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The broadband bonus: Estimating broadband Internet's economic value

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ABSTRACT

How much economic value did broadband Internet create? Despite the importance of this question for national policy, no research has estimated broadband's incremental contribution to U.S. GDP by calibrating against historical adoption and incorporating counterfactuals. This study provides benchmark estimates for 1999 through 2006 and finds that broadband accounts for $28 billion of the $39 billion observed in 2006. Depending on the estimate, households generated $20–$22 billion of broadband revenue and approximately $8.3–$10.6 billion was additional revenue created between 1999 and 2006. Consumer surplus accounted for $4.8–$6.7 billion of this amount, which is not measured in GDP. An Internet-access Consumer Price Index would have to decline by 1.6–2.2% per year for it to reflect this unmeasured value. These estimates differ from existing benchmarks by an order of magnitude and relate to several policy debates.

1. Introduction

How much economic value did broadband Internet create? This study examines this question during the first wave of broadband adoption in the United States between 1999 and 2006.

This is an interesting period in which to examine the value created during deployment and adoption. First, there were extensive changes in Internet access in this period. In September 2001 approximately 45 million U.S. households accessed the Internet through a dial-up connection, while only 10 million used a broadband connection.[2] Broadband became more reliable and more widely available thereafter, and, consequently, many households paid to upgrade their Internet service. By March 2006 approximately 47 million households (and growing) had broadband connections, while 34 million (and declining) used dial-up.[3]

This period also attracts interest because U.S. policy was altered to accommodate the belief that the upgrade had many positive economic features. At the start of the new millennium, for example, the Federal Communication Commission (FCC) adopted a set of policies designed to give telephone companies incentives to build out broadband access to homes, which cleared U.S. Supreme Court review in 2005.

The belief in the value of the upgrade persisted over time, and survived the scrutiny of distinct political philosophies, leading to more initiatives at the end of the decade. For example, the U.S. Congress added billions of dollars in rural

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[2] NTIA (2010) is the source for these statistics.
[3] See Horrigan (2007) retrieved from http://www.pewinternet.org/.

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broadband subsidies to the American Recovery and Reinvestment Act, popularly known as the Stimulus Bill, which was passed in February 2009. In the same month, Congress authorized the FCC to write a National Broadband Plan, which touched on universal service policy and competition policy for broadband in the United States. It was released in March 2010.

This study reexamines the economic premises behind these beliefs, addressing two related economic questions: (1) how much consumer surplus did broadband create for household users? and (2) how much did GDP increase from broadband?

The estimates in this study are as follows. While broadband accounted for $28 billion of Internet GDP in 2006 (out of $39 billion in total for Internet access), this study estimates that approximately $20–$22 billion was associated with household use. Of that amount, broadband's deployment created approximately $8.3–$10.6 billion of new GDP. In addition, between $6.7 and $4.8 billion constituted new consumer surplus. In both cases, this is above and beyond what dial-up would have generated. The newly created GDP is between 40% and 50% of measured total GDP, while consumer surplus (which is not measured) is between 31% and 47% of the newly created GDP.

By one yardstick these estimates are very low, and by another, very high. Specifically, these findings are much lower than those found in typical stake-holder funded policy analysis and lobbyist reports, which regularly estimate the benefits from broadband in the range of hundreds of billions of dollars. At the same time, official U.S. government statistics trend in the opposite direction. For example, the CPI for Internet access does not include an adjustment for the broadband upgrade. The study suggests that Internet-access price indices would have had to decline an additional 1.6–2.2% per year to account for the consumer benefits generated from merely upgrading to broadband.

The study is not arguing that broadband lacks value. Indeed, the estimates suggest the private incentives to upgrade were quite substantial. However, the estimates show that the scale of returns were not outsized, but, rather, comparable to the scale of monetary investment made by suppliers. Related, if there were outsized gains from these investments, then it was not in the direct economic gains from broadband. It would have to stem from complementary investments in applications and other software services, or in growth spillovers.

The study offers a perspective that differs from the existing literature about private incentives to build broadband. There has been no research accounting for Fogel's counterfactuals, namely, what would have happened in the absence of broadband.[4] No previous research defines what is included in the estimates of broadband's economic impact (as a direct effect), using a common economic definition for externality. There also has been no research calibrating the estimates against actual historical adoption. This study is the first to do all of the above.

This paper also covers areas that existing research has not covered.[5] This includes the forecast in Crandall and Jackson (2003) and its better-known working paper from July 2001. This study's forecasts were not calibrated against the experience after 2000, though many policy advocates treated the forecast as historical data. Later work contained many issues, such as the absence of correction for Fogel's counterfactual, included Connected Nation (2008), and Atkinson, Ezell, Andes, Castro, and Bennett (2010), which includes an economic forecast that largely relies on the estimates in Interactive Advertising Bureau (Internet Advertising Bureau, 2009). Each lacks a discussion of the role of Fogel's alternative and a precise definition of an externality, and lacks full calibration against historical data.

A more recent line of work, citing earlier drafts of this study, corrects for Fogel counterfactuals. This includes FCC (2010), known as the National Broadband Plan. It also includes Rosston, Savage, and Waldman (2010) and Dutz, Orszag, and Willig (2009). The latter two differ from the present study, however, in its focus on the estimating the heterogeneity in the willingness to pay for broadband in the most recent experience, and the determinants of its extraordinary skewness.

Another line of research, such as Hazlett and Caliskan (2008), has examined the broadband market from a different perspective.[6] It stresses how regulatory constraints shaped private incentives, while this study stresses the role of several additional factors, such as the identity of the producer, the size of potential business stealing and cannibalization, and the speed of household willingness to respond to new options.

While this study touches a contemporary policy debate, it aims at a broad research agenda, as outlined in Flamm, Friedlander, Horrigan, and Lehr (2007). They examined the poor state of U.S. statistics for the Internet and called for developing a new research on the economic impact of broadband.[7] Related, this study seeks to move towards a U.S. broadband policy informed by standard economic reasoning and transparent statistical approaches. To be clear, this study does not address all of the many important items in Flamm et al. (2007), such as, for example, business access to broadband or its impact on productivity. This study examines households only, leaving many items for future work.

The paper is organized as follows. Section 2 briefly discusses prior work and how this study's approach differs. Section 3 reviews standard statistics about the diffusion of Internet access between 1999 and 2006. Section 4 discusses the data.

[4] Fogel (1962) also pioneered use of calculation of a rate of return in comparing the size of the private and social benefits to an infrastructural investment. Insights into such effects will be apparent in the study's findings as well.

[5] Earlier drafts of this paper discussed these papers in detail. See NBER Working Paper 14758, February 2009, accessed at http://www.nber.org/papers/w14758.

[6] For an overview, see Goldstein (2005), Neuchterlein and Weiser (2005), and Greenstein (2008).

[7] Flamm et al. (2007) focus on a wide range of issues, such as measuring productivity and assembling new data to accommodate novel online economic behavior. The primary goal of our paper is to dig deeply into one aspect of this broad agenda.

Section 5 estimates the value created by the diffusion of broadband. Finally, Section 6 concludes with an assessment of future directions for policy discussions.

2. Policy and the economic benefits from broadband

Two key questions motivate the study. First, what is the increase in producer surplus (GDP) affiliated with the diffusion of broadband beyond what would have been generated had dial-up continued? Second, what is the increase in consumer surplus beyond what would have occurred had dial-up continued?

It is well known that these two questions require overlapping but not identical data.[8] The first question can be addressed (minimally) with information about costs and revenue and investment costs, or (more ideally) with prices and quantities. The second question requires (minimally) information about demand, namely, revenue and the willingness to pay for the upgrade to broadband, supplemented by (more ideally) prices and quantities.

A conventional economic approach measures the economic factors considered by the parties involved in a transaction—in this case, anything that shapes the perceived or anticipated costs and benefits of using dial-up or broadband. More precisely, broadband is one of many components in a network delivering value to end users. The other inputs include components such as software, personal computers, hosting services, content creation, content aggregation, electronic retailing services, search services, and so on. The parties involved in a transaction for broadband Internet access can anticipate some incremental value from that transaction, while the externalities are benefits or costs not considered by those parties.

This study's analysis of GDP growth assumes the following factors shape revenue for suppliers: sale of second phone lines, revenue for dial-up access, and revenue for broadband access. Information about the costs of generating this GDP will also be discussed. This definition also puts a boundary on externalities. For example, externalities pertain to suppliers who are not suppliers to cable or phone companies, such as Netgear, which sells more Wi-Fi equipment to broadband households than dial-up households; Amazon, which makes additional sales because broadband users experience more-satisfying service; or Google, which makes more incremental advertisement sales because users stay online longer. This study will highlight the open question about the size of those externalities.

