ESSAYS IN BROADBAND ECONOMICS

by

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of
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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at George Mason University

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Dedication

I dedicate this dissertation to my parents, InHwan and Miejoo Oh, and my brother and sister-in-law, Simon and Sophie Oh. I'm grateful for the encouragement of many friends.

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Abstract

ESSAYS IN BROADBAND ECONOMICS

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Chapter 1 of my dissertation is a study of a federal infrastructure program. I examine cost forecasts for 49 fiber-optic and wireless networks funded by the Recovery Act. I find that grantees did not systematically underbid for projects. They did, however, underestimate and overestimate costs with nearly equal frequency, and escalate costs on average by 202 percent in cost per institution and 37 percent in cost per fiber mile. For four outputs, I ask whether cost forecasts predicted actual construction. I find that grantees overestimated fiber miles and indirectly connected institutions, while meeting targets for directly connected institutions and points of interconnection. I do not find budget, technology, or institution effects to explain the quality of cost forecasts in these outputs. My findings suggest that low-price bids can be cost-effective across project types. With data from the applicant pool, I compare offers from 116 projects with 657 rejected proposals.

Chapter 2 of my dissertation focuses on a universal service program for broadband subsidies to schools and libraries. Broadband in schools has been financially supported by the E-rate program for over fifteen years in the United States. This study focuses on distribution effects of priority 2 internal connections funds from 1998 to 2012. Regressions estimate the effects of the discount matrix and effects of the National School Lunch Program

(NSLP) student population on fund distribution by state. Regressions also provide per-student and per-school estimates of funds from the number of city, suburb, town, and rural students and schools per state. Treatment groups provide more detailed comparisons across the 50 states and the District of Columbia, a smaller sample of 48 states excluding New York, California, and Texas, and a quasi-experiment from FY2010. The effect of the discount rate is statistically significant, along with the number of NSLP students in the treatments. Results show that NSLP students in city locales account for a large proportion of funds directed toward New York, California, and Texas. Given these results, E-rate reformers may consider student population demographics implicit in the discount matrix to evaluate distribution of priority 2 funds.

Chapter 3 of my dissertation studies technology adoption of converter boxes subsidized by the Digital Television Transition of 2005. I find that broadband adoption explains participation in the coupon program at the zip code level. Broadband adoption may have facilitated coupon requests, but the opposite may be true as well. Coupon seekers might have adopted broadband for access to savings. In regression analysis, I also control for over-the-air television households, coupon redemption rates, broadband availability, location affordability, income, population density, age, and dependents per capita. My study does not solve the endogeneity problem, but suggests a preference explanation for broadband adoption. Broadband adopters may use the internet to seek coupons, deals, and opportunities. By finding a relationship between coupon participation and broadband adoption, I add to the digital divide literature and suggest a question for further study. I provide empirical analysis of a campaign that spent 160 million dollars to distribute 1.34 billion dollars in coupons redeemable in electronics stores nationwide.

Chapter 1: How Predictive Are Cost Forecasts for Broadband Stimulus? Evidence from the Recovery Act

1.1 Introduction

In the winter of 2009, Congress authorized broadband stimulus in the Recovery Act. Federal staff would read stacks of proposals for new fiber-optic networks later that fall. Before they did, seventy-one economists signed a letter of concern on how the government should select projects. Rather than grant review, they asked the agencies to run a procurement auction instead.[1] They knew that infrastructure can stimulate the economy, yet boondoggles and cost overruns come with the territory. I respond to the economists' letter with a study on cost forecasts for broadband stimulus in the Recovery Act. In Part 1, I apply frequency analysis to measure underestimation or overestimation of costs. I investigate causal factors for cost escalation, such as project size, technology, and institution. In Part 2, I ask if proposals predicted actual construction across projects. I find that grantees did not systematically underbid for projects with controls for budget, technology, and institution. In Part 3, I study the applicant pool. I ask if applications were statistically different from selected projects. In Part 4, I discuss comparative benefits of broadband stimulus and universal service reform.

1.2 Economists' Letter

Seventy-one economists signed a letter recommending procurement auctions for broadband stimulus in the Recovery Act (Concerned Economists, 2009).[2] They wrote in April 2009,

[1] Concerned Economists, 2009. A list of signers is available in the reference section.

