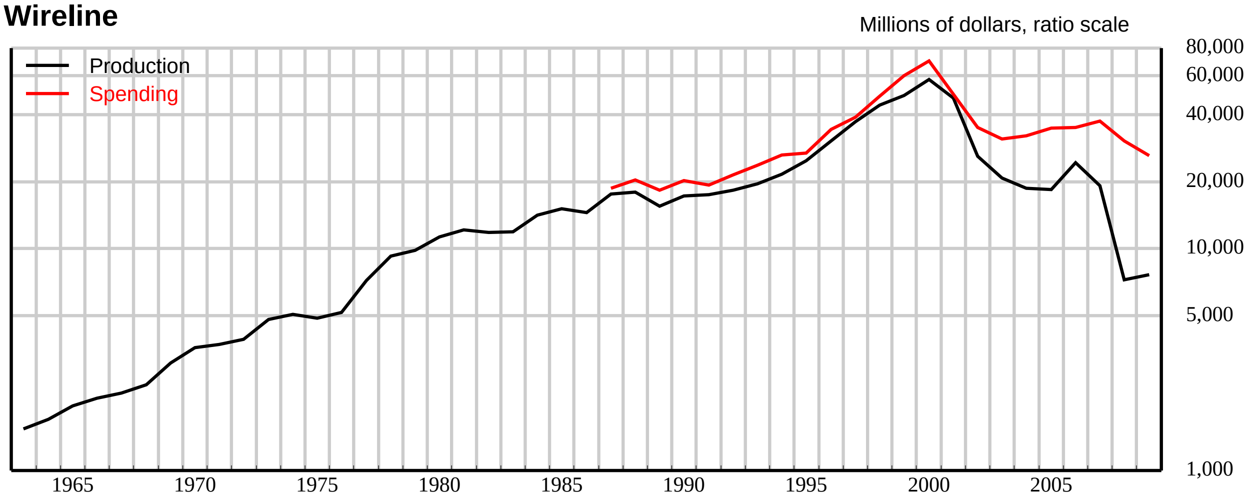
Watanbe, Naoki, Ryo Nakajima, and Takanori Ida (2010). "Quality-adjusted Prices of Japanese Mobile Phone Handsets and Carriers' Product/Marketing Strategies." mimeo (University of Tsukuba).

Wohleber, Curt (2000). "The Answering Machine." *Invention and Technology Magazine* 15:4 (http://www.americanheritage.com accessed February 2, 2011).

Figure 3
Communications Equipment
Total and Major Components

Total


Wireless


Wireline


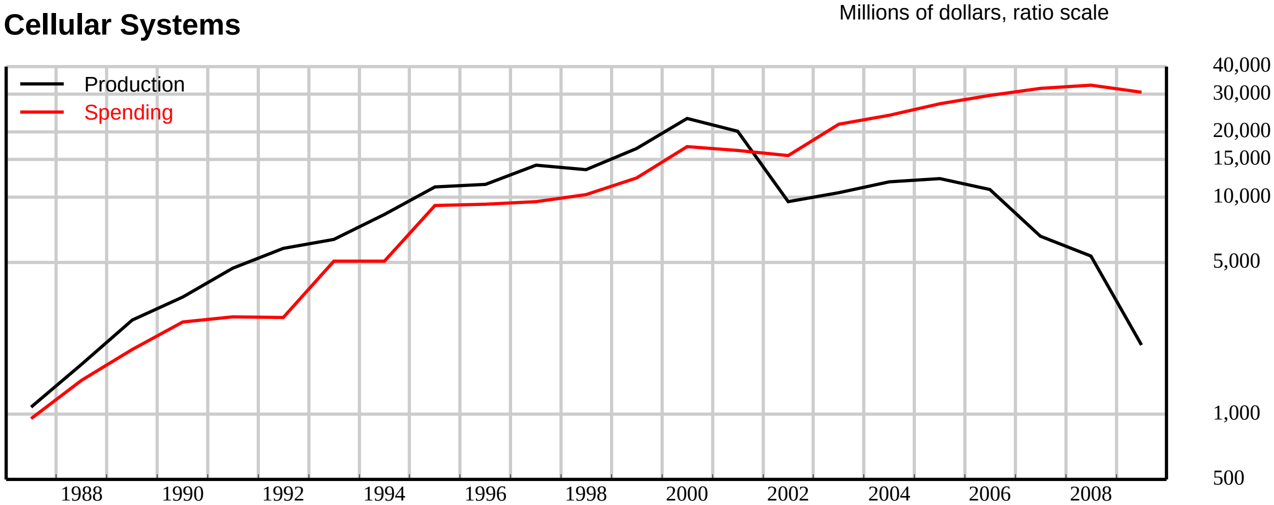
Source. Census Bureau surveys, supplemented with data from trade groups, consultancies and authors' estimates. See Appendix C.