The study focuses on estimating the changes in revenue in the final output market, and not changes in producer surplus. The latter requires precise data on investment expenses for build-out. At best, this study has ''ballpark'' estimates for such costs, and only in recent times.

When discussing consumer surplus, this study does include benefits that users anticipated. The following factors shape the anticipated value of broadband service and, hence, the willingness to pay for an upgrade: savings on a second line and/or dial-up subscription (which is also part of revenue loss/gain to other suppliers), anticipated savings on commute time, anticipated health and entertainment benefits, and anticipated savings on phone bills. Externalities are factors that would not shape perceived costs or gains. Several related mechanisms would produce both positive externalities (e.g., one household's participation online alters the value of participation for another) and negative externalities (e.g., online fraud). These factors are not externalities if they shape the anticipated benefits that generate a purchase, and otherwise they are. There is no way to tell from this data how (un)important these are. Once again, their size is an open question.

This study works with historical data on adoption of broadband and dial-up, and supplements it with assumptions about average prices. It will also use estimates about the average willingness to pay from surveys in the middle of the period.

Consistent with these definitions, total revenue will be the summation of broadband revenue, dial-up ISP revenue and second line revenue. Increases in revenue for a phone company in a given year will be change in broadband revenue and change second phone line revenue, where the first term is usually positive and the second is negative. This will be estimated as follows:

$$\text{(new broadband phone adopters)}*\text{(average price for broadband)}$$
$$-\text{(decline in dial-up adopters)}*\text{(average price for a second line)}.$$

The increase in revenue for a cable broadband provider will be the following:

$$\text{(new cable broadband adopters)}*\text{(average price for broadband)},$$

since there is no second line revenue. To get total change in access revenue requires an additional term:

$$\text{(change in dial-up ISP users)}*\text{(average dial-up ISP price)}.$$

Estimating these requires information about how many former dial-up users convert to become new broadband adopters in a given year and how many broadband adopters are new users, which is something discussed below. To estimate producer surplus requires additional information about private costs of supply.

[8] This conceptual point is well known, but easily overlooked by self-interested policy discussion. Comparing changes in revenues from technical improvement is not the same as improvements due to a high willingness to pay for the improvement. If the consumer surplus is large for broadband at competitive prices, research measuring prices paid will miss the gains to consumer surplus. It is also possible for revenues to increase or not, quite independent of the gains to consumer surplus.

Consumer surplus in a given year comes from estimates of willingness to pay for broadband over dial-up among existing dial-up users, revenue for broadband, dial-up ISP revenue, and second line revenue. Total change in surplus due to adoption of broadband, once again, requires information about knowing what fraction of broadband adopters converted from dial-up, such that the increase in willingness to pay exceeded the increase in expenditure for broadband, dial-up and a second line.

The research challenge is to calibrate the value for each year against the actual history of broadband use, dial-up use, and second-line use in the United States. This represents a novel approach for the literature.

3. Measuring broadband services

The diffusion of dial-up coincided with the initial use of the Internet in most households. Broadband became available in only a few locations in the 1990s and the early 2000s, and became more available over time. Many households adopted it thereafter.

In this period broadband service was delivered to households primarily in two forms of wire-line service—over cable or telephone lines. The former involved a gradual upgrade to cable plants in many locales, depending on the generation of the cable system.[9] The latter involved upgrades to telephone switches and lines to make it feasible to deliver a service called digital subscriber line (DSL). Both of these choices typically supported higher bandwidth to the household than from it—typically asymmetric digital subscriber line (ADSL) in the latter case. Some cable firms built out their facilities to deliver these services in the late 1990s, and many—especially telephone companies—waited until the early to mid-2000s.

Broadband has several appealing features. In comparison to dial-up service, broadband provides households with faster Internet access and better online applications. In addition, broadband services are also "always on," and users perceive that as a more convenient service.[10] Broadband also may allow users to avoid an additional phone line for supporting dial-up.

Many factors shape the quality of a user's experience, such as the capacity/bandwidth of lines, the number of users in the neighborhood in a cable system, the geographic location of a system in the national grid, the frequency of use of sites with geographically dispersed caching, and the time of day at which the household performs most activities. In brief, generalizations are hard to make beyond the obvious: broadband gives the user a better experience than dial-up access.[11]

Fig. 1 illustrates results from the federal government's efforts to collect data about Internet adoption during the decade of the study's sample period.[12] The first questions about broadband use appeared in 2000 and showed a growth in adoption, peaking at close to 20% of households in 2003, when these surveys were discontinued for some time, forcing a linear interpolation in Fig. 1, which masks the true pattern of adoption and conversion.[13] Data about household use, collected by the Pew Internet and American Life Project, show that diffusion continued in the anticipated direction, but was not linear.[14] Notably, adoption reached more than 47% of households by 2006.

Table 1 provides the FCC's efforts to measure the deployment of broadband lines.[15] It tells the vendor-side of the market: vendors were increasingly deploying broadband lines, presumably to meet growing household demand. Once again, the linear growth does not quite match the data.

There are no revenue estimates for household broadband services, but it is possible to place a bound on an estimate for the combination of household and business revenues. The U.S. Census Bureau estimates revenues and publishes these in its Annual Service Survey. Table 2 provides an adjusted summary of these reports (see Appendix A).[16] That suggests that

[9] In many areas, households also had access to direct supply of high-speed lines, such as T-1 lines. This was prohibitively expensive for almost all users except businesses, and even then, it was mostly used by businesses in dense urban areas, where the fiber was cheaper to lay. Fiber to the home has recently become cheaper, and may become a viable option sometime in the future. See Crandall (2005). During the 1990s most cable companies sold access to the line directly to users, but made arrangements with other firms, such as Roadrunner or @Home, to handle traffic, routing, management, and other facets of the user experience. Some of these arrangements changed after 2001, either due to managerial preferences, as when @Home lost its contract, or due to regulatory mandates to give users choice over another Internet Service Provider (ISP), as occurred after the AOL/Time Warner merger. See Rosston (2009).

[10] Surveys show that a maximum rate of 14.4 K (kilobytes per second) and 28.8 K were predominant in the mid-1990s for dial-up modems. The typical bandwidth in the late 1990s was 43–51 K, with a maximum of 56 K. DSL and cable achieved much higher maximum bandwidths, typically somewhere in the neighborhood of a maximum rate of 750 K to 3 M (megabytes per second), depending on the user choices and vendor configuration.

[11] While engineers understood that download speed may not reach the advertised maxima, there was considerable contemporary debate about whether users understood this fact. In cable networks, for example, congestion issues were possible during peak hours. In DSL networks, the quality of service could decline significantly for users far away from the central switch. The results are difficult to measure with precision. This debate is summarized succinctly in Connecting America, The National Broadband Plan, retrieved from http://www.broadband.gov/.

[12] This figure comes from NTIA (2010). The first government surveys of household Internet adoption date back to 1997, building on surveys of home personal computer use begun a few years earlier. These came from additional questions in the CPS supplement, which had added questions about household use of personal computers in 1995 (see NTIA, 1995). These were continued with surveys in 1997, 1998, 2000, 2001, 2003, 2007, and 2009 (NTIA, 2010). The survey was stopped after 2003, reinitiated in October 2007 without questions about PC use. CPS supplement surveys prior to 1997 also examined PC use at home, but asked about use of generic online services, such as CompuServe, not Internet access.

[13] The descriptive results were published in NTIA (2010).

[14] See http://www.pewinternet.org/. More details are discussed in later sections.

[15] The FCC has never asked about deployment of dial-up. It also has never asked about the prices of broadband.

[16] The adjustments are for changes in sampling frame; the Census does not return to historical estimates and review the sampling frame of prior estimates to make all the estimates consistent over time.

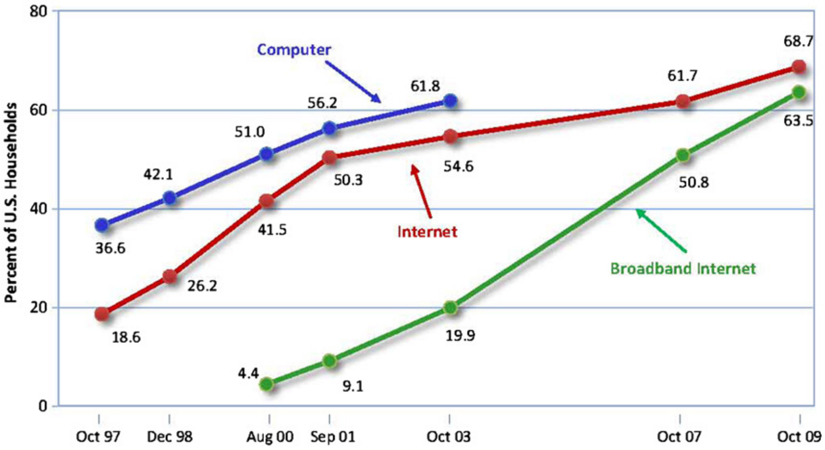

Fig. 1. Percent of households with computers and Internet connections, selected year, 1997–2009*.