[2] American Reinvestment and Recovery Act of 2009 (ARRA) (Pub.L. 111–5). The concerned economists taught generations of students the limits of regulator knowledge in dynamic industries. Several are credited

"The traditional grant application process is long, complicated, and involves subjective and arbitrary decisions regarding which projects to fund." (*Id.* at 1). Pointedly, they said, "Reviewing grant applications is not an appropriate way to distribute broadband stimulus grants." (*Id.* at 3). The economists listed the benefits of auctions. They wrote, "[Auctions] relieve the government of the task of identifying the 'best' projects." (*Id.* at 3–4). Auctions prevent subjective judgment calls. "[I]t will be difficult to choose between, say, a fiber project in Texas and a wireless project in North Dakota." (*Id.* at 2). Instead, auctions could help administrators discover appropriate subsidy levels. "[T]he government could attempt to calculate the necessary subsidy using available information, but this effort would be time–intensive, costly, and inaccurate." (*Id.*). Civil servants would otherwise rely on the "applicant's own estimate," when "applicants have little incentive to ask for the bare minimum [subsidy] required." (*Id.*). Referring to international examples, they said, "Experiences in other countries, including Australia, India, Chile, Peru, and others demonstrate that procurement auctions can substantially bring down the subsidies required to induce buildout." (Concerned Economists, at 4 n.10). Auctions, rather than grant reviews, could provide market discipline. "[An auction] also enables and encourages bidders to tailor their projects to the government's actual criteria." (*Id.* at 4).

1.2.1 Broadband Stimulus

The agencies chose traditional grant review. Federal staff proceeded on the "herculean task of distributing broadband stimulus grants." (Concerned Economists, at 10). Broadband stimulus projects are nearly complete years later.[3] One-hundred sixteen projects reached

with developing market mechanisms like spectrum auctions to liberalize the airwaves. Others on the letter advised municipalities against starting costly building campaigns for sports stadiums. Some led the way in evidence-based economics in the mid-twentieth century.

[3]My inquiry is limited to the Comprehensive Community Infrastructure section of the Broadband Technology Opportunities Program which funded middle mile broadband connections. The National Telecommunications and Information Administration of the Department of Commerce managed the infrastructure program and distributed another 2.7 billion dollars to narrow the digital divide through sustainable broadband adoption grants and public computing centers. Last mile projects managed jointly with the Rural Utilities Service of the Department of Agriculture are excluded from analysis here.

25,634 community anchor institutions. Community anchor institutions include schools, libraries, colleges, universities, health offices, public housing, government offices, and community support centers.[4] These projects indirectly reached 65,363 institutions that can extend lateral strands just a few miles for gigabit bandwidth. The average cost to directly connect an institution was 178,796 dollars.[5] This number is 3 times a cost estimate of 50,000 dollars per institution in adequate density areas, and 1.3 times a cost estimate of 134,000 dollars for remote locations put forward by a schools coalition.[6] The Gates Foundation estimated costs of 65,000 to 205,000 dollars per institution in a federal filing.[7] The Massachusetts broadband project compared its cost estimate of 51,469 dollars per institution as falling within the Gates Foundation target range.[8]

However, a closer look at results shows that project-level averages rise to 358,776 dollars per institution. With quality variation across grantees, this cost is 7 times the schools coalition estimate, and nearly twice as large as the upper range of the Gates Foundation estimate. Some stimulus projects delivered according to plan, and a number fell far below proposed results. The range of costs spanned from 8,069 to 2,950,703 dollars per institution (s.d. 491,426 dollars).

Table 1.1 breaks out average costs for direct and indirect connections. Thirteen projects were terminated early due to limitations on their ability to fulfill grant terms.[9] Public

[4]University of Hawaii Systems Application, p. 4. Hawaii now has 384 institutions directly connected with 10 gigabits per second in maximum speeds and 2 gigabits per second in average speeds at a cost of 110,589 dollars per institution.

[5]This average is consistent with the stimulus report that measured 184,141 dollars per institution over 21,240 new connections. *See* ASR Report, "Broadband Technology Opportunities Program Evaluation Study," Order Number D10PD18645, September 15, 2014, at 15. *See* `http://www2.ntia.doc.gov/files/asr_final_report.pdf`.

[6]Schools, Health, and Libraries Coalition, "Cost of Building Fiber to America's Anchors," September 2009. *See* `https://ecfsapi.fcc.gov/file/7020243815.pdf`.

[7]Bill and Melinda Gates Foundation, "Preliminary Cost Estimates on Connecting Anchor Institutions to Fiber," September 25, 2009. *See* `https://apps.fcc.gov/edocs_public/attachmatch/DA-09-2194A1.pdf`. More recent industry estimates cite 65,000 to 130,000 dollars per building for fiber-optic broadband. *See* Singer, Hal. 2016. "Assessing the Consequences of Additional FCC Regulation of Business Broadband: An Empirical Analysis."