Figure 4

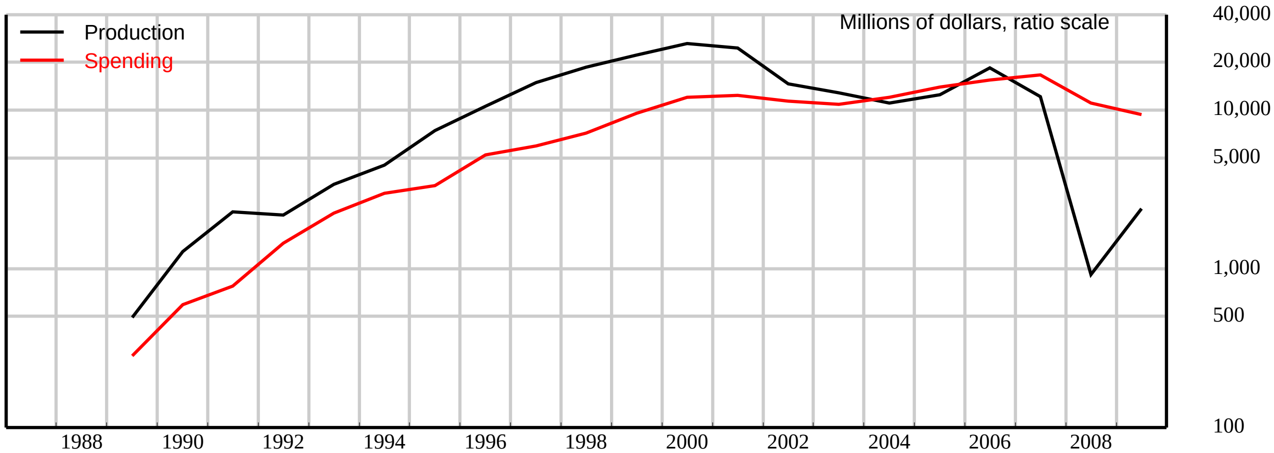
Communications Equipment

Selected Components

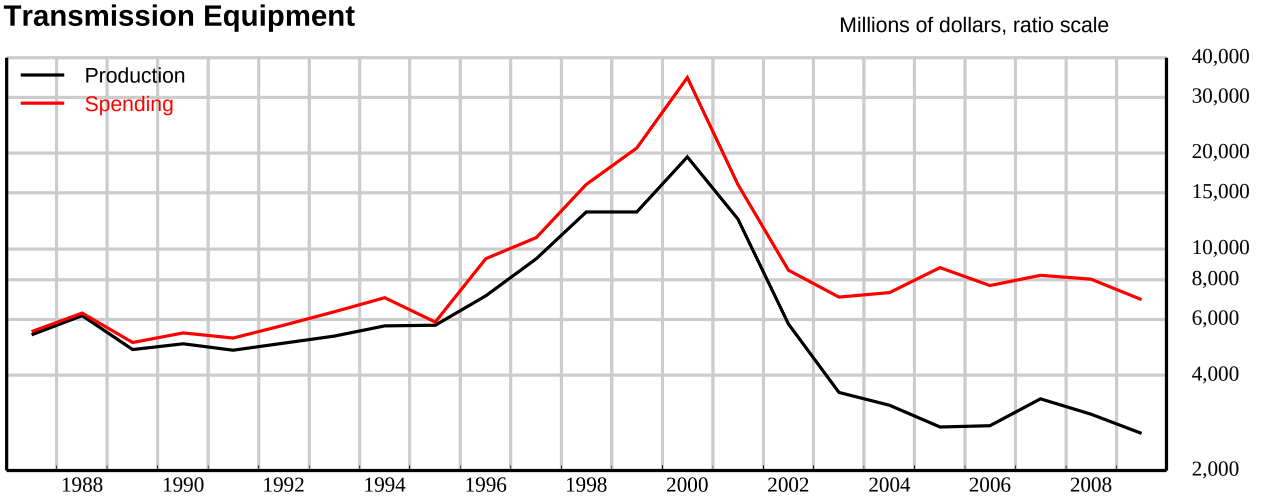
Cellular Systems



Data Networking Equipment



Transmission Equipment



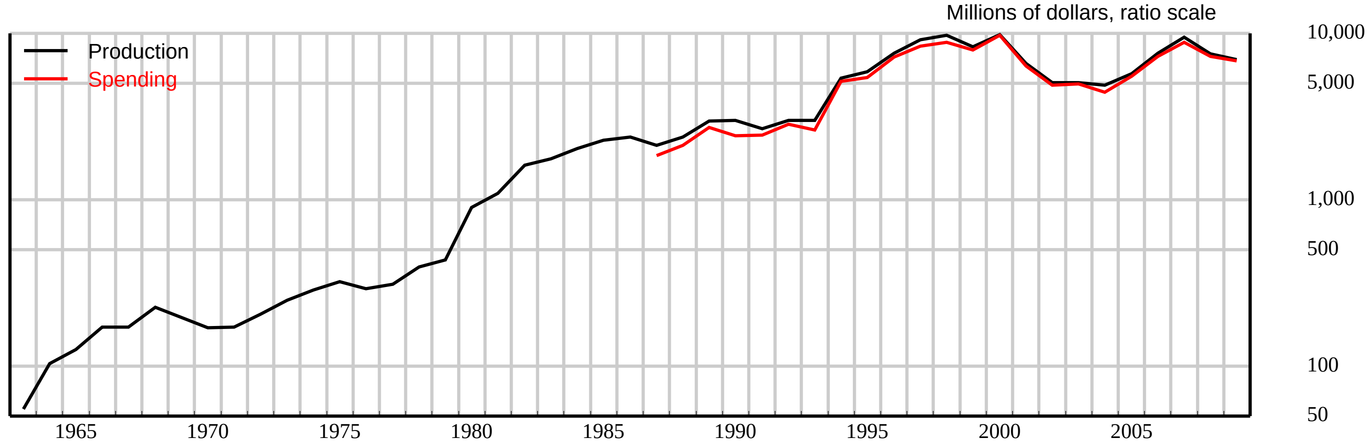
Source. Census Bureau surveys, supplemented with data from trade groups, consultancies and authors' estimates. See Appendix C.

Figure 5

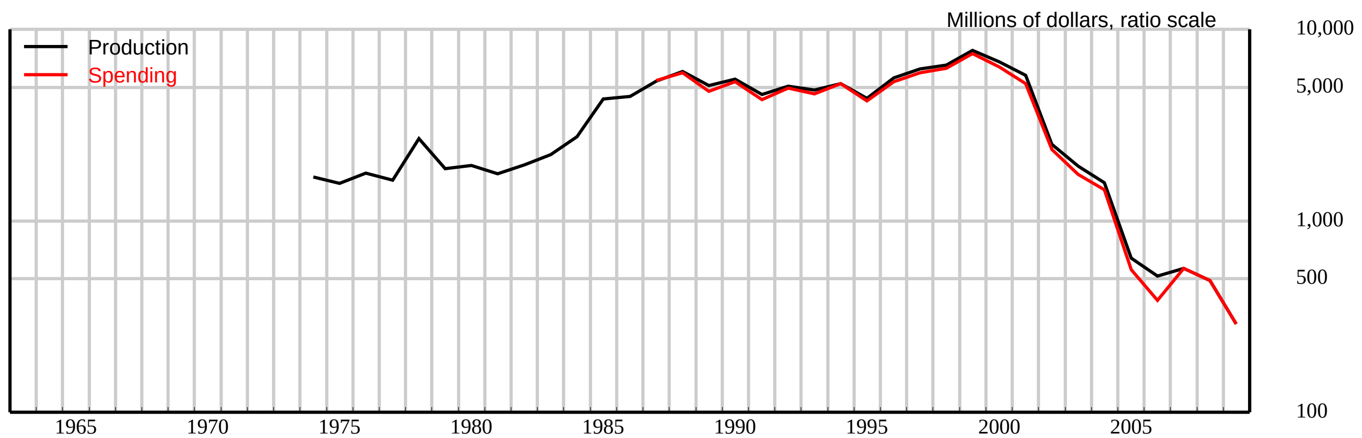
Communications Equipment

Selected Components

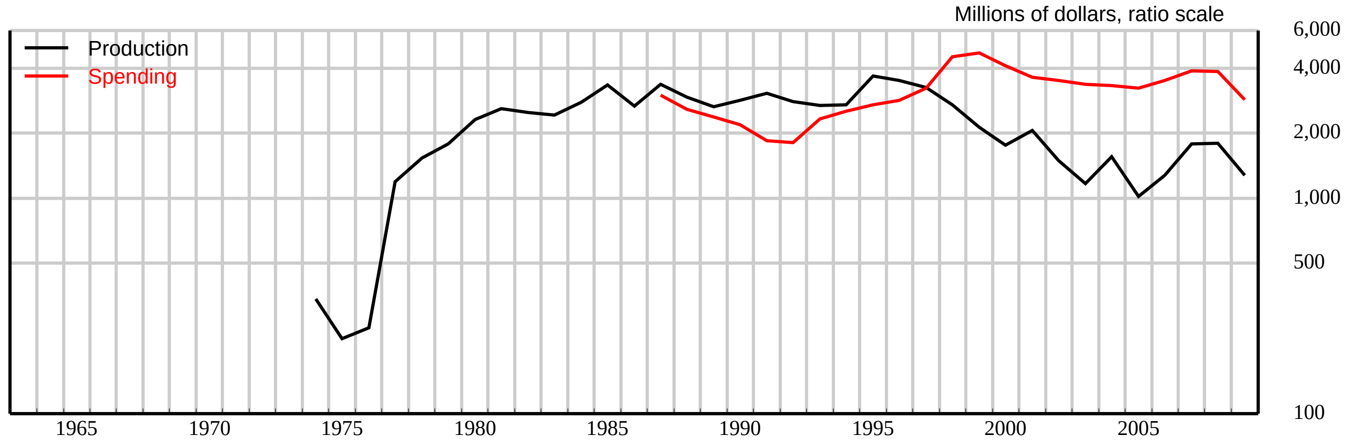
Satellites and Related Ground Equipment



Central Office Equipment



Enterprise Voice Switching Equipment



Source. Census Bureau surveys, supplemented with data from trade groups, consultancies and authors' estimates. See Appendix C.