Table 1
Residential broadband deployment, 100s of households.
Source: Federal Communications Commission.

Year	1999	2000	2001	2002	2003	2004	2005	2006
DSL	2918	15,949	36,160	55,292	89,090	131,193	173,711	201,433
Cable	14,024	32,945	70,507	13,425	164,164	212,702	246,900	277,204
Satellite	502	1024	1950	2570	3419	4226	5294	18,394

See http://www.fcc.gov/wcb/iatd/comp.html, *Broadband Reports*, Table 3, for precise definitions. This table covers any line with at least 200 kps advertised in *either* direction.

Table 2
Adjusted revenue for access markets (millions of dollars).
Source: Census Annual Surveys. See Appendix A for adjustments.

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006
Dial-up	5499	8966	12,345	13,751	14,093	14,173	14,081	12,240	10,983
DSL		228	1245	2822	4316	6954	10,240	12,034	15,066
Cable modem	138	274	903	2600	4117	7372	9435	11,139	13,156
Wireless							668	1140	.

between 60% and 75% of the revenue in Table 2 came from households, depending on the year and access mode.[17] The growth in revenues in Table 2—from $5.5 billion in 1998 to $39 billion in 2006—is astonishing for an entirely new market, especially one that did not start growing quickly until after 1995. Broadband revenues constitute approximately half the total revenue over the eight years, beginning with less than 6% in 1999 and growing to 72% of the total revenue in 2006.

These revenue levels are important to stress, because access fees generated most of the revenue during the first decade of the commercial Internet. The typical household spent more than three-quarters of its time online at free or ad-supported sites, devoting most of its Internet budget to access fees, not subscription fees.[18] Although subscription-based services and advertising services have started growing rapidly after 2003, the amount spent on access fees each year far exceeds advertising revenue. Advertising revenue is now growing at a more rapid pace than subscription fees, and it may exceed access revenue soon, but not as of this writing.[19]

[17] This estimate comes from the following: First, the estimates below suggest household revenue for the Internet overall makes up 70–75% of the total revenue. Second, the FCC broadband deployment report puts the number of broadband lines to households at roughly two-thirds of the total number of lines deployed. Since revenue per line for business likely exceeds that for households, it is plausible that household revenue is closer to 60% of total revenue. See Table 13: High Speed Services for Internet Access, which can be retrieved from http://www.fcc.gov/wcb/iatd/comp.html. Hence, the text says "60% to 75%." Note that Tables 1 and 2 are not comparable, since Table 1 is for households only, while Table 2 is for households and businesses.

[18] See Goldfarb (2004).

[19] The following will provide a sense of the magnitudes of different activities. In the 2006 Annual Services Survey, retrieved from http://www.census.gov/services/sas/historic_data.html, Web search portals generated $6.3 billion in advertising in 2006, out of $9.1 billion in total revenue. This is up from $4.5 billion and $3.3 billion in advertising revenue in 2005 and 2004, respectively. In addition, Internet publishers generated $2.6 billion in revenue in 2006, up from $2.3 billion and $1.8 billion in 2004 and 2005, respectively. That is still far less than the $39 billion in access revenue in 2006.

Table 3
Household statistics, 1999–2006 (MM).
Sources: See text.

Year	1999	2000	2001	2002	2003	2004	2005	2006
Total households	105.0	106.0	107.0	108.0	109.0	110.0	111.0	112.0
Total internet adopters	35.5	44.0	53.8	56.7	59.5	66.0	73.3	81.8
Total broadband adopters	0.9	3.2	9.6	13.0	18.5	27.5	41.1	47.0
Total dial-up adopters	34.5	40.8	44.2	43.7	41.0	38.5	32.2	34.7
Total second phone lines	23.6	26.2	26.3	18.4	16.0	13.8	12.1	10.5

4. Data

Table 3 summarizes the data used for adoption. Broadband revenue comes directly from the adoption data and estimates of average prices. The estimate about lost dial-up and second line revenue will use estimates of average prices for dial-up ISPs and second lines, and calibrating the 1 conversion from dial-up to broadband, which is why this study's estimates consider different assumptions about average prices and about the rates of conversion. Now follows more detail about the sources for Table 3's data.

4.1. Adoption of the Internet

To derive the total number of adopters, the percentage use of dial-up and broadband technologies are estimated across all households and then multiplied by the percentage of adopters across all households.[20] Data about household use of dial-up and broadband Internet come from two sources, the National Telecommunications and Information Administration (NTIA) and Pew. [21] This study uses the NTIA estimates through 2003 and uses the Pew estimates thereafter. Pew's data are good for measuring adoption, but incomplete for measuring price and quality.[22] Data about total number of households come from the U.S. Census estimates.

4.2. Second lines

Table 3 provides estimates of the total number of households in the United States with at least one second line. These come from FCC reports, which do not break out second-line use into its primary purpose.[23] Prior research has shown that several factors determined the growth of second lines in the 1990s, including use of the Internet.[24] The growth and decline in households with second lines is highly correlated with the growth of dial-up Internet access and its replacement with broadband lines.[25] For example, in the latter part of the 1990s, the use of second lines grows from 11.4% in 1994 to 26.3% in 2001. It declines after 2001—from 26.3% to 10.5% in 2006.[26]

These trends put bounds on estimates of the second lines supporting Internet dial-up. For example, 16 million households had an active second line in 2003, a decline from 18.4 million in 2002. The 2.4 million drop in second phone lines represents the upper bound for dropped lines by broadband adopters, meaning that a maximum of 53% of dial-up converts dropped a line that year.[27] The percentage varies between 2002 and 2006, rising no higher than 53% and falling no lower than 25%.[28]

[20] This method is preferable because it builds on surveys of users rather than estimates of broadband deployment, such as those kept by the FCC. That choice does not matter until the end of the sample. While the FCC numbers do not differ much overall from Pew's, they do differ recently, and it produces one minor issue, a slight uptick in dial-up adopters between 2005 and 2006 (which in the greater scheme of things matters very little in our simulations). The Pew data are preferable because they are consistent with the data from the NTIA, and surveys of users also inform about other relevant factors for the estimates below.

[21] For years between 1997 and 2003 when there was no direct observation, an interpolation between the two closest known measures of adoption percentage with a target towards midyear is used.

[22] Pew's surveys were supervised by John Horrigan. The surveys ask a variety of questions, most recently including questions about bandwidth, prices, and use, but did not get complete answers. For example, 80% of respondents did not know the advertised bandwidth/speed of their broadband in the 2005 survey. John Horrigan, private communication (July 2008). Though advertised and actual bandwidth/speed can vary, as of this writing there is no consensus benchmark for measuring actual delivery of bandwidth, so this study contains no viable way to make an adjustment for the quality of service. This is an important topic, and a subject of on-going research. See for example, Wallsten and Mallahan (2010), Bauer, Clark, and Lehr (2010), or Greenstein and McDevitt (2011).

[23] See the FCC's (2007) Trends in Telephone Service, Table 7.4: Additional Residential Lines. Retrieved from http://www.fcc.gov/wcb/iatd/trends.html.

[24] See Duffy-Deno (2001) and Eisner and Waldon (2001).

[25] The other primary driver of the decline in second lines is the growth of cell phone use.

[26] The last available year of data is from 2006, as of this writing.

[27] Strictly speaking, the upper bound could be larger if more than 2.4 million broadband adopters dropped a second line at the same time others were adding lines, since only a net change is observed.

[28] In other years, different percentages obtain, and prior to 2002 there is no decline in use of second lines one year to the next. Clearly, increasing use of cell phones has something to do with the decline in addition to declining use of dial-up Internet. The FCC does not distinguish between these causes.

Table 4
New revenue created by broadband each year (100 thousands of dollars).
Source: Authors' calculations. See Appendix A.