[8]Massachusetts Technology Park Application, p. 51.

[9]Grantees who invoiced less than half of their allocated funds are coded as terminated early. These include Education Networks of America IN (Easy Grant 144), State of Wisconsin (Easy Grant 174), Level 3 KS, CA, TX, TN, FL, GA (Easy Grant 477, 1971, 1973, 1974, 1975, 1976), State of Louisiana (Easy Grant

Table 1.1: Project Averages.

	Directly Connected Institutions	Cost Per Institution	Indirectly Connected Institutions	Cost Per Institution
Projects with Connected Institutions	272	$358,776	629	$227,267
(N = 94)	*(537)*	*($491,426)*	*(1,037)*	*($425,625)*
Projects with Few Connected Institutions	1.2	$12,432,159	496	$577,447
(N = 9)	*(1.3)*	*($11,934,826)*	*(643)*	*($1,176,463)*
Terminated Early	4.6	$351,541	134	$421,652
(N = 13)	*(16.6)*	*(-)*	*(342)*	*($271,093)*
Project Averages	221	$962,373	564	$262,532
(N = 116)	*(494)*	*($3,602,215)*	*(967)*	*($512,733)*
Stimulus Total	25,634	$178,796*	65,363	$70,093*

Ninety-four projects directly connected 25,563 anchor institutions (N = 94). Nine connected fewer than ten institutions each, for another 11 anchor institutions (N = 9). Thirteen projects were terminated early, but connected 60 anchor institutions (N = 13). Standard deviations in parentheses. *Indicates a general average of total budget ($4,581,461,018) divided by connected institutions.

safety projects faced obstacles in building infrastructure based on cellular technology.[10] Seven projects were co-listed with the last mile program and are not considered in this study.[11] Half of the infrastructure funds were allocated to states and university systems. The Virgin Islands, Hawaii, and Guam each received significant awards for gigabit networks. The District of Columbia spent 25 million dollars on 211 miles of new fiber for gigabit connections to 291 anchor institutions and free WiFi service in Anacostia.

2239), State of Mississippi (Easy Grant 4289), City of Charlotte (Easy Grant 6251), State of New Jersey (Easy Grant 7254), and San Francisco Motorola (Easy Grant 7309).

[10]Recovery Act projects that overlapped with the FirstNet public safety network were suspended and reinstated. The Los Angeles public safety project invoiced all its funds, but had a partial suspension for FirstNet compatibility studies. As of September 2016, public safety projects from the Recovery Act are still under construction. Projects in the public safety category have not been completed as of 2016, and Congress extended the program until 2020. NTIA, "Broadband Technology Opportunities Program Quarterly Program Status Report," September 2016. *See* `https://www.ntia.doc.gov/files/ntia/publications/ntia_btop_28th_qtrly_report_09122016.pdf`. This report lists 116,702 new and improved fiber miles, exceeding 41,142 fiber miles in the 2013 dataset released in October 2015. Between FY2011 and FY2013, fiber miles increased from 29,000 to 111,000 in the quarterly filings.

[11]These include Buggs Island Telephone Cooperative (EasyGrant 1946), City of Williamstown (EasyGrant 1425), DigitalBridge Communications Corp. (EasyGrant 393), DigitalBridge Communications Corp. (EasyGrant 402), DigitalBridge Communications Corp. (EasyGrant 408), Pine Telephone Company, Inc. (EasyGrant 2614), and Public Utility District of Pend Oreille County (EasyGrant 1854).

1.2.2 Cost Escalation

With results from the stimulus program, I review project-level costs. Cost overruns and time overruns are par for the course in megaprojects. Megaprojects cost from 250 million dollars to 500 million dollars to 1 billion dollars. (Altshuler and Luberoff, 2003). Forecasting errors can arise for a variety of reasons, from technical, economic, psychological and political sources. (Cantarelli et al., 2010). Some scholars count as many as 21 sources of mega-error. (Mackie and Preston, 1998). Appraisal optimism bias, pork barrel politics, and lack of competition all lead to systematic errors in cost underestimation in public works projects. (*Id.*).[12] Bold forecasts and optimism bias arise in systematic fashion, particularly for capital investment in new technology. (Kahneman and Lovallo, 1993; Merrow, 1988).[13]

Aspirational projects, such as the Olympic games, are more prone to cost overruns. Flyvbjerg et al. (2016) estimate average cost overruns at 156 percent for Olympic games, with 760 percent topping the list for the Montreal summer games of 1976. Earlier research by Hufschmidt and Gerin (1970) reviewed cost overruns from differences in estimated and final costs. They measured factors such as project type, project size, timing, administration, construction, and institutional biases.