Appendix A

Sources and Control Variables for Research Price Indexes*

Series Number	Product Class	Sources	Products	Additional Controls
	Telecom equipment			
	Wireless			
	Cellular systems			
1	Cell phones	1983-1987: Hausman (1989) ave. rate reported 1983-1999		
		1987-1994: TIA	cell phone	
		1994-2005: Gartner, Inc.	cell phone	function (basic, enhanced, smart, clamshell PDA, tablet PDA), transmission technology (AMPS, iDEN, GSM, TDMA, CDMA, W-CDMA; cellular, PCS)
		2005-2009: Phoneraiser used phone prices	cell phone	matched-model index of used phone prices adjusted for depreciation
2	Network equipment	1983-1986: Bias-adjusted BEA index		Industry price for SIC 3663
		1986-1993: Bias-adjusted PPI		
		1993-2000: Gartner	base station transceiver base station controller channel card mobile switching center packet control unit serving node	technology standard (GSM/GPRS/EDGE, CDMA, PDC, TDMA, W-CDMA/TD-SCDMA) size (macro, micro, pico)
		2000-2009: Dell'Oro	radio access network base station controller mobile switching center	technology standard, size, capacity (transponders)
	Satellites and related equipment			
3	Satellites	1963-2009: Census CIR (value) The Satellite Encyclopedia (capacity) Futron Corp. (capacity) 2006-2009: ave. rate 2000-2006	satellite	bandwidth (phone circuit equivalents) design life power (EIRP) frequency band usage (C-band, Ku-band, L-band, Ka-band) number of spot beams
4	Earth station equipment	1963-1978: Flamm (1989) transmission index 1978-1985: ave. rate 1963-1979, 1985-2005 1985-2009: geomean of PPI "other wireless" and cellular base station index		
	Other radio station equipment	see satellite earth station equipment		
	Wireline			
	Networking / switching equipment			
5	Data networking	1986-1992: BEA computers index (NAICS 3341)		
		1992-2000: Gartner, Inc.		bias-adjusted, Doms & Forman (2005), Corrado (2001)
		2000-2009: Dell'Oro, Gartner, Inc.	router (Dell'Oro, Gartner) ethernet switch (Dell'Oro) wireless LAN (Gartner, Dell'Oro) storage network switch (Dell'Oro) security (Gartner)	router: class (highend, midrange, etc.), port capacity by technology (OC, ethernet, T1, etc.) switch: layer, modularity (fixed, modular), bandwidth WLAN: user class (service provider, enterprise, sm. office), function (access point, router, network card, appliance), standard (802.11a/b/g) SAN: function (switch / host bus adapter, modular / fixed, stand-alone / mezzanine), speed, ports, ethernet security: VPN equip. type (access, midrange, enterprise)
6	Enterprise voice (PBX/KTS/VoIP)	1963-1992: Byrne-Corrado central office index		
		1994-2001: Gartner, Inc.	PBX/KTS	IP content (traditional, IP-enabled, pure IP) extension lines
		2001-2009: Dell'Oro	IP PBX Hybrid (TDM/IP) PBX Traditional (PBX/KTS) Telephone sets (3 types)	scale, number of extension lines, chassis v. network

Appendix A

Sources and Control Variables for Research Price Indexes*

Series Number	Product Class	Sources	Products	Additional Controls
7	Public network telephone switching	1963-1982: Flamm (1989)/Gordon (1990) 1982-1996: Currie (2005), smoothed 1996-2002: Gartner, Inc. 2002-2009: ave. rate 1996 to 2002	PSTN switches, 3 types	lines
	Transmission equipment			
	Total	1963-1974: Flamm (1989)		
8	Long-haul fiber optic	1974-1980: Flamm (1989) 1980-1993: central office index 1993-2001: Doms (2005) 2001-2009: Dell'Oro	Gartner: SONET multiplexer, DWDM Dell'Oro: SONET multiplexer, DWDM, optical switch	Gartner: SONET: capacity, function (add/drop, terminal) DWDM: capacity, type (terminals, cards) Dell'Oro: DWDM: type (metro, longhaul), capacity SONET/SDH: capacity (wavelengths), OC type switch: ports
9	Other long-haul	1974-1980: Flamm (1989) 1980-1990: central office index 1990-2000: PPI "digital carrier line equipment" 2000-2009: PPI "telephone apparatus, carrier line equipment, non-consumer modems"		1990-2009: geometric mean of PPI (1/2), long-haul fiber optic (1/4) and local loop (1/4)
10	Local loop	1974-1980: Flamm (1989) 1980-1993: central office index 1993-1998: Gartner, inc. 1998-2009: Dell'Oro	Gartner: FITL, access multiplexer, DLC/IMAP HDSL, pair gain, WLL, xDSL CO equipment Dell'Oro: access concentrators	Dell'Oro: type (cable, DSL, PON), capacity
	Terminals			
11	Telephone	1963-1975: Economic Census 1975-1987: CIR 1987-1998, 2006-2009: TIA 1998-2006: CEA	pushbutton, rotary dial pushbutton, rotary dial corded, cordless corded, cordless	bias-adjusted v. CEA (see text) type (basic, feature), transmission frequency (3 frequencies), signal type (analog, digital. DSS)
12	Fax	1963-1987: telephone index 1987-1996, 2006-2009: TIA 1996-2006: Gartner	fax	Gartner: technology (direct thermal, inkjet, page, thermal transfer) TIA: unit cost (Fax production ceased in 2006)
13	Modem	1963-1976, 1998-2009: BEA computers index 1976-1989: Census CIR 1989-1998: Doms (2005) 1998-2009: Dell'Oro (broadband)	proxy for analog modem analog modem analog modem cable DSL PON	 transfer speed transfer speed cable: type (data only, voice and data) DSL: type (ADSL, G.SHDSL, VDSL) PON: type (BPON, EPON, GPON)
14	Voice message equipment	1963-1987: telephone index 1987-1998, 2006-2009: TIA 1998-2006: CEA	answering machine	CEA: function (stand-alone, w/ corded phone, w/ cordless phone), phone type (basic, feature), transmission frequency (3 frequencies), signal type (analog, digital. DSS) TIA: bias-adjusted v. CEA (see text)
	Broadcast / other equipment			
		1963-1972: Byrne-Corrado central office index		
	Broadcast, studio and related	1972-1977: Industry index (SIC 3663) 1977-2000: Product index (SIC 36632,36622) 2000-2009: PPI "broadcast, studio, and rel."		Note: Industry and product price indexes are from the industrial production data system and are based on data originally obtained from BEA. SIC is the 1987 version.
	Traffic, intercom, alarm systems	1972-1977: Industry index (SIC 3669) 1977-1987: Product index (SIC 36622) 1987-2009: Industry index (SIC 3669, NAICS 334290)		
	Other communications equipment	1972-1985: traffic, intercom, alarm index 1985-2009: PPI "other comm. systems and equip."		

Notes. BEA: Bureau of Economic Analysis. BLS: Bureau of Labor Statistics. CEA: Consumer Electronics Association. CIR: Census Bureau Current Industrial Report. IPI: BLS Import Price Index. PPI: BLS Producer Price Index. TIA: Telecommunications Industry Association.