Year	Total	1999	2000	2001	2002	2003	2004	2005	2006
Baseline high price[a]	105,954	2269	5364	15,480	7374	12,334	19,863	30,050	13,220
Baseline low price[b]	83,374	1814	4291	12,384	5776	9661	15,558	23,536	10,354
Aggressive conversion[c]	83,265	2269	5364	15,480	5354	8956	14,423	21,820	9599
Not aggressive[d]	114,105	2698	7245	21,321	7374	12,334	19,863	30,050	13,220

[a] Baseline high price: Broadband price = $40; 100% are converts 1999–1901; 81% converts 2003–2006.
[b] Baseline low price: Broadband price = $36; 100% are converts 1999–1901; 81% converts 2003–2006.
[c] Aggressive conversion: Broadband price = $40; 100% are converts 1999–1906.
[d] Not aggressive conversion: Broadband price = $40; 81% converts 1999–1906.

Table 5
Consumer surplus in 100 thousands of dollars (as a fraction of sum of consumer surplus plus revenue).
Source: Authors' calculations. See Appendix A.

Year	Total	1999	2000	2001	2002	2003	2004	2005	2006
Baseline high price[a]	(31.2%) 48,187	680	1609	4644	3672	6142	9892	14,965	6583
Baseline low price[b]	(44.4%) 67,357	1134	2682	7740	4967	8309	13,379	20,241	8905
Aggressive conversion[c]	(43.2%) 63,497	680	1609	4644	5035	8421	13,563	20,518	9027
Not aggressive[d]	(30.0%) 46,879	551	1303	3761	3672	6142	9892	14,965	6583

[a] Baseline high price: Broadband price = $40; 100% are converts 1999–1901; 81% converts 2003–2006.
[b] Baseline low price: Broadband price = $36; 100% are converts 1999–1901; 81% converts 2003–2006.
[c] Aggressive conversion: Broadband price = $40; 100% are converts 1999–1906.
[d] Not aggressive conversion: Broadband price = $40; 81% converts 1999–1906.

The base specification below will try to identify the role of assumptions about second lines. Specifically, it assumes that one-third of broadband adopters drop a second line between 2002 and 2006, while it assumes no broadband adopter drops a second line between 1999 and 2001. That results in the right level of dropped second lines by 2006. It is a conservative approach (i.e., a deliberate undercount).

A second telephone line can cost a household as little as $16 a month in some cities and as much as $24 before including per-minute usage charges, which are generally low. The simulation uses the average of $20.

4.3. *New users and converts*

There is no way to know the rate of conversions precisely since public surveys only ask about total adoption in a given year, and do not provide a yearly tally of new Internet users. Neither the NTIA reports nor the Pew reports provides statistics for each year about whether new broadband adopters are new Internet users or converts from dial-up.[29]

This study's baseline specification assumes a pattern of conversion consistent with historical facts. It assumes that 100% (all 10 million households) are converts in 1999–2001. There are approximately 37 million additional adoptions in 2002–2006, with 31 million of those occurring prior to 2005. The number of new users finally becomes large enough to notice near the end of the sample, but cannot exceed 50% of the 6 million adopters in 2006, and, to remain consistent with Horrigan's observation, it must be less than 50% of the 14 million adopters in between 2004 and 2005. In other words, 10 million new Internet users among broadband adopters is too high a number, and 3 million is too low. For lack of a better number, the baseline estimate will split the difference and assume 7 million in the baseline specification, then test alternatives assumptions. The baseline, therefore, estimates that 30 million broadband adopters between 2001 and 2006 were converts from dial-up. For convenience, it will assume an 81% conversion rate for 2002 through 2006 (instead of concentrating it all in 2005 and 2006).

To test the importance of this assumption, the estimates include extreme bounds (81% convert rate and 100% convert rate for all years). These bounds will move estimates in a predictable direction, and show that this assumption affects the final level of the estimates, but not the qualitative inference. Below, in rows three and four of Tables 4–6, a summary of such extreme bounds in comparison to the benchmark estimate is provided.

[29] At first there was good reason for the lack of information in surveys; when broadband initially began to diffuse there was no question that virtually all household broadband adopters had experience with dial-up before upgrading. Some new users, however, moved directly to broadband in later years. As illustration, in his report describing adoption behavior in the Pew survey between 2005 and 2006, John Horrigan, the Pew researcher who analyzed the results, mentions that new Internet users constituted a large percentage of the adopters of broadband that year. Altogether, this suggests the vast majority of the broadband adopters between 1999 and 2004 were former dial-up users, while that was unlikely in the last year, between 2005 and 2006.

Table 6
Weighted average of price decline.
Source: Authors' calculations.

Year	1999	22000	2001	2002	2003	2004	2005	2006	Average
Baseline high price[a]	99.6	99.3	98.4	98.9	98.3	97.5	96.6	98.7	98.4
Baseline low price[b]	99.4	98.9	97.3	98.5	97.7	96.7	95.5	98.3	97.8
Aggressive conversion[c]	99.6	99.3	98.4	98.7	97.9	96.7	96.0	98.2	98.1
Not aggressive[d]	99.7	99.4	98.7	98.9	98.3	97.5	96.6	98.8	98.5

[a] Baseline high price: Broadband price=$40; 100% are converts 1999–1901; 81% converts 2003–2006.
[b] Baseline low price: Broadband price=$36; 100% are converts 1999–1901; 81% converts 2003–2006.
[c] Aggressive conversion: Broadband price=$40; 100% are converts 1999–1906.
[d] Not aggressive conversion: Broadband price=$40; 81% converts 1999–1906.

4.4. Price levels

Prices are not observed directly. Consistent with the generally reported patterns for nominal prices and for simplicity, the estimates assume for all of the simulations that price is unchanging over time, setting the average price level for dial-up at $20.[30] That price is the reported average dial-up price for users in two CPS supplements in the 1990s.[31] The estimates assume the average price for broadband is either $36 or $40, depending on the simulation. Again, this is consistent with reported price levels in Pew reports and other research.[32]

5. Benchmarks

The estimates show the revenue generated by broadband and then consider estimates of consumer surplus. Following are estimates of an equivalent price index. Throughout, the estimates maintain a conservative approach and show how a range of assumptions alters the qualitative results. Unlike an econometric exercise that varies parameters to estimate demand, this study holds fixed the known facts about broadband's deployment (i.e., Table 3) and shows how changes to key assumptions about the underlying features of conversion alter inferences about consumer surplus and new revenue generation.

The estimates maintain the comparison between broadband and a counterfactual, namely, what would have been supplied by dial-up in the event that broadband had not arisen. This is kept to a straightforward counterfactual: for example, it does not consider endogenous technical change, such as how other complementary services might have changed (e.g., music or video downloads) had the counterfactual technology (dial-up) remained dominant and un-replaced by broadband.

5.1. Creation of new revenue

Consider a calculation in a single year, 2003. This will illustrate a full accounting of the new revenue affiliated with broadband, and illustrate the principles that apply to all years.

Because the average price of residential broadband access was somewhere between $36 and $40 a month in 2003, residential broadband generated an annual revenue of somewhere between $8 billion ($36/month × 12 months × 18.5 million households) and $8.9 billion (if the price is $40/month).

The conversion rate gives an estimate for how many new broadband users formerly used dial-up. With an adoption rate of 81%, converts—those who switched from dial-up—generated between $1.9 billion and $2.1 billion in revenue. 4.3 million households of broadband were converts. The new 1.2 million adopters of the Internet (not converts) generated between $455 million of revenue (if the price was $36) and $505 million of revenue (if the price was $40) in 2003.

That leads to a calculation of the proportion of revenue generated by dial-up converts that was cannibalized, that is, when the revenue source changed while staying within the same firm. If the average price of dial-up Internet access was $20 a month, it would account for $1.1 billion of cannibalized revenue. In addition, there was a loss of revenue from retired second phone lines, with which many households had supported their dial-up Internet. Using 2003 as an illustration once

[30] One could examine the effect from small price fluctuations. This study does not do so since, for obvious reasons, the qualitative results change very little.

[31] It is also the median price in Savage and Waldman (2004) and Stranger and Greenstein (2007). The CPS supplement asked about monthly expenditure in only two years and not thereafter. The consumer expenditure survey, however, continued to ask about online expenditures for Internet services every year. While it is not a price index, it looks close to prices (but does not distinguish between use of broadband and dial-up until after 2001). Once again, it seems to indicate little change in average price. It becomes less reliable as an indicator as conversation to broadband accelerates. The difference between some expenditure and none is a good indicator of a household's use of the Internet, and correlates with changes in other levels of expenditure for related goods, such as music and videos, as well as other forms of entertainment (see Hong, 2007).