Cost overruns commonly arise in infrastructure projects internationally. The World Bank estimated 10 to 15 percent mark ups in procurement costs in developing countries. (Hobbs, 2005). In Indonesia, for example, up to 24 percent of costs in road construction go missing after accounting for inputs and outputs. (Olken, 2006). Construction firms report on cost leakage through bribes and missing equipment when dealing with state customers.[14] Scholars estimate that at least 5 percent of construction costs are lost to bribes, and rising

[12] *See generally* Frankel, Jeffrey A, "Over-Optimism in Forecasts by Official Budget Agencies and Its Implications," *Review of Economic Policy,* 27(4): 536-562 (2011).

[13] Merrow (1988) studied 160 fixed capital projects with budgets of 500 million dollars or more. He separated projects by institution (public, mixed, or private) across 47 projects.

[14] Kenny, Charles, "Measuring Corruption in Infrastructure: Evidence from Transition and Developing Countries," *The Journal of Development Studies,* 45(3): 314-332 (2009); Gulati, M., and Rao, M., "Checking Corruption in the Electricity Sector," *Mimeo, World Bank, Washington D.C.* (2006).

to as much as 20 percent in the electricity sector.[15] In the water and transportation sectors, state regulators extract concessions in contract renegotiations. (Guasch, Laffont, and Straub, 2008). For these reasons, the International Monetary Fund cautions economists to be "more restrained in their praise of high public sector investment spending." (Tanzi and Davoodi, 1998).

American grantees of broadband stimulus likely protected their reputations and minimized strategic behavior. Yet, with exigent economic circumstances, grantees may have rushed through cost forecasts and network estimates.[16] Modest forecasts often can be eclipsed by political hubris. Megaprojects with political support can escape scrutiny as they become gold-plated with wasted resources. In construction projects, gold-plating often remains hidden and underappreciated. Public servants and reporters attempt to monitor infrastructure programs, but have few resources to investigate excess.[17]

From an earlier era of telecommunications regulation, Laffont and Tirole (1986) and Crew and Kleindorfer (1986) measured effects on output and costs when firms gold-plated under rate-of-return regulation.[18] Zajac (1972) and Bailey (1973) studied gold-plating under regulatory constraints. When prices are regulated, suppliers maximize profits by lowering quality or quantity. Spulber (1989) and Besanko and Spulber (1992) measured underinvestment when a regulator pre-committed to regulated prices. Spiegel (1994) showed that firms select projects with higher variable costs and lower fixed costs under regulated prices to correlate profits with variable costs. Suppliers may choose to favor variable costs over fixed costs to hedge their exposure to losses. Builders may buy short-term supplies rather

[15] *Id.*

[16] McKinsey Global Institute, "Infrastructure Productivity: How to Save $1 Trillion a Year," January 2013. Cost savings of up to 60 percent are available with smarter cost forecasts.

[17] Tony Romm, "Wired to Fail," *Politico,* July 28, 2015, `http://www.politico.com/story/2015/07/broadband-coverage-rural-area-fund-mishandled-120601` ("We are left with a program that spent $3 billion," Mark Goldstein, an investigator at the Government Accountability Office, told *Politico,* "and we really don't know what became of it."). The article focuses on the last mile stimulus program run by the Rural Utilities Service. With 62,307 miles of fiber-optic cable, grantees connected 639 educational providers, 132 libraries, 393 healthcare providers, and 455 public safety providers. This amounts to 1.5 million dollars per institution and 40,124 per fiber mile for remote rural locations.

[18] Similar studies revealed losses from regulation by the Civil Aeronautics Board (Kahn, 1971).

than invest in long-term improvements. If economic conditions change, regulated firms can also implement time delays to postpone payments.

Technology and Institutions

Studies on cost overruns show that project type and institutions matter (Flyvbjerg et al., 2002). I ask whether this holds true for broadband stimulus. Administrators funded three technologies of fiber, fiber & wireless, and wireless networks, built by six types of institutions, public and private, as seen in Table 1.2. I ask whether certain technology and institution types are more prone to cost errors than others.

Technology type may affect the quality of cost forecasts. Fiber networks provide higher bandwidth with greater installation costs, while wireless networks can reach rural areas with less hardware. Yet not all wireless networks are cost-effective; public safety wireless networks have suffered severe cost overruns and time delays. Several public safety stimulus projects were terminated early or amended, such as the San Francisco Motorola project and the Los Angeles Regional Interoperable Communications System project.[19]

Institution type may affect cost forecasts and proposal quality. Institutions differ in size and experience to manage large-scale fixed capital investments. Many public institutions already procure fiber networks through auction, such as state governments and universities. These institutions comply with state procurement law and carry over that expertise to stimulus projects.[20] Other institutions, such as large cities, small cities, non-profit organizations, for-profit organizations, and tribal entities have varying capacity to manage fiber-optic networks.