Appendix B

Table B.1. Price Indexes for Cellular Phones

	Byrne-Corrado	Ave. Price TIA Data	Fisher MM Gartner Data	Smartphone Ave. Price TIA Data	Basic Phone Ave. Price TIA Data	Fisher MM TIA Data
1983	11,413.0	3,000.0*				
1984	8,206.0					
1985	5,900.1					
1986	4,242.2					
1987	3,050.1	800.0				780.3
1988	2,954.8	775.0				755.9
1989	2,573.5	675.0				658.4
1990	2,058.8	540.0				526.7
1991	1,181.9	310.0				302.4
1992	1,162.9	305.0				297.5
1993	1,029.4	270.0				263.3
1994	915.0	240.0	914.7			234.1
1995	829.5	225.0	829.2			219.5
1996	643.5	203.0	643.3			198.0
1997	543.3	220.0	543.1			214.6
1998	448.2	200.0	448.1			195.1
1999	338.8	189.0	338.6			175.6
2000	284.3	176.0	284.2			163.5
2001	212.5	162.0	212.4			150.5
2002	165.2	138.0	165.2			128.2
2003	130.0	129.4	129.9	401.0	121.0	112.4
2004	106.0	125.3	106.0	379.0	112.0	104.3
2005	100.0	130.1	100.0	355.0	108.0	100.0
2006	93.1	140.7	93.1	341.0	116.0	104.4
2007	78.2	147.1	88.2	329.0	115.0	102.6
2008	54.7	148.7		301.0	113.0	98.3
2009	56.2	152.0		282.0	111.0	94.7

Notes:

1. "MM" stands for "matched model."

2. TIA data are "average manufacturer prices." Smartphones have advanced functions consisting of at least PDA capability and access to email. The 1983 price observation is from Hausman (1999).

3. Gartner data are annual unit values for phones grouped into 6 feature classes: basic, enhanced (camera, MP3 player), basic smartphone (advanced multimedia, gaming), enhanced smartphone (business class features), tablet cellular PDA (data-centric w/ rich PDA functions) and clamshell cellular PDA. Further detail by transmission standard (AMPS, iDEN, GSM, TDMA, CDMA) is available through 2000.

4. Used equipment data are prices for approximately 1,300 specific phone models. Observations are approximately annual (6 price lists between 11/2005 and 1/2011). Price indexes by brand constructed by unweighted geometric mean of model price relatives. Brand indexes aggregated using US market share weights.

Table B.2. Price Indexes for Cellular Network Infrastructure

	Byrne-Corrado	Fisher MM Dell'Oro Data	Fisher MM Gartner Data	BLS PPI "Cellular System Equipment"	BLS PPI "Comm. Systems and Equip. (ex. broadcast)"
1983	3,835.3				98.4
1984	3,361.7				102.1
1985	2,878.9				103.8
1986	2,447.8				104.9
1987	2,086.6				106.3
1988	1,768.3				107.1
1989	1,512.6				108.8
1990	1,258.5				108.0
1991	1,074.9				109.6
1992	936.3				113.0
1993	802.9		664.0		115.0
1994	691.9		572.2		116.8
1995	549.1		454.1		116.0
1996	444.2		367.4		116.7
1997	358.8		296.7		118.4
1998	281.7		232.9		117.5
1999	239.3		197.9		116.1
2000	200.9	200.9	166.1		111.9
2001	195.2	195.2	139.0		112.2
2002	168.5	168.5	133.5	130.6	108.0
2003	122.3	122.3	116.8	117.6	103.7
2004	100.8	100.8	107.8	109.2	101.0
2005	100.0	100.0	100.0	100.0	100.0
2006	91.6	91.6		98.8	99.3
2007	84.5	84.5		98.3	99.7
2008	56.3	56.3			101.5
2009	42.0	42.0			101.8

Notes:

1. "MM" stands for "matched model."

2. Dell'Oro data are quarterly unit values and global revenue for equipment grouped into 19 classes: base transciever stations by size class (pico, micro, and macro), base station controllers, and mobile switching centers with further detail for transmission standard (GSM, CDMA, TDMA, WCDMA, WiMAX).

3. Gartner data are annual unit values and U.S. revenue for equipment grouped into 8 functional classes (base transciever station, base station controller, mobile switching center, packet control unit, gateway general packet radio service (GPRS) support node, serving GPRS support node, radio network controller,and packet data server node) with further detail for transmission standard (GSM/GPRS/EDGE, CDMA, TDMA, WCDMA).

4. The BLS PPI for "cellular system equipment" (NAICS product 33422012) covers cellular base stations, cellular mobile telephone switching equipment, and other cellular networking equipment. Also included are cellular handsets, wi-fi public equipment, and wi-max equipment, which are out of scope for our cellular network equipment product class. In addition, the BLS PPI for "communications systems equipment (except broadcast)" (NAICS product code 3342201), includes "radio station equipment" such as satellites and earth stations, includes checkout, monitoring, evaluation and other electronic support equipment, and includes antenna systems and other communications systems and equipment. (Census CIR, 2006) Prior to 2005, the scope of this NAICS product code included fiber optic transmission equipment, as implemented in the Census CIR. PPI index is extended to 1983 using BEA industry price index for NAICS 334220.

Table B.3. Price Indexes for Satellites and Other Radio Station Equipment

	Byrne-Corrado Satellites	Byrne-Corrado Radio Station Equip. ex. Satellites
1963	6,101.50	107.0
1964	12,494.60	106.1
1965	5,854.50	82.5
1966	1,005.40	82.5
1967	447.1	72.8
1968	287.3	71.1
1969	166.3	71.1
1970	104.2	78.1
1971	83.9	92.1
1972	95.9	100.0
1973	93.4	100.0
1974	44.2	113.2
1975	46.6	131.6
1976	38.5	149.1
1977	88.6	152.6
1978	114.8	159.6
1979	106.3	160.0
1980	100	160.4
1981	79.1	160.9
1982	103.1	161.3
1983	82.8	161.7
1984	124.7	162.1
1985	177.8	162.6
1986	415.4	149.0

	Byrne-Corrado Satellites	Byrne-Corrado Radio Station Equip. ex. Satellites	BLS PPI "Space Satellite Comm. & Related"
1986	415.4	149.0	101.0
1987	175.8	138.9	99.3
1988	81.0	127.7	99.6
1989	64.6	117.7	100.4
1990	31.1	110.2	97.1
1991	24.1	104.7	95.3
1992	17.8	99.1	94.3
1993	16.9	92.5	93.4
1994	27.6	87.6	94.4
1995	21.6	78.4	94.2
1996	24.2	71.7	93.9
1997	17.1	65.2	94.5
1998	11.6	58.0	93.7
1999	10.3	52.8	93.4
2000	9.8	46.8	93.4
2001	10.3	45.9	
2002	6.2	42.0	
2003	7.3	36.5	
2004	4.9	34.9	
2005	6.2	35.8	
2006	5.4	34.5	
2007	4.9	33.2	
2008	4.4	28.8	
2009	4.0	25.6	