[32] For U.S. price quotes, see Savage and Waldman (2004), Chen and Savage (2011), Crandall, Sidak, and Singer (2002), Rappoport, Kridel, Taylor, Dunny-Deno, and Alleman2003a) and Flamm and Chadhuri (2007). All indicate average broadband prices in the ranges assumed.

again, newly retired phone lines from dial-up converts amounted to a loss of $357 million in revenue for phone companies in 2003. That puts the total opportunity cost of lost dial-up revenue and second-line revenue at $1.4 billion.

In summary, broadband created additional revenue between $964 million and $1.2 billion in 2003. That accounts for both new revenue and cannibalized revenue from former dial-up users and retired second phone lines.

Table 4 shows the result for similar calculations for each year, 1999–2006, which are provided in Appendix A. The aggregate revenue gain for 1999–2006 stemming from broadband adoption is $10.6 billion in the baseline specification when broadband prices are $40. That is 46% of an estimated $22.6 billion in total revenue at the end of the sample (i.e., 47 million households × 12 months × $40 per month).

How do different assumptions shape the benchmark? Table 4 shows the results. Specifically, if prices are $36 instead of $40, then the total estimate reaches $8.3 billion (41% of $20.3 billion). If all broadband adopters are converts (which is a higher rate of conversion than could have actually occurred) and prices are $40, then the estimates of revenue gains are $2.3 billion lower than in the baseline case. If 81% of adopters are converts every year (which is lower rate) and prices are $40, then the estimates are $0.9 billion higher.

In other words, while changes to each of these assumptions about the rate of conversation move the estimate for the level of created new revenue in each year in the expected direction, none of these alters the general pattern over time as more households switch from dial-up to broadband, remaining within 20% of the benchmark all of the time, and within 10% most of the time. The additional revenue from the adoption of broadband is large, somewhere between 40% and 50% of measured revenue for households.

GDP includes measured total revenue, less adjustments for double counting for costs (which can be someone else's revenue), which is why this study focuses on the changes in revenue in the final output market. Total measured revenue is not an estimate of additional revenue. Approximately 40–50% of that measured revenue is new. This means that 60–50% of the measured revenue replaces revenue in dial-up and second lines with revenue in broadband—an amount that is a combination of business stealing (when revenue goes from one company to another) or cannibalization.

It is possible to redo the simulations with one additional change, accounting for changes in dial-up's prices in late 2006, after AOL dramatically lowered its prices and competitors followed. The only appreciable effect is that converts no longer save $20 at the end of 2006 (when AOL's prices become zero after September 2006). That reduces the cannibalized revenue from converts by approximately $500 million in 2006.[33] This makes a little difference in that year, but does not change any other inference.

There is one additional way to look at these results, in terms of the total revenue change over the eight years from 1999 to 2006, which is not expressed in Table 4. This is one number and here is how to calculate it: The largest gains come from those households who adopt in 1999. In their first year of adoption they generate a $226 million gain (in the baseline estimate with a high price). Assuming they receive the same revenue gain in all subsequent seven years in comparison to the alternative, which is going back to dial-up. The same reasoning holds for the group that adopts the next year in 2000. By this reckoning the total revenue gains over the eight years are 36.8 (29.0) billion for high (low) price baseline estimate.

Is that a big number? It depends on the point of comparison. It is 36% (29%) of the size of the total revenue ($100 billion) generated by dial-up over the same time period (adding revenue from 1999 to 2006 from Table 2). The majority of it comes from the latter part of the sample when there is more adoption.

5.2. Reinterpreting incentives for build-out

These calculations so far have focused on revenue gain, but not included costs of a build out. Adding such information provides insights about economic incentives to perform upgrades and provide new insight into a debate about the role of regulatory policy. For example, other research has noticed that cable companies were the dominant supplier of broadband at the beginning of the diffusion of broadband, but local telephone companies had a slightly higher market share than cable companies by 2006.[34] Hazlett and Caliskan (2008), for example, build an analysis that argues the timing of the switch in market share is consistent with changes in regulatory rules. This study's analysis shows that costs and other factors shaped incentives too. These depended on the identity of the provider, the density of the location, and technical change (i.e., decreasing costs of build-out). In short, regulation may have played a role, but so did other factors.

Most estimates for the costs of upgrade are not precise enough to map directly into the data in Table 3, but it is possible to get in the ballpark. Estimates from the early millennium put the cost of initial upgrading of lines to cable and DSL at $400–$500 per household in most urban settings, with slightly higher estimates for suburban settings (e.g., an additional $100 dollars) and much higher estimates for rural settings (e.g., another $500–$1000 per household or more). In all cases, these cost estimates decline over time to the industry rule-of-thumb for per-household upgrade costs—as little as $250

[33] That figure assumes that AOL has 13.1 million households in 2006, which is a 38% decline from the prior year, when the level was 19.5 million households. Those 6.4 million households faced an opportunity cost of $20 a month for eight months of 2006 instead of twelve, which reduces the opportunity cost close to $500 million. The data on AOL come from Alex Goldman's market share rankings, retrieved from http://www.isp-planet.com/research/rankings/usa_h.html.

[34] This is one place where the data from Pew and the FCC do not entirely agree. Table 1 (from the FCC) gives high market share to cable in the latest years (2005 and 2006) while Table 3 (from NTIA and Pew) does not. They generally agree in prior years. If the FCC's data are correct, then the statement in the text is not correct, and cable firms have done better in the later years than telephone firms.

(for cable) and $150 (for basic DSL) for residences in dense urban settings, which is reasonable for the end of the sample.[35] In most cases, post-adoption maintenance costs are estimated to be low, at just more than $100 per household per year.[36]

What do those costs mean? Consider the following illustration for a cable firm that does not experience any cannibalization. Assume the firm upgrades its system for 2500 homes and expects only 20% of them to take up the service. A cost of $250 per household results in new revenues (at $480 a year) in Internet service. With a ten percent borrowing cost, this will cover the cost of the upgrade in four years.[37] Additional revenue through (VoIP) telephone service could result in covering those costs sooner. Higher take-up rates also resulted in covering costs sooner. Earlier in the period those costs were higher, so more revenue was required to cover costs. A similar calculation holds for DSL.[38] In other words, for most providers, the private incentives to upgrade were sufficient to motivate investing in upgrading most urban and suburban areas, and would not have been sufficient only if regulatory rules severely reduced revenue. Similarly, take-up rates would need to be extraordinarily high to justify even a monopoly build-out in most rural areas.[39]

Table 4 leads to a reinterpretation of one common occurrence in recent communications industry lobbying: cable firms have crowed in public forums about the industry's willingness to invest in the last decade, as represented by their aggregate capital expenditure. The industry's total capital expenditures between 1999 and 2005 amounted to $87.1 billion, never dropping below $10 billion in any given year. Some of this covered the costs replacing depreciated capital, to be sure. Yet the acceleration in expenditure after 1998 (from $5 to $10 billion or more annually) is consistent with expenditure aimed to convert cable systems to a digital delivery of cable services,[40] as well as facilitate additional services, such as telephone and Internet access.[41]

This analysis does not contradict Hazlett and Caliskan (2008), who argue that telephone companies faced regulatory uncertainty in the earlier part of this sample period over the treatment of their investments, and that uncertainty can explain why telephone companies reacted to the market opportunity in broadband less aggressively than cable companies.[42] Rather, the analysis adds several additional explanations for the same outcome. Cable did not cannibalize any existing revenue stream, such as from second telephone lines or an existing dial-up ISP (e.g., Ameritech.com). Even without regulatory uncertainty, incremental gains at cable firms were higher than at a local telephone company, and that should induce faster deployment. That is, cable companies should have been willing to address costly areas that telephone companies were unwilling to address.[43] In either case, the only big revenue losers were dial-up ISPs, from whom all the

[35] David Burstein, editor of DSL Prime, private communications, September 2008. See also Crandall (2005) for a range of estimates from a variety of sources. In a cable setting this assumes the HFC network has already been built out to support two-way access. It is impossible to infer from public data for cable firms, which mixes upgrades for a variety of services in one reported number. Following OECD (2007), Chapter 5, in the case of DSL, this assumes the main cost elements are: customer premises equipment (modem); local loop (access/operational fee for the copper twisted pair); digital subscriber line access multiplexer (DSLAM); aggregation network (L2 switch); broadband remote access server (BAS); and a management system. For a closely related set of estimates, see http://www.ictregulationtoolkit.org/en/PracticeNote.aspx?id=2899. For more recent estimates, see Elixmann, Ilic, Neumann and Plückebaum (2008).

[36] Note what these assumptions imply for a static definition of producer surplus using yearly variable costs. At $480 dollars per year in revenue and $100 in yearly cost, the variable profits per household are $380. With 47 million households in 2006, that implies $17.8 billion in variables costs (absent other capital upgrade expenses). That static view seems less relevant to us than a definition that incorporates the cost of initial retrofit to enable cable modem service or DSL service, which is the spirit of the discussion below.