[19] Public safety networks have suffered cost overruns and time delays. Oregon's public safety wireless interoperability network includes radio towers and fiber backhaul at a price of 592 million dollars with time delays and 22 percent cost overruns, as of 2010. New York rescinded a contract for a 2.1 billion dollar public safety wireless network due to severe time delays and rising costs. FirstNet is a 12 to 47 billion dollar federal-state public safety network, already 15 years delayed from the first request for proposals. Steven Brill, "The $47 Billion Network That's Already Obsolete," *Atlantic Magazine,* September 2016, `http://www.theatlantic.com/magazine/archive/2016/09/the-47-billion-network-thats-already-obsolete/492764/`. FirstNet may cost 30 billion dollars over 10 years. Congressional Research Service, July 2016, `https://www.fas.org/sgp/crs/misc/R42886.pdf`.

[20] For-profit fiber providers also comply with the Davis-Bacon Act and other federal contract requirements to hire subcontractors to outsource construction.

State governments fund and build fiber-optic networks. Private operators and state buyers have experience in contract disputes. In Idaho, for instance, the state failed to make payments to network providers due to budget shortfalls. CenturyLink and Education Networks of America sued Idaho for 37 million dollars.[21] Dispute resolution shifts to state attorney general's offices. General contractors and subcontractors abide by state procurement rules and price schedules. In the Recovery Act, the largest grants were awarded to state governments with audit compliance enforced by law.[22]

Table 1.2: Networks in the Recovery Act.

	Fiber	Fiber & Wireless	Wireless	Total
State Govt	12	6	2	20
Local Govt	8	2	3	13
Non-Profit	22	6	0	28
For-Profit	36	4	3	43
Higher Ed	6	2	0	8
Tribe	1	2	1	4
Total	85	22	9	116

Non-Profit organizations include cooperatives and mutuals. Institutions of higher education are separated out from state government entities and non-profit organizations. Coded by technology and institution by the author. *See* Appendix A.

Universities, public and private, forecast costs to build high-capacity fiber-optic networks. Higher education entities often are subsidiaries of state governments who run the procurement auctions. In 2013, the University of Wisconsin procured a fiber network through an auction held by State of Wisconsin. The auction led to some controversy when the winning bid went to WiscNet, a non-profit membership organization, to formal protest by AT&T and CenturyLink. Parties to the deal raised questions on the state's authority to

[21] Idaho's broadband network was funded by 3 million dollars in federal grants, 6 million dollars in private grants, and 3 million dollars in state funds. Idaho allegedly violated procurement rules by awarding a winning bid to Syringa in 2008.

[22] New Mexico Department of Information Technology Application, p. 37; State of Wisconsin Application, p. 39; University of Wisconsin Application, p. 68.

select contractors for telecommunications services. The Wisconsin case was connected to the BadgerNet project in the Recovery Act, which terminated early.[23] In other instances, universities operate fiber networks with their own staff. Research networks are owned and operated by non-profit membership organizations and public-private partnerships.[24]

Cities with significant budgets, such as Chattanooga, have issued bonds to own and operate fiber networks.[25] Revenues from fiber networks are monitored by city councils. A few cities have already sold their fiber networks to private providers due to difficulties in generating revenue from new broadband subscriptions.[26]

Counties, school districts, townships, housing authorities, tribes, and smaller cities seek funds to connect their government buildings to home-grown fiber networks too. At any given time, representatives from 89,004 local governments may propose broadband initiatives. Municipalities vary in resources to manage infrastructure projects.[27] City councils pay consulting fees for cost forecasts from entrepreneurial broadband experts. City councils balance ambitions of running fiber networks with fiscal conservatism.[28]

Mayors, city councils, and committees often want to raise taxes or issue bonds to run their own fiber networks. Policy scholars have measured effects of municipal broadband

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[23] State of Wisconsin BadgerNet Project (Easy Grant 174).

[24] Missouri and Ohio run networks through university systems. *See* "UW System's Role in WiscNet and Grant-Funded Networks," 2012. *See* `http://legis.wisconsin.gov/lab/reports/12-18full.pdf`.