Table B.4. Price Indexes for Data Networking Equipment

	Byrne-Corrado	Bias-Adjusted Fisher MM Gartner Data (FRB Index)	Ethernet Switch Fisher MM Dell'Oro Data	Router Fisher MM Dell'Oro Data	WLAN Fisher MM Dell'Oro Data	SAN Fisher MM Dell'Oro Data	Security Equip. Fisher MM Gartner Data	BEA Computers	BLS PPI "Data Comm. Equipment"
1986	1,530.7							1,992.9	
1987	1,303.8							1,697.5	
1988	1,211.0							1,576.8	
1989	1,130.9							1,472.4	
1990	1,026.1							1,335.9	
1991	921.8							1,200.2	
1992	786.7	786.7						1,024.2	
1993	657.2	657.2						870.3	
1994	584.0	584.0						765.4	
1995	489.2	489.2						640.6	98.0
1996	449.9	449.9						488.5	101.2
1997	374.7	374.7						376.6	100.4
1998	270.2	270.2						279.8	99.7
1999	221.3	221.3						217.8	97.0
2000	196.8	196.8	213.3	153.0	431.2	208.2	140.7	190.6	94.9
2001	170.8		187.2	129.4	375.3	199.4	132.0	157.8	90.9
2002	154.3		170.2	123.5	242.8	171.5	123.7	137.1	83.0
2003	129.9		138.0	113.1	163.6	142.5	115.9	122.6	77.8
2004	112.5		114.6	107.9	117.3	118.3	109.1	113.6	73.9
2005	100.0		100.0	100.0	100.0	100.0	100.0	100.0	70.3
2006	91.2		90.0	91.3	93.8	91.5	94.9	87.4	66.8
2007	81.6		78.7	83.2	86.8	77.8	89.6	78.6	64.2
2008	74.9		73.2	74.1	80.6	72.4	84.3	71.1	64.7
2009	64.7		62.5	63.2	73.3	62.1	79.2	65.3	64.7

Notes:

1. "MM" stands for "matched model."

2. Detailed domestic product production data by product class (switches, routers, wireless LAN, storage, security) are not available within data networking. Component price indexes for product classes are aggregated to the total index in column 1 using global sales mix for 2000-2009. Sources and methods for FRB index for 1992-2000 period are discussed in Corrado (2001).

3. Dell'Oro ethernet switch data are quarterly unit values and global revenue for layer 2 and 3 switches, grouped into 6 classes (fixed switches: managed 100Mbps, managed 1000 Mbps, unmanaged; modular switches: 100 Mbps, 1000 Mbps, 10 Gbps), and for layer 4 to 7 grouped into 5 classes (fixed switches: 100 Mbps, 1000 Mbps; modular switches: 100 Mbps, 1000 Mbps, modules)

4. Dell'Oro router data are global annual price per port for 11 types of high-end router, plus 2 types of access router and two types of WAN switch. Index is extended to 2000 using comparable Gartner data.

5. Dell'Oro wireless LAN data are quarterly unit values and global revenues for equipment grouped into 19 classes: enterprise access points (dependent, independent; each for 802.11g, 802.11a/g, 802.11n); enterprise switch/ server appliance; SOHO access point (3 standards); wireless router (3 standards); broadband CPE with WLAN (3 types); network interface card (3 types). Dell'Oro WLAN data covers 2003-2009; index is extended to 2001 using comparable Gartner data; and to 2000 using average rate for 2001-2009.

6. Delloro storage area network data are quarterly unit values and global revenues for equipment grouped into 16 classes: switches (fixed, modular; 1 Gbps, 2 Gbps, 4 Gbps, 8 Gbps plus, fiber channel), and host bus adapter cards (stand-alone, mezzanine; each for 4 speeds). Dell'Oro data cover 2001-2009; index extended to 2000 using average rate.

7. Gartner security data are annual unit values and U.S. revenue for equipment grouped into 3 classes of VPN / firewall equipment (access and broadband, midrange, concentrators). Gartner data cover 2003-2007; index extended to 2000 and 2009 using average rate.

8. The BLS PPI for "data communication & other telephone & telegraph apparatus, including telephone sets & fax" corresponds to NAICS product code 3342107

Table B.5. Price Indexes for Enterprise Voice Equipment

	Byrne-Corrado	Fisher MM Dell'Oro Data	Fisher MM Gartner Data
1994	177.5		162.5
1995	183.0		167.5
1996	170.7		156.3
1997	160.4		146.9
1998	152.4		139.6
1999	140.7		128.8
2000	134.1		122.8
2001	128.5	128.8	117.6
2002	116.6	117.0	111.7
2003	108.0	108.3	105.1
2004	101.7	101.9	101.9
2005	100.0	100.0	
2006	98.0	98.0	
2007	96.7	96.7	
2008	92.5	92.7	
2009	89.3	89.3	

Notes:

1. "MM" stands for "matched model."

2. Dell'Oro data are quarterly unit values and global revenue for PBX systems grouped into classes distinguished by scale (large/ small), technology (IP PBX/ hybrid PBX/ traditional (TDM) / Key), chassis-based v. network-based, and number of lines, and for system telephones grouped into 4 classes (conference, desk, WLAN, and legacy; softphones are excluded)

3. Gartner data are annual unit values and U.S. revenue for equipment grouped into 4 technology classes (PBX Traditional, IP-Enabled PBX Traditional, IP-Enabled PBX IP, PBX IP).

Table B.6. Price Indexes for Central Office Equipment

	Byrne-Corrado	Flamm/Gordon Bellcore Switching Aggregate	Currie	Currie Smoothed
1963	797.9			
1964	808.5			
1965	706.4	953.2		
1966	736.6	994.0		
1967	767.8	1,036.1		
1968	799.9	1,079.4		
1969	833.9	1,125.3		
1970	868.8	1,172.4		
1971	905.7	1,222.1		
1972	944.4	1,274.4		
1973	938.7	1,266.7		
1974	999.2	1,348.3		
1975	873.6	1,178.8		
1976	723.4	976.2		
1977	686.6	926.5		
1978	651.6	879.3		
1979	627.1	846.2		
1980	615.7	830.9	618.7	
1981	636.5	858.9	699.6	
1982	661.1	892.1	656.2	661.1
1983	659.8	762.1	660.4	659.8
1984	652.5	652.5	652.5	652.5
1985	611.5		587.8	611.5
1986	581.1		569.5	581.1

	Byrne-Corrado	Currie	Currie Smoothed	Fisher MM Gartner Data
1986	581.1	569.5	581.1	
1987	548.7	534.8	548.7	
1988	515.0	498.5	515.0	
1989	483.9	471.0	483.9	
1990	458.1	447.2	458.1	
1991	436.3	426.8	436.3	
1992	421.8	417.2	421.8	
1993	411.9	408.4	411.9	299.311
1994	376.2	355.0	376.2	285.244
1995	321.3	293.7	321.3	267.584
1996	243.9	207.3	243.9	243.939
1997	235.3	58.4		235.259
1998	231.7	88.4		231.667
1999	227.2			227.177
2000	219.1			219.096
2001	152.1			152.05
2002	131.4			131.398
2003	120.0			
2004	109.5			
2005	100.0			
2006	91.3			
2007	83.4			
2008	76.1			
2009	69.5			

Notes:

1. "MM" stands for "matched model."

2. Flamm/Gordon Bellcore index is the transmission and switching equipment index reported in Gordon (1980), constructed by aggregating prices reported in Flamm (1989) for three size classes for local office switches and for toll and tandem switches.

3. Currie index is Currie (2005) hedonic index for digital circuit switching equipment. The smoothed index is constructed by putting weights of 0.6, 0.3, and 0.1 on the relative prices for the current period and previous two periods respectively.