[37] Even though only 20% adopt, the revenue has to cover cost of upgrading all homes, which is assumed to be incurred at the outset. Maintenance expenses, however, are assumed to be incurred continuously, and only for adopting households (at $8.33 per month). At 2500 households and $250 per household, the total expense is $625,000. With $40 per month in revenue, the investment costs are covered in 43 months with a 5% discount rate. With a 10% the investment costs are covered in 48 months.

[38] If the costs to upgrade were $150 instead of the $250, then for the same number of homes and without any other changes (i.e., 20% take rate, 10% discount, 100/year maintenance expense, and $40/month revenue) the investment covers itself in 27 months. If prices for DSL service reach (a more plausible) $30 per month then the investment covers its expense in 41 months. That said, overall the calculation is more plausible with cable firms than telephone firms for reasons alluded to in the text, because national broadband policy for cable investment did not appreciably change over this period. Hence, it is possible to examine investment and its consequences in a constant regulatory policy environment. In contrast, the changes in telephone broadband investment were complex over this time period, so the simulation should include an adjustment for regulatory risk, which is impossible to estimate. For overview of changes to regulatory policy, see Goldstein (2005), Neuchterlein and Weiser (2005), and for a focus on Internet access see Greenstein (2008).

[39] For example, consider a cable firm that does not face any cannibalization issues. Even with a 50% take up rate, the economics are not favorable for a $40 service for a rural community of 2500 homes with $1500 per household upgrade costs and $100 per household maintenance costs. With 10% discount rate, investment costs are not covered until after 175 months. This may simply be cost-prohibitive.

[40] The number of digital households increased from 12.2 million households in 2001 to 30.4 in 2006. See http://www.ncta.com/Statistic/Statistic/DigitalCableCustomers.aspx.

[41] The number of households with voice service from cable firms grew from 1.5 million in 2001 to 7.5 at the outset of 2006. The growth has accelerated thereafter, reaching 15.1 at the end of 2007. See http://www.ncta.com/Statistic/Statistic/ResidentialTelephonyCustomers.aspx.

[42] The evidence for this statement is partially evident in Table 1, which shows the growth of household lines. Over this period, cable reached levels of adopters typically two years sooner than similar levels by telephone firms. It is only partially evident in Table 2, which shows revenue growth, because this includes both household and business growth. Cable firms, however, get very little of their revenue from business customers, while telephone companies get a much higher fraction. For example, comparing FCC statistics on broadband diffusion to all users with those for residential users for January 2006 suggests that less than 3% of the cable lines go to business customers (0.8 out of 29.1 million), while business generates a much higher fraction of telephone company revenue: just more than 10% of ADSL lines (2.4 out of 22.5 million) and 35% of fiber lines (244,000 out of 685,000). See Tables 1 and 3 in the reports for high-speed services for Internet access, retrieved from http://www.fcc.gov/wcb/iatd/comp.html. Hence, Table 2 also suggests that cable modem access grew sooner than DSL.

[43] To be clear, the statement holds in monopoly markets or settings where each firm has market power in the broadband market. In a competitive setting the statement depends on expectations. If local telephone companies invest recognizing that they will lose the second line revenue and dial-up

business stealing took place. In some cases, this also was a telephone company, and that cannibalization concern also would have reduced net gains to telephone firms.

To summarize, several factors played a role in calculating incremental gains, such as the identity of the producer, the size of potential business stealing and cannibalization, and the speed of household willingness to respond to new options. Looking at it this way, it should come as no surprise that private firms invested large sums of money when the additional gains from doing so were potentially large, as they were for cable firms facing no cannibalization issues over all this time period, and as they were for both cable firms and telephone firms that faced low upgrade costs in urban and suburban settings later in this time period.

5.3. Creation of consumer surplus

In most studies, estimates of broadband demand indicate that there is substitution between different forms of broadband – that is, substitution between cable and DSL – but only weak substitution between dial-up and broadband. The latter places some constraint on demand for broadband, but not much. There also is evidence of upgrade behavior, with broadband constraining dial-up demand, but not vice-versa.[44] Estimates of broadband demand generally find that it is elastic, though U.S. estimates tend to be lower than those of households in other countries.[45]

The estimates of consumer surplus in this study rely on one set of estimates from Savage and Waldman (2004). This study is representative of the type of findings seen in other studies, but easier to use in this context. These authors conducted an extensive survey of dial-up and broadband users in 2002. This study is based on slightly later data than other studies, and also because it included both users and nonusers. In addition, the authors used this survey to directly estimate willingness-to-pay measures for attributes of dial-up and broadband service, which facilitates some simple accounting of the value of broadband in comparison to dial-up for existing dial-up users, which helps estimate the gains to conversion.[46]

Savage and Waldman's estimates of the willingness to pay for broadband are net of benefits users receive from dial-up. To remain consistent with their model, users are assumed to adopt broadband if the additional benefit exceeds the additional cost of converting. The conversion cost sums (1) the increase in subscription fees and (2) the net savings in expense for a second line. If the price of broadband is \$36, then the average increase in subscription fee is \$16 (\$36 less \$20). Additionally, many converts dropped a second phone line, saving, on average, \$20 per month. This impact affects the average consumer surplus of converts differently each year, depending on the average drop rate.

For example, Savage and Waldman's lowest estimate of the average willingness to pay (WTP) for broadband's speed is around \$11 per month, and their highest is around \$22 for the most experienced and educated user. They also find that users pay more for broadband because it is more reliable and always on—between \$1 and \$18 more, depending on how much more reliability the user perceives in broadband. Savage and Waldman (2004) assume that dial-up has half the reliability of broadband, yielding an additional value of \$9 on average.[47]

(*footnote continued*)
ISP revenue whether they replace it or a rival does (i.e., under any scenario), then these cannibalization concerns are a wash and do not shape incentives for future markets.

[44] For example, Rappoport et al. (2003a) find that broadband service is partially a substitute for dial-up, with cross-price elasticities of 0.7 among those with dial-up service, while dial-up does not act as a substitute for those with broadband (cross-price elasticity of .02). The cross-price elasticities between cable and DLS are in the 0.6 and 0.7 range. Flamm and Chadhuri (2007) use the 2002 Pew Survey and try imputing fewer prices than Rappoport et al. (2003a) They find that demand for broadband is comparatively more insensitive to prices and their detailed data show that demographic factors shape demand quite a bit. Cardona, Schwartz, Yurtoglu, and Zulehner2009) find qualitatively similar results to Rappoport et al. (2003a), with cross-price elasticities between broadband and narrow band of no greater than 0.5, and that only when these are the only two options. Often their estimates are smaller.

[45] For example, Rappoport et al. (2003a) report an own-price elasticity of -1.46 for DSL for a nested logit model applied to a sample of U.S. households in 2000, while Crandall et al. (2002) find an own-price elasticity of -1.184 for a slightly different sample in a similar time period. Using the same sample, Rappoport, Taylor, and Kridel (2003b), p. 82, estimate elasticities for different price levels, finding evidence of more elastic demand. The estimates range from an elasticity of close to 1 for DSL and cable modem prices close to \$20 a month, and they change in the expected direction. For \$30 DSL prices they estimate a price elasticity of -2.1, and for cable modem prices of \$40 they estimate -2.35. Estimates on samples of households in other countries tend to find more elastic demand. For example, Pereira and Ribeiro (2006) find an own-price elasticity for broadband (cable and DSL) of -2.84 for a sample of households in Portugal. In a sample of Austrian households Cardona et al. (2009) find similar elasticities for broadband (approximately -2.5) in areas where there are many options, and more inelastic demand (approx -0.97) when DSL is the only broadband option and dial-up provides the only competition to DSL.

[46] To be clear, this choice comes with one drawback. It does not fully account for heterogeneity in household willingness-to-pay. It averages out such differences. Such accounting would not alter the benchmark calculations much, though it remains an open question. The study of Rappoport et al. (2003b), takes steps in that direction, but did not provide sufficient information to make a full estimate (such as the distribution of dial-up among this population and its correspondence to WTP for broadband, or standard errors on their estimates of heterogeneous demand).