[25] To finish their fiber network, Chattanooga issued 229 million dollars in 25-year bonds at a 4.5 percent rate, received an 111 million dollar grant from the Department of Agriculture, and borrowed another 50 million dollar loan. The city maintains a AA+ municipal bond rating. In contrast, Chicago municipal bonds have a BBB-minus rating from 20 billion dollars in unfunded liabilities. *See* `https://www.cga.ct.gov/2012/rpt/2012-R-0515.htm`.

[26] City of Groton, Connecticut transferred ownership of its fiber network. "Groton mayor Marian Galbraith stated that the increasing costs to subsidize [Thames Valley Communications] put a strain on the finances of the city and Groton Utilities.... [C]apital costs to stay current in the competitive cable market have outweighed the benefits to the city of owning and operating the company." *See* `https://www.cga.ct.gov/2012/rpt/2012-R-0515.htm.` Provo, Utah sold its fiber network to Broadweave Networks in 2008, Google Fiber in 2013, and wrote-down 5.4 million dollars in debt through a new "Telecom Debt Charge" on residential, commercial, and industrial entities. Monthly for 15 years, Provo residents are paying 5.35 dollars, businesses 10 dollars plus 2.3 percent of their energy bill, and industrial entities 2,000 dollars plus 0.34 percent of their energy bills. *See* `http://www.codepublishing.com/UT/Provo/html/ProvoCFS.html#utilities.`

[27] Illinois alone has 6,968 local governments. Census of Governments, 2012. *See* `https://www.census.gov/govs/cog/`. In 2011, 9,700 municipal general obligation and revenue bonds were issued by local governments, each with limited federal bankruptcy protection under state law.

[28] Consultants for the City of Palo Alto recommended against a city-funded overbuild project. The new fiber network would need 72 percent uptake to justify investment.

on economic outcomes to varying results.[29] Debates on the fiscal risk of public fiber-optic networks occur in state legislatures.[30] The U.S. Court of Appeals for the Sixth Circuit recently upheld state statutes that define municipal entities.[31]

Local institutions receive federal and state grants for broadband projects. Many local governments currently receive funds for broadband networks.[32] The federal Universal Service Fund subsidizes infrastructure from a fund of 8 billion dollars per year. State funds assist municipalities to interconnect with research networks.[33]

Anchor Institutions and Fiber Miles

In civil engineering studies, cost errors are measured against construction output, such as road miles and plant installations. Flyvbjerg, et al. (2002) studied 258 rail, train and transport projects and measured outputs such as rail miles. Merrow (1988) reviewed cost errors with outputs such as the number of nuclear power plants. For broadband stimulus, output is the number of directly connected institutions and new fiber miles installed. Administrators use these output measures in describing performance of the broadband projects. Quality differences arise within each connection or fiber mile, but quantity benchmarks provide a baseline metric of assessment.[34]

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[29] Gillett, Sharon, et al., "Local Government Broadband Initiatives," *Telecomm. Policy* 28: 537-558 (2004).

[30] In Utah, the Utopia network has less than one-quarter of predicted subscribers in its overbuild network, leading to revenue shortfalls to pay down 355 million dollar debt from a 185 million dollar bond offering and a 40 million dollar loan from the Department of Agriculture.

[31] Legislatures in Tennessee and North Carolina restricted municipal utilities from building fiber networks. State law governs the creation of municipal electric utilities and provision of telecommunications services "within its service area," *Tenn. Code Ann.* § *7-52-601,* and "within the corporate limits of the city," *N.C. Gen. Stat. Ann.* § *160A-340.1(a)(3).* The Federal Communications Commission will not appeal the decision in *Tennessee v. FCC* (CA6, 2016). The agency does not have authority to preempt state law in municipal telecommunications services. *See* `http://www.opn.ca6.uscourts.gov/opinions.pdf/16a0189p-06.pdf`.

[32] Nearly 500 towns, cities, and counties are connected to consortium fiber networks. Executive Office of the President, "Community-Based Broadband Solutions," 2015. Other studies note 135 municipal fiber-to-the-home networks. Deignan, Brian, "Community Broadband, Community Benefits? An Economic Analysis of Local Government Broadband Initiatives," Mercatus Graduate Policy Essay, 2014. The Rural Utilities Service spends 280 million dollars per year on local networks. The Economic Development Administration spends 200 million dollars per year. Department of Health and Human Services, Department of Housing and Urban Development, and Environmental Protection Agency spend tens of millions of dollars annually on broadband subsidies.

[33] Minnesota's fund is 35 million dollars, California's 20 million dollars, and Colorado's 2.4 million dollars.