4. Gartner data are unit costs per line and U.S. revenue for equipment grouped into 3 classes (digital local line, ISDN B-channel, and trunk).

Table B.7. Price Indexes for Transmission Equipment

	Total Transmission	Long-Haul Fiber Optic Transmission					Other Long-Haul Transmission	Local Loop Transmission		
	Byrne-Corrado	Byrne-Corrado	Flamm Transmission	Byrne-Corrado Central Office	Fisher MM Doms, Extended	Fisher MM Dell'Oro Data	Byrne-Corrado	Byrne-Corrado	Fisher MM Dell'Oro Data	Fisher MM Gartner Data
1974	489.9	880.9	880.9	999.2			286.2	1,554.6		
1975	569.5	1,024.0	1,024.0	873.6			332.7	1,807.2		
1976	645.3	1,160.2	1,160.2	723.4			376.9	2,047.6		
1977	660.4	1,187.5	1,187.5	686.6			385.7	2,095.6		
1978	690.7	1,241.9	1,241.9	651.6			403.4	2,191.8		
1979	595.9	1,071.5	1,071.5	627.1			348.1	1,891.0		
1980	455.7	819.4	819.4	615.7			266.2	1,446.1		
1981	471.1	847.0		636.5			275.2	1,494.9		
1982	489.3	879.7		661.1			285.8	1,552.5		
1983	488.3	878.0		659.8			285.2	1,549.4		
1984	482.9	868.3		652.5			282.1	1,532.3		
1985	452.6	813.7		611.5			264.3	1,436.1		
1986	430.1	773.3		581.1			251.2	1,364.7		
1987	406.1	730.2		548.7			237.2	1,288.6		
1988	381.1	685.3		515.0			222.6	1,209.4		
1989	358.1	644.0		483.9			209.2	1,136.5		
1990	339.1	609.6		458.1			198.0	1,075.9		
1991	329.8	580.6		436.3			195.2	1,024.7		
1992	323.6	561.3		421.8			193.5	990.5		
1993	321.2	548.1		411.9	548.1		194.5	967.2		967.2
1994	310.1	527.3		376.2	527.3		192.3	878.4		878.4
1995	301.8	495.1		321.3	495.1		198.6	758.4		758.4
1996	282.2	447.6		243.9	447.6		191.9	669.3		669.3
1997	275.9	426.5		235.3	426.5		189.4	646.1		646.1
1998	265.1	405.7		231.7	405.7	320.2	185.5	584.5	584.5	584.5
1999	228.6	356.4		227.2	356.4	244.4	168.0	413.9	413.9	453.6
2000	210.6	299.5		219.1	299.5	213.6	159.6	359.2	359.2	416.7
2001	180.1	237.9		152.1	237.9	237.9	144.3	266.6	266.6	368.2
2002	155.4	243.9		131.4		243.9	131.0	182.5	182.5	343.0
2003	126.6	163.2		120.0		163.2	115.3	133.1	133.1	333.9
2004	114.9	136.2		109.5		136.2	107.9	115.4	115.4	323.8
2005	100.0	100.0		100.0		100.0	100.0	100.0	100.0	
2006	90.3	86.3		91.3		86.3	94.4	84.8	84.8	
2007	82.8	74.9		83.4		74.9	92.7	72.8	72.8	
2008	74.4	65.6		76.1		65.6	87.2	61.8	61.8	
2009	68.6	59.2		69.5		59.2	83.0	55.4	55.4	

Notes:

1. "MM" stands for "matched model."

2. Flamm index is the marginal capital cost of AT&T transmission equipment.

3. The Doms index, through 2000, is based on data from Gartner, RHK, and KMI. See Doms and Forman (2005). The index is extended with similar data from Gartner.

4. Dell'Oro fiber optic transmission data are quarterly global revenue and unit values for equipment grouped into 10 classes: SONET/SDH equipment w/ control for wavelength capacity and OC type, DWDM equipment (metro, longhaul) with control for capacity, and switches with control for capacity measured in ports.

5. Other long-haul transmission consists of non-fiber-optic line transmission and radio-wave transmission.

5. Dell'Oro local loop equipment data are quarterly global revenue and unit values for access concentrators grouped into 7 classes: cable, DSL (ADSL, G.SHDSL, VDSL), and PON (EPON, GPON, BPON). Note that customer premises equipment is included in modems.

6. Gartner local loop equipment data consists of annual global revenue and unit values for equipment grouped into 7 classes: FITL, access multiplexer, DLC/IMAP, HDSL, pair gain, WLL, xDSL CO equipment.

Table B.8. Price Indexes for Telephones

	Byrne-Corrado	Fisher MM Economic Census Data	Fisher MM Current Industrial Report Data
1963	907.3	907.3	
1964	951.1	951.1	
1965	997.0	997.0	
1966	1,045.1	1,045.1	
1967	1,095.5	1,095.5	
1968	1,119.6	1,119.6	
1969	1,144.3	1,144.3	
1970	1,169.4	1,169.4	
1971	1,195.2	1,195.2	
1972	1,221.5	1,221.5	
1973	1,248.4	1,248.4	
1974	1,275.9	1,275.9	
1975	1,304.0	1,304.0	1,304.0
1976	1,489.0		1,489.0
1977	1,487.2		1,487.2
1978	1,472.4		1,472.4
1979	1,804.0		1,804.0
1980	1,756.2		1,756.2
1981	2,035.2		2,049.6
1982	2,075.1		2,123.6
1983	1,598.3		1,688.1
1984	1,852.0		2,011.8
1985	2,293.7		2,574.5
1986	1,908.4		2,269.5
1987	1,554.6		1,979.7

	Byrne-Corrado	Fisher MM TIA Data	Fisher MM CEA Data	BLS PPI "Telephone Sets"
1986	1,908.4			93.2
1987	1,554.6	311.5		90.5
1988	1,681.4	357.5		92.3
1989	1,536.9	353.3		90.4
1990	1,411.3	353.5		91.0
1991	1,317.4	359.0		86.9
1992	1,013.4	305.6		85.7
1993	827.5	274.6		82.4
1994	798.6	287.5		81.6
1995	745.0	291.8		82.2
1996	574.8	249.1		82.2
1997	480.9	228.8		82.3
1998	406.5	212.2	406.5	81.8
1999	295.2	173.8	295.2	80.7
2000	241.0	154.1	241.0	78.7
2001	183.9	182.2	183.9	
2002	163.0	131.9	163.0	
2003	143.7	122.0	143.7	
2004	126.9	120.5	126.9	
2005	100.0	100.0	100.0	
2006	91.5	104.7	91.5	
2007	83.6	98.0		
2008	72.6	80.6		
2009	60.7	92.5		

Notes:

1. "MM" stands for "matched model."

2. Economic Census data are unit values and U.S. production for pushbutton and for other telephones observed in 1963, 1967, 1972, 1974, and 1975. Intervening years are interpolated.

3. Current Industrial Report data are annual unit values and U.S. production for pushbutton and for rotary dial telephones.

4. Telecommunications Industry Association data are annual unit values and U.S. revenue for corded and for cordless telephones.

5. Consumer Electronics Association data are monthly unit values and U.S. revenue for telephones grouped into 23 classes distinguished by frequency band (900MHz, 2.4GHz, 5.8GHz), analog / digital / digital spread spectrum (DSS), corded / cordless, and number of lines.