[47] It is reassuring that the average in the Savage and Waldman (2004) study, which examines a sample of only previous dial-up users, is in the same range as the estimates for (WTP) from Rappoport et al. (2003b), which examines a sample of all households. In the latter case the average WTP in their entire sample is \$36.8 for cable and \$32 for DSL. Among a truncated sample of likely adopters – those with WTP for broadband above \$40 – the average WTP is \$53.45 for cable and \$52.05 for DSL. Note: to make these estimates into a WTP for a conversation from dial-up to broadband, one would then need information about (or make assumptions about) the distribution of former dial-up users in this sample and, among that sub-sample, make further assumptions about their use of second telephone lines. This is one place where Savage and Waldman's estimates are much easier to use than the estimates of Rappoport et al. (2003b). Though the latter provide a skewed distribution of WTP, they give no other indication about how these estimates compare against observable features of the data, such as whether households had prior experience with dial-up Internet.

Savage and Waldman (2004) provide an estimate for the number of users who switched from dial-up, but not one for new Internet users. New adopters started becoming more frequent after the 2002 survey used by Savage and Waldman (2004). Even though some of the new adopters (surely) had experience with the Internet (e.g., as students or at work), the estimates take a conservative approach to estimating surplus for nonconverts. It assumes their willingness to pay is what they paid, namely, they received no consumer surplus. This is consistent with the focus on generating a conservative estimate of the substitution bias arising solely from upgrade behavior among previous dial-up users.

In the base specification, if the subscription fees for broadband are $40 a month, and someone converts from a $20 a month dial-up account, then the conversion cost is $20, and called that the maximum conversion cost. For those who paid the maximum conversion cost, the low end of the estimates of willingness-to-pay is just enough to cover the additional cost.

To be clear, this model does not predict which household did and did not adopt broadband, as Savage and Waldman (2004) did with their model. Rather, this estimate assumes that the quantity demanded must result in the number of adopting households, as in Table 3. Then the estimate calculates the level of consumer surplus consistent with Savage and Waldman's estimates, while varying assumptions about prices and conversions.

A full accounting of this surplus can be found in Appendix A. It varies from $6/$10 per month on average in 1999–2001 (when the price is $40/$36 and, by assumption, no household drops its second phone line), to $11.35/$15.35 per month after 2002 (when, by assumption, converts dropped their second line).

Table 5 provides a summary of these results. The approximately 40 million households that converted to broadband since the beginning of the dial-up market received an additional benefit from their conversion that amounts to somewhere between $4.7 billion and $6.7 billion in 2006.

Comparing Tables 4 and 5 also shows how different assumptions shape estimates of the distribution of gains from innovation. In the two baseline cases, the distribution of returns differs.[48] As expected, higher prices lead to lower consumer surplus as a fraction of new value generated, that is, 31.2% and 44.4% for broadband prices equal to $40 and $36, respectively.

Comparing two assumptions – that 100% of broadband users upgraded from dial-up (an aggressive conversion, which is too high) versus 81% of them (an unaggressive conversion, which is too low) – alter estimates of the distribution of returns. Aggressive conversion results in much high consumer surplus, but much lower revenue growth (compared to the baseline) with lower total of $0.8 billion (compared to the baseline). Unaggressive conversion does the opposite, increases the total by $0.6 billion.

These estimates place limits on the range of the benchmark for consumer surplus. Consumer surplus is between 31.2% and 44.4% of the new revenue generated.

Once again, there is one additional way to look at these results, in terms of the total benefits over the eight years from 1999 to 2006, which Table 5 does not express. This is one number, calculated here. The largest consumer surplus accrues to those households who adopt in 1999. In their first year of adoption they receive a $68 million gain (in the baseline estimate with a high price), and then assume they receive the same amount in all subsequent seven years. By this reckoning the total revenue gains over the eight years are 15.4 (22.2) billion for high (low) price baseline estimate.

Is this a large number? By comparison with the size of the total new revenue, which is $36 billion ($29 billion), the gains to consumers generated by broadband over the same time period is 42% (76%) of the size of total new revenue gains.

Once again, these are benchmark estimates. First, other researchers found considerable heterogeneity in the demand for broadband, with some adopters of broadband willing to pay far above the market price. The Savage and Waldman (2004) estimate also measures some of this inelastic demand, but it truncates the level of that valuation among the biggest fanatics. It has not counted this highly inelastic demand in this valuation.

Second, the estimates have made no adjustment to account for the change in dial-up pricing, particularly AOL's. This seems acceptable because adoption is a slow process; and the price decline came too late in 2006 to have an effect on broadband adoption. It almost goes without saying, but nobody expects that most broadband users would switch back to dial-up even if some dial-up became free.

Third, survey research tends to find a larger willingness to pay from users who are paying not to have something taken away after they have experienced it than those who are paying for something they have yet to experience. Savage and Waldman (2004) corrected for this effect by asking both users and nonusers about their valuations; however, the survey was conducted before widespread broadband adoption, so the answers about value would most likely be higher if the survey were conducted today among actual users.

5.4. An adjusted price index

Standard economic reasoning suggests that the price index will be mismeasured when a new good results in large consumer surplus. That must be true in this example, too. The study briefly reviews the mechanics in order to (1) verify that intuition, (2) provide a range for the estimates, (3) decompose the causes, and (4) compare against the CPI.

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[48] In the $40 baseline estimate, the total gains are 4818.7+10,595.4=15,414.1. In the $36 baseline estimate the total gains are 6735.7+8337.4=$15,073.1. When only 81% of the broadband adopters has upgraded from dial-up, then a reduction in price reduces new producer surplus each year, but increases consumers surplus by only 81% of the new revenue for vendors. The 19% consumer surplus is lost to the assumption that new Internet users generate no consumer surplus. The estimates for total surplus are not the same under different prices except under the assumption that all broadband users are converts from dial-up. Accordingly, in the simulation at $40 (and $36) with aggressive conversion, the total is 6349.7+8326.5=$14,676.2. At $40 without aggressive conversion, the total is 4687.9+11,410.5=$16,098.4.

The standard recommendation is to use the adopters' reservation value for the new good; that is, the price index should use the maximum of what a user would have been willing to expend to get the new good prior to adopting the new good. Thus, the starting point is straightforward. Converts were willing to pay a virtual price of $51.35 per month on average, but had to pay less. For converts, this was equivalent to a decline in price of $11.35 ($15.35), but none of this was measured. In other words, against a $40 ($36) price for broadband, an average of $11.35 ($15.35) consumer surplus is equivalent to 22% (30%) of the monthly price paid by converts for service.

How far a price index would have to fall in order to capture the gains that converts experienced? Table 6 illustrates this result, calculating a weighted average of the price change for each year as if only converts experienced a price decline. Weights fall into four categories: (1) dial-up users, (2) existing broadband users, (3) new broadband users who are new Internet users, and (4) broadband users making an upgrade this year. In the baseline specification, converts to broadband (who do not retire a second line, by construction) experience a 13% decline in price (from $46 to $40) from 1999 to 2001, which is represented as 0.87. Converts from 2002 to 2006 (who do retire a second line, by construction) experience a 22% decline in price (from $51.35 to $40), which is represented as 0.78. It assumes all others experience no price decline, which can be represented as 1.0.

Table 6 shows that this exercise results in an average price decline between 0.984 and 0.978, because in most years only a small percentage of households with Internet access upgraded to broadband. That means the price index for all Internet access should decline between 1.6% and 2.2% a year by 2006. In this exercise the correction is largest in the most recent years, when there are more upgrades as a percentage of all Internet households.

Another way to represent the price decline is through a Paasche and Laspeyeres index[49] over eight years—that is, using either the populations in 1999 and 2006 as the baseline. The baseline matters because there was so much change in the characteristics of this population over these eight years (Table 3). In 2006, there were 47 million broadband users and 34.7 million dial-up users. Hence, the 2006 Paasche and Laspeyeres indices will use different base populations because of (1) the entry of new Internet users who later convert to broadband, (2) the entry of new Internet users who use dial-up in 2006, and (3) the entry of new users who go straight to broadband.

The different base years matter. If the population in 2006 serves as the baseline, then 48.9% (39.1/81.7) of households adopted broadband after converting from dial-up in the baseline estimates. In the baseline estimates, 24.5% (9.6/39.1) of households experienced a 13% price decline in 1999–2001 and 59.8% (23.4/39.1) experienced a 22% price decline from 2002 to 2006.[50] Over eight years that adds up to an 8.0% decline in the Internet access price index, even with high broadband prices (i.e., $40). It is an 11.2% decline in prices with lower broadband prices (i.e., $36). In contrast, if the 1999 population serves as the baseline, then it is plausible that all of the users converted to broadband by 2006.[51] The assumption is that adoption behavior consistent with the baseline model. That is, 9.6 million households experienced a 13% (21%) price decline between 1999 and 2001 if broadband prices are $40 ($36). The assumption is that the remainder (34.7–0.9–9.6=24.2) upgraded between 2002 and 2006, and that translates into a 22% ($30) price decline. Accordingly, when broadband prices are $40 ($36), this population experiences an 18.4% (27.3%) price decline.[52]

The Paasche and Laspeyeres index groups the estimates in Table 6. The minimum is 8.0% (11.2%) and the maximum is 18.4% (27.4%), or an average of 1.0% (1.4%), and 2.1% (3.4%) decline per year. The baseline results are 1.6% (2.2%), just between the minimum and maximum.[53] More importantly, there is a big difference in the timing of the recorded price decline. Accounting for the upgrade when users upgraded would have realized a large fraction of the benefits at an early moment.