[34] The National Broadband Plan listed 10,500 to 21,120 dollars per fiber mile from Gates Foundation estimates and 3,000 to 42,000 dollars per fiber mile from vendor estimates. National Broadband Plan, 2010.

Total Budget

Construction projects with large budgets may suffer from cost overruns and missed forecasts with greater likelihood. Flyvbjerg et al. (2004) cites prior studies (Merewitz, 1973) that find a positive relationship between cost overruns and size of project. Flyvbjerg et al. (2004), however, does not find significant results. Extensive buildouts may generate economies of scale in favorable equipment prices and supply contracts, but may increase the likelihood of unexpected changes. General contractors amend contracts as new costs are discovered.[35] In the stimulus program, grantees filed amendments without accruing fines for underperformance or missed targets.[36] Costs could not be overrun because funds were capped by Congress.

1.2.3 Did Grantees Underestimate Costs?

Did grantees underestimate costs in their applications? I ask this first question to assess cost forecast quality. Since grantees could not delay or charge additional costs, I use backwards induction to measure cost underestimation or overestimation in proposals. I define cost escalation by the difference in proposed unit costs and actual unit costs, divided by proposed unit costs. I generalize a unit cost by dividing the total budget by institutions or fiber miles.[37] By generating a unit cost in dollars, I can compare projects that differed in size. Cost escalation is transformed to a percentage as seen in other cost overrun studies. I focus on directly connected institutions, rather than indirectly connected institutions.[38] I

See `http://www.broadband.gov/plan/6-infrastructure/`. Urban or suburban costs rise to 100,000 dollars per fiber mile.

[35]Cost overruns arise when alterations are added after the initial proposal. To mitigate strategic behavior, penalties are shifted to the general contractor who is best situated to monitor subcontracting firms. Agency theorists grapple with *ex ante* incentive alignment to reach efficient and timely completion of publicly-funded projects.

[36]Grantees filed quarterly performance reports with stimulus administrators. Government Accountability Office noted weaknesses in the reliability of self-reported filings without audit controls. *See* GAO Report.

[37]Unit cost and cost escalation formulas are included in Appendix A.

[38]Appendix A includes data on indirectly connected institutions in Table A.7 according to the number of schools, libraries, universities and colleges, health care offices, other government offices, non-government offices, public housing, and public safety offices. Indirectly connected institutions are also included in a cost analysis in the next section.

consider costs for new and improved fiber miles.[39]

I run a frequency analysis to test whether grants showed a systematic bias in cost errors. I ask if cost underestimates or overestimates were more likely than not across the 116 projects. I compare proposed to actual results to determine cost underestimates (actual costs greater than proposed) and cost overestimates (actual costs below proposed). I also compare the magnitude of cost errors. I ask if the size of cost underestimates exceeded that of cost overestimates by a statistically significant level. Prevalent cost underestimation, or cost escalation, would be consistent with optimism bias.

Next, I investigate cost escalation ΔC (%) across i projects.[40] I regress cost escalation on output measures that relate to each type of cost. For cost per institution ($\Delta C_{Inst.}(\%)$), output measures of relevance are directly connected institutions, proposed institutions, and total budget. For cost per fiber mile ($\Delta C_{FM}(\%)$), output measures of relevance are fiber miles, proposed fiber miles, and total budget. Flyvbjerg et al. (2004) applies this analysis to cost overruns in transport networks. Like his study, my null hypothesis is that output levels have no effect on cost escalation. Eq. (1.1) shows the regression equation which is run for different output measures x.

$$\Delta C_i(\%) = \alpha_i + \beta_i log(x)_i + \varepsilon_i \tag{1.1}$$

I consider cost escalation separately by technology and institution. Flyvbjerg et al. (2003) notes that subgroups should be compared against subgroups and not to mean total overruns, noting a statistical error in Merewitz (1973). I follow Flyvbjerg's method here. He and other scholars seldom find statistical significance for drivers of cost overruns, aside

[39] Fiber miles in the data are from the variable *FiberMile_Num*. Proposed fiber miles are from the key metric dashboard in the application files (N = 60) for *New Construction Miles*, along with Backbone and Lateral Miles. Directly connected institutions are listed in the results data as *ComInst_Total_Num* which include both new and improved connections, and indirectly connected institutions as *TotalComInst_Num*. From applicant files, direct connections are compared to *Funded* Connections and indirect connections are compared to *Potential* Connections as proposed by grantees. The *Directly Served* Connections and *Third Party CAI* are not used in this study.

[40] I multiply ΔC by 100 to transform the result into a (%) similar to the related literature.

from time delay. (*Id.*).