Table B.9. Price Indexes for Fax Machines and Answering Machines

	Fax Machines					Answering Machines		
	Byrne-Corrado	Business Equip. Ave. Price TIA Data	Home Equip. Ave. Price TIA Data	Fisher MM Gartner Data		Byrne-Corrado	Ave. Price TIA Data	Fisher MM CEA Data
1987	823.4	1,642.0			1987	839.4	72.9	
1988	785.8	1,600.0			1988	823.4	72.6	
1989	613.0	1,280.0			1989	781.9	71.0	
1990	587.6	1,252.6	733.3		1990	737.3	70.1	
1991	406.3	891.2	700.0		1991	745.0	74.9	
1992	407.7	912.1	582.4		1992	680.1	73.8	
1993	372.3	851.1	507.1		1993	609.9	72.6	
1994	316.0	739.4	462.0		1994	572.7	75.5	
1995	306.4	731.7	392.9		1995	471.8	71.0	
1996	292.3	712.8	358.9	292.3	1996	374.7	65.6	
1997	249.7		379.7	249.7	1997	300.0	62.1	
1998	197.9		258.7	197.9	1998	288.4	68.7	288.4
1999	165.1		182.0	165.1	1999	212.4	57.4	212.4
2000	139.5		166.7	139.5	2000	214.9	56.9	214.9
2001	121.2		156.5	121.2	2001	166.5	57.6	166.5
2002	118.9		150.4	118.9	2002	133.0	58.9	133.0
2003	106.6		134.3	106.6	2003	114.0	61.9	114.0
2004	93.9		137.2	93.9	2004	106.0	60.8	106.0
2005	100.0		144.7	100.0	2005	100.0	52.5	100.0
2006	84.4		130.0	84.5	2006	107.6	49.6	107.6
2007	90.3		125.4		2007	107.1	47.8	
2008	70.1		119.2		2008	101.8	46.4	
2009	62.6		112.7		2009	93.5	46.0	

Notes:

1. "MM" stands for "matched model."
2. TIA data are "average manufacturer prices."
3. Gartner fax machine data are global revenues and unit values for equipment grouped into 4 classes: direct thermal, inkjet, page, and thermal transfer.
4. CEA answering machine data are U.S. revenues and unit values for equipment grouped into 11 classes: integrated corded phone, integrated cordless phone, no integrated phone, further broken down by analog/digital/DSS technology and by frequency band.

Table B.10. Price Indexes for Modems

	Byrne-Corrado	Analog Byrne-Corrado	Analog Fisher MM Census CIR Data	BEA Computers
1963	128,787.7	56,482.2		56,482.2
1964	107,732.8	47,248.2		47,248.2
1965	89,020.3	39,041.5		39,041.5
1966	62,396.9	27,365.3		27,365.3
1967	50,697.4	22,234.3		22,234.3
1968	43,262.6	18,973.6		18,973.6
1969	39,171.0	17,179.2		17,179.2
1970	35,185.0	15,431.0		15,431.0
1971	26,790.2	11,749.3		11,749.3
1972	21,608.9	9,477.0		9,477.0
1973	20,487.5	8,985.2		8,985.2
1974	16,727.3	7,336.1		7,336.1
1975	15,473.5	6,786.2		6,786.2
1976	12,923.4	5,667.8	7,027.4	5,667.8
1977	11,755.3	5,155.5	6,392.3	4,932.3
1978	11,402.1	5,000.6	6,200.2	3,336.2
1979	13,568.5	5,950.7	7,378.3	2,764.4
1980	14,281.9	6,263.6	7,766.2	2,157.6
1981	10,900.3	4,780.5	5,927.4	1,896.1
1982	12,238.3	5,367.3	6,654.9	1,696.8
1983	8,575.5	3,760.9	4,663.2	1,414.6
1984	9,008.1	3,950.7	4,898.4	1,144.5
1985	7,981.2	3,500.3	4,340.0	972.9
1986	7,071.1	3,101.3	3,845.2	838.1

	Byrne-Corrado	Analog Byrne-Corrado	Analog Doms Hedonic	Analog Fisher MM Census CIR Data	BEA Computers	Broadband Fisher MM Dell'Oro Data
1986	7,071.3	3,101.3		3,845.2	838.1	
1987	4,708.8	2,065.1		2,560.5	713.9	
1988	4,094.4	1,795.7		2,226.4	663.1	
1989	3,120.7	1,368.6	1,368.6	1,697.0	619.2	
1990	3,031.4	1,329.5	1,329.5	1,389.2	561.8	
1991	2,833.5	1,242.7	1,242.7	1,242.7	504.7	
1992	2,465.5	1,081.3	1,081.3		430.7	
1993	1,881.9	825.4	825.4		366.0	
1994	1,492.0	654.3	654.3		321.9	
1995	1,236.5	542.3	542.3		269.4	
1996	1,071.9	470.1	470.1		205.4	
1997	761.5	334.0	334.0		158.4	
1998	637.9	279.8	279.8		117.7	965.6
1999	498.7	217.8			91.6	779.7
2000	423.5	190.6			80.2	622.8
2001	327.0	157.8			66.4	450.7
2002	242.6	137.1			57.7	298.0
2003	173.4	122.6			51.5	190.1
2004	125.1	113.6			47.8	126.7
2005	100.0	100.0			42.1	100.0
2006	88.8	87.4			36.8	88.9
2007	81.8	78.6			33.0	81.9
2008	77.6	71.1			29.9	77.7
2009	71.4	65.3			27.5	71.5

Notes:

1. "MM" stands for "matched model."

2. Doms hedonic index is based on quaterly advertised model-level retail prices for 681 analog modems, PC World Magazine.

3. Census CIR data are unit values and U.S. shipments for modems grouped into four frequency classes (less than 300 MHz, 300 to 2000 MHz, 2000 to 4800 MHz, greater than 4800 MHz).

4. DellOro data are unit values and U.S. sales for modems groupe into classes as follows: DSL, for each of ADSL, G.SHDSL, VDSL : simple modem, with data router, with data and voice router; Cable: data modem, voice and data modem; PON for each of single-user and multi-user systems: BPON, EPON, GPON modem.

Table B.11. BLS Producer Prices

	other system	studio & broadcast	intercom	traffic control	alarm
1985	102.1	102.1	102.1	102.1	102.1
1986	100.6	104.2	104.2	104.2	104.2
1987	103.3	105.1	105.1	105.1	105.1
1988	101.8	107.7	105.5	105.5	105.5
1989	104.1	108.9	108.6	108.6	108.6
1990	106.9	108.0	109.4	109.4	109.4
1991	110.8	109.3	107.1	107.1	107.1
1992	115.6	111.2	107.3	107.3	107.3
1993	118.0	111.9	108.3	108.3	108.3
1994	122.7	109.9	110.1	110.1	110.1
1995	123.8	110.5	111.9	111.9	111.9
1996	127.9	110.9	113.9	113.9	113.9
1997	131.0	109.3	115.0	115.0	115.0
1998	131.9	110.1	116.0	116.0	116.0
1999	128.7	109.8	114.7	114.7	114.7
2000	120.4	112.1	113.7	113.7	113.7
2001	121.0	112.5	115.5	115.5	115.5
2002	119.8	112.9	116.8	116.8	116.8
2003	118.3	112.1	116.9	116.9	116.9
2004	119.4	111.5	116.8	116.8	116.8
2005	120.7	111.6	116.8	116.8	116.8
2006	119.9	111.6	118.6	118.6	118.6
2007	120.4	112.0	119.1	119.1	119.1
2008	122.6	113.5	121.2	121.2	121.2
2009	124.3	113.4	122.8	122.8	122.8

Appendix C
Product Weights for Production and Spending

To create the weights used to aggregate the product prices presented in the paper, we employ data from the Census Bureau's Current Industrial Report (CIR) for communications equipment, Annual Survey of Manufactures (ASM), Census of Manufacturers, and International Trade in Goods and Services that we supplement with data from trade associations, high tech consultancies, and company reports when necessary.