That simulation informs the puzzling inconsistency between widespread adoption of broadband, as documented in Table 1, and the lack of measured appreciable decline in transactional prices over eight years, as displayed in the CPI for Internet access. A properly measured broadband price index shows a large change in prices, resolving this apparent puzzle. If the pricing concentrates on a population of households that were early adopters of the Internet, then the unmeasured price decline is quite large.

How much price decline arises from the retirement of second phone lines? As it turns out, second lines are not as important as new surplus from conversion. For example, in the baseline estimates for $40 broadband, the gain is $11.35. The dropped second phone line is responsible for $5.35, while the consumer surplus is responsible for $6. When the baseline price is $36, then consumer surplus is comparatively more important. The second line is still responsible for $5.35,

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[49] This is the most convention approach to constructing an index in this setting, and the two answers largely bound any other sensible methodological approach in this setting. For more on the broader topic, see Diewart (2005).

[50] It is plausible because there are 47 million broadband adopters by 2006. The total was 0.9 million in 1999 and 7 million are new Internet users between 2002 and 2006 by construction. Of the remainder, 9.6 million convert from dial-up to broadband between 1999 and 2001. Hence, if all households converted, then 23.4 million households converted between 2002 and 2006. This is well below 39.5 (47 – 7 – 9.6 – 0.9). See Appendix A.

[51] This seems natural because it does not come close to the total 39.1 million broadband converts between 1999 and 2006.

[52] Using the 2006 broadband population as the baseline, a price index that leaves out dial-up users can be estimated, but is averaged over a different base. In the baseline estimate when prices are $40 ($36), 20.8% (9.6/46.1) of upgrading households experienced an average of a 13% (21%) price decline from 1999 to 2001 and 63.9% (29.5/46.1) experienced a 22% (30%) price decline from 2002 to 2006, while 15.1% (7/46.1) experienced no price decline. That yields a 16.7% (23.4%) price decline over all eight years for upgrading households. Including all broadband users (i.e., adding the 0.9 million adopters prior to 1999) yields 16.3% and 22.9%, respectively.

[53] The comparison in the text is over the entire population of households, and each household experiences only one upgrade, by construction. Hence, to make them comparable it is appropriate to look at the average rate of decline per year.

but consumer surplus is now responsible for $10. These expenses only shape decision making during 2002–2006 in the baseline estimates. In other words, removing the savings on the second line from the price index would remove anywhere from 30% to 40% of the total savings in 2002–2006, or 21–28% of the savings for 1999–2006.

The Bureau of Labor Statistics (BLS) price indices do not normally count the savings of expenditure in one category (on a second telephone line) as an input into calculating the price index for another (Internet access). While one can appreciate this procedural consistency at the BLS, it potentially produces misunderstanding for policy at the FCC and NTIA, which keeps no price index for its policy making. The price-equivalent index above comes closer to what informs policy, not what BLS normally does.

6. Conclusion

This study sought to alter the scale of monetary values used in policy conversation, and to move towards a U.S. broadband policy informed by temperate economic reasoning and transparent statistical approaches. The study concludes that prior research of broadband's effect on the U.S. economy mismeasures its true economic impact. Prior research did not attempt to calibrate their conclusions against all available historical data, and did not provide economically plausible forecasts about the range of economic gains from broadband.

The conclusions of this study were as follows. While broadband accounted for $28 billion of the GDP in 2006, approximately $20–$22 billion was associated with household use in 2006. Of that amount, this study showed that approximately $8.3 and $10.6 billion of it was additional revenue (above and beyond what dial-up would have generated), and between $6.7 and $4.8 billion was consumer surplus. That is, broadband generated new additional revenue between 40% and 50% of measured GDP, while consumer surplus (which was not measured) was between 31% and 47% of the newly created revenue. The upgrade was equivalent to an unmeasured decline in price of between 1.6% and 2.2% per year in all Internet access prices.

This study does not argue that broadband lacks value. Rather, the estimates show that the scale of returns was not outsized. It was comparable to the scale of monetary investment made by suppliers. In this sense, the study argues that broadband displayed characteristics that tend to arise in other capital investments. It also concludes that the incremental returns were sufficiently large enough to generate large investments by broadband providers, especially cable firms. This latter explanation differs from hypotheses that stress the role of regulatory change.

The conclusions also support a related conclusion. If there were outsized gains from investments in broadband, then it was not in the direct economic gains from broadband. It would have had to come from complementary investments in applications and other software. That conclusion raises several open questions, and opens up direction such questions must pursue.

One open question concerns the debate about universal service policy, and whether it is based on correct assumptions that there are low private economic incentives for build-out in low-density (e.g., high-cost) environments. The study suggests that non-private economic gains from such deployment would have to be substantial to justify large subsidies. Indeed, the study stresses that it is an open question whether many high-cost areas would or could pass such a social cost/benefit economic benchmark. Further, this is an interpretation for why the National Broadband Plan stresses the social reasons for national subsidies (e.g., fostering public health, better education, and civic communication) rather than economic reasons (e.g., local growth and employment).

A second open question concerns the change in value for broadband among recent adopters and experienced users. While the study used estimates of the willingness to pay from the middle of the period, more recent estimates by Rosston et al. (2010), show a different picture, reflecting demand seven years later. These show that recent adopters have a willingness to pay just above average prices (not surprisingly, since they are recent adopters), and experienced users have a much higher willingness to pay (which is more surprising), on the order of $30 per month more than seven years earlier. Because prices have not changed much over the period (Greenstein & McDevitt, 2011), two interpretations explain this finding: (1) the development of Internet applications that exploit broadband raised its value to early adopters, who continue to have higher willingness to pay than recent adopters and non-adopters; (2) User learning by early adopters was directed at new functions exploiting broadband and its applications, which altered the appreciation of broadband's functionality, changing willingness to pay for it.

In either case, some of these gains were anticipated and some were not. The anticipated gains could have motivated some users to adopt sooner in order to begin to learn how to exploit applications complementary to broadband. In that case, those anticipated (and realized) gains should go into a price index. At present they do not. That said, it would be challenging to distinguish the anticipated from the unanticipated gains. A range of investments by many participants have increased the quality of experience for users over the latter part of the decade, but it would be stretch reality to claim users anticipated such gains.

Better broadband clearly helped some experimentation occur, and although the monetary costs are easy to tally, the benefits are not. Relatedly, the costs are focused, but the gains are diffuse, making it difficult to show that broadband caused the associated gain, even if, broadly speaking, everyone recognizes that broadband raised firms' productivity and enhanced users' experience.

Consider YouTube, which is just over five years old, and the fourth most popular site on the Internet in the US. This site obviously benefits from the widespread use of broadband. Have YouTube's economic gains been high? There is no way to tell because YouTube has never contributed a positive sum to measured GDP. According to financial analysts, Google has lost several hundred million dollars a year since it bought the site (Google shrugs, 2009). YouTube incurs heavy expenses transmitting so much data. Moreover, Google's experiments with different forms of advertising have not worked as well as hoped, at least not yet.[54] Do the general gains to users outweigh the losses to measured GDP? Probably, because YouTube must be delivering something appealing to be as popular as it is. However, no careful method exists for calculating the consumer surplus for an unpriced good with widespread user contributions, so the question remains unaddressed.

A third open question concerns business access to broadband and its impact on productivity. The analysis of household gains took considerable effort and care. That suggests suspicion towards any blithely developed analysis, and suggests the need for similar effort oriented to understanding business gains.

The exercise in this study is far from the final word on the estimation of the size of these effects; rather, the study tried not to allow stakeholder interests to shape the analysis, nor let the presence of externalities to become a license to inflate the gains from the deployment. In doing so, perhaps the study will motivate others to undertake related exercises with greater care than previously shown.

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Appendix A. Supplementary materials

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.telpol.2011.05.001.

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[54] Other societal costs and benefits exist as well, of course. YouTube draws viewers away from television, reducing advertising dollars there, but more recently advertisers have been finding creative ways to use the site for their purposes. The site also reduces some sales for some copyrighted material, such as movies and television shows, but that is a debatable proposition too.

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