Production

We employ the highly detailed data in the CIRs to construct indicators of production for all categories in table 1 spanning 1975 to the present. We then use ASM and Economic Census figures to control the overall total by six-digit NAICS industries and to extend the measures to 1963.

The production indicator for each component in table 1 is an aggregate of product shipments for many detailed CIR product classes. At times, these details are not consistently disclosed and estimates are obtained by applying an interpolated share to a higher level aggregate or by supplementing the published CIR data with information from industry sources. Also, because new products are often only shown separately in Census reports with significant delay, output is extrapolated back to the first shipments of the product. For example, before the introduction of the data networking product code in the CIR in 1991, production is extended back to 1987 based on the annual revenue of Cisco, and cell phone production before 2004 is extended to the dawn of the industry using subscriber data and reported production of higher level aggregates.

The figures for the value of production and shipments of the communications equipment industry developed for use in this paper pertain to the scope defined by NAICS 3342 (or the 1987 SIC, which is the same).

All told, the task of assembling detailed production figures requires sifting through many varied CIR publications, as reports and names changed over the years. The Census Bureau survey, Selected Electronic and Associated Products MA-36N, was first conducted in 1961 and last issued in 1984. The survey covered products produced by several industries according to the classification used at the time, including Communications Equipment Manufacturing (SIC 366). We located the issues for 1964-72 and for 1975-84 (including the 1972 supplement and 1978 change sheet) in the Federal Reserve and Georgetown University libraries.

For the first ten years, the MA-36N reported data for about 50 detailed product classes in SIC 3662, Radio and TV Communications Equipment Manufacturing, including the product class 3662741, Space satellite communications systems (complete). Comparable data were reported as product class 36227 in the ASM/COM. The product class 36639, Microwave and mobile telephone communication equipment, was not covered in the CIR series until much later, but details are in the 1963, 1967, and 1972 COM. The ASM for 1968-1971 and for 1973-1976 included data for this product class. In the 1977 COM, this category was no longer shown separately.

The MA-36N (72) Supplement reported detail on about 15 products primary to SIC 3661, Telephone and Telegraph Apparatus Manufacturing. Thereafter the MA-36N continued the broader coverage and was renamed *Selected Electronic and Associated Products, including Telephone and Telegraph Apparatus*.

In 1973 the Census Bureau substantially revised the content of the product classes in industry SIC 3662. Detailed components of the new product classes for 1974 and 1975 were presented in the issue, MA-36N (75). Another change occurred in 1980, when three new classes (36624, 36626, and 36628) were formed from a previous one (36623). Detailed components of these classes for 1980 and 1981 were first reported in the issue, MA-36N (81).

In 1985 the MA-36N was divided into three annual surveys, one of which concentrated on communications equipment entitled, *Communications Equipment, Including Telephone, Telegraph, and Other Electronic Systems and Equipment* (MA36P).

The 1987 revision to the SIC system narrowed the scope of what was measured in the communications equipment manufacturing industry.

1. A new industry, Computer Terminals (1987 SIC 3571), was created from detailed components of SIC 3661 and moved to the computer industry; the MA35R (88) issue of *Computers and Office and Accounting Machines* showed the new series starting in 1986.
2. A new industry, Search and Navigation Equipment (1987 SIC 3812), as created from the previous product class 36625, Search and detection, navigation and guidance systems and equipment.

The new North American Industry Classification System (NAICS), introduced in 1997, made no changes to the communication equipment manufacturing industry other than renumbering the industry code from 366 to 3342 and the series number for the CIR from MA36P to MA334P. That there was no systematic review of the industry is somewhat surprising, given the emergence of the Internet and the IT revolution at the time.

The MA334P (2005) introduced substantially updated product classes and was discontinued in 2006 and replaced by the MQ334P, which reports essentially the same product detail but is issued on a quarterly basis. This MA334P (2005) report was the starting point of our "working our way backwards" through Census publications.

In August 2006, the Census Bureau introduced a revamped system of detailed CIR product classes for the Communications Equipment Manufacturing industry. The new product class structure substantially modernized and updated the detailed product class structure used in previous issues of the report. An important—and somewhat unusual—feature of the new results was that previously issued data for 2004 were restated using the new product class structure. The restatement made possible the development of a detailed concordance between the new and the old product classes. The availability of this concordance enabled the construction of consistent time series for the new product detail back to the early 1990s. Many dynamic components of the industry began to be produced in large volumes then.

The MQ334P was discontinued in 2011. Henceforth official data will be limited to the annual 5-digit product groupings introduced in 1980 (and last renumbered, as 7-digit NAICS product groups, in 1997).

Spending

In principal, one can construct measures of spending using production estimates and Census figures on net trade.[54] In practice, the CIR concordances between production and trade that are shown since 1985 do not provide complete coverage of the communications equipment industry. In particular, the mappings for the newer, recently revamped product classes are incomplete, and in important ways: The components of data networking equipment and enterprise phone systems are not found in the Harmonized Trade System (HTS).

On the other hand, direct estimates of spending for many components are available from industry sources. For example, we use Dell'Oro, Gartner and Telecommunications Industry Association reports. Occasionally, these are difficult to align with Census figures on production and trade; in such cases we defer to the direct spending estimates.[55] All in all, from the late-1980s on, we find that information from industry sources yields a more reasonable picture of domestic spending on the *components* of communications equipment than do measures of component spending (more precisely, absorption) built from detailed data on production and net trade. That being said, the overall spending results are fairly well aligned with aggregate statistics on production less net trade.

[54] "Spending" refers to the domestic demand for communications equipment in the United States, which includes imports and excludes exports. Final demand from business, government, and household sectors is included.

[55] A specific example is private branch exchange (PBX) equipment—the equipment that switches calls within enterprises, provides voice mail and other functions, and routes calls to the public switched telephone network. Gartner and Synergy both report U.S. spending on PBX equipment in the neighborhood of $3.5 billion in 2005. In the CIR, PBX equipment production in 2005 is small at under $1 billion, but the trade data that reportedly correspond to this category of production show a trivial value for imports.

With regard to Census foreign trade data, in 1970, the MA-36N added appendixes comparing domestic shipments with exports and imports by five-digit product class. Concordances between detailed census product codes and trade codes also were shown. In 1985 exports and imports were no longer shown by five-digit product class; only sub-groups of detailed products were compared with the trade flows. In reports for recent years, the concordance does not include the information that is needed to determine the value of spending for detailed sub-components from data on the value of production, exports, and imports.

That being said, some important components of spending—central office equipment, satellites and related equipment, facsimile machines, and broadcasting equipment—are determined by the results of mapping detailed product classes for production to the harmonized trade system (HTS) used for classifying exports and imports. The CIRs are the primary source for these mappings and data, and their availability for the products listed above is from the early 1970s on.