1.2.4 Data

Proposal data included fiber miles, connected institutions, and other network characteristics.[41] Unredacted data was available for less than half of the 116 grantees. Regarding missing data, I assume that redactions are randomly distributed across the 116 projects. If redactions are more common for underperforming projects, then results would also underreport the extent of positive cost escalation.

I coded grantees by technology and institution.[42] I separated grantees by two levels of government, state and local.[43] Other entity types include non-profit (including cooperatives and mutuals), for-profit, higher education, and tribes. Institution type was self-reported by grantees in the first section of their application forms.

I check that cost per institution and cost per fiber mile are not correlated. I cannot reject the null hypothesis that cost escalation by cost per institution and cost per fiber mile are causally related. In an ordinary least squares regression with robust standard errors, the correlation is not statistically significant ($p < 0.22$, $R^2 = 0.16$, N = 42). Thus, I consider cost escalation separately for each metric.

Table 1.3 shows that average cost escalation in cost per institution is 202 percent (s.d. 903 percent, N = 53). Average cost escalation in cost per fiber mile is 37 percent (s.d. 124 percent, N = 49). Table 1.4 shows a matrix of average cost escalation for technology by institution. The interaction term is not studied due to data limitations. Cost escalation appears to be greater on average for fiber & wireless projects with an average 659 percent

[41]Grantees self-reported final outcomes. Stimulus administrators released a public dataset with quarterly and annual metrics on a variety of project goals. *See* Data Sources.

[42]NTIA provided this categorization of fiber, fiber & wireless, and wireless networks, and government, non-profit, for-profit, higher education, and tribe. NTIA, "Expanding Broadband Access and Adoption in Communities Across America, Overview of Grant Awards." *See* `https://www.ntia.doc.gov/files/ntia/publications/ntia_report_on_btop_12142010.pdf`. *See also* Congressional Research Service, R41775, Aug. 2015. *See* `http://digital.library.unt.edu/ark:/67531/metadc809547/m2/1/high_res_d/R41775_2015Aug04.pdf`.

[43]Municipalities could have been more fine-grained to townships, housing authorities, school districts, and utilities. Instead, I include all local government entities in an omnibus category.

escalation in cost per institution (s.d. 193 percent). Cost escalation changes, however, in cost per fiber mile in fiber & wireless projects to 67 percent (s.d. 202 percent). Non-profit organizations had an average of 623 percent escalation in cost per institution, but escalation of 7 percent (s.d. 53 percent) in cost per fiber mile.

Among higher education grantees, average cost escalation in cost per institution was -12 percent (s.d. 79 percent, N = 4) and -16 percent (s.d. 23 percent, N = 3) in cost per fiber mile. Among tribal grantees, the average cost escalation by cost per institution was -10 percent (s.d. 15 percent, N = 2) and -45 percent (N = 1) for cost per fiber mile.

Table 1.3: Average Cost Escalation ΔC (%).

	Cost per Institution $\Delta C_{Inst.}$(%)			Cost per Fiber Mile ΔC_{FM}(%)		
	Number of Projects	Average	S.D.	Number of Projects	Average	S.D.
By Technology						
Fiber	38	64%	*222%*	40	29%	*106%*
Fiber & Wireless	11	659%	*193%*	8	67%	*202%*
Wireless	4	258%	*301%*	1	104%	-
Total	53	202%	*903%*	49	37%	*124%*
By Institution						
State	12	14%	*268%*	9	109%	*218%*
Local	6	94%	*188%*	6	92%	*184%*
Non-Profit	12	623%	*1859%*	11	7%	*53%*
For-Profit	17	81%	*185%*	19	15%	*59%*
Higher Ed	4	-12%	*79%*	3	-16%	*23%*
Tribe	2	-10%	*15%*	1	-45%	-
Total	53	202%	*903%*	49	37%	*124%*

Cost escalation is derived from proposed and actual results for institutions and fiber miles. Formulas for cost escalation and unit costs are included in Appendix A.

By technology, fiber projects have the most observations for cost per institution (N = 38) and cost per fiber mile (N = 40). Average cost escalation is 64 percent (s.d. 222 percent) and 29 percent (s.d. 106 percent) for each cost type. Fiber projects had lower average cost escalation than overall average cost escalation of 202 percent (s.d. 903 percent) and 37 percent (s.d. 124 percent) for cost per institution and cost per fiber mile.

Table 1.4: Average Cost Escalation ΔC (%) Matrix.

	Number of Projects	Fiber	Fiber & Wireless	Wireless	Total
Cost per Institution $\Delta C_{Inst.}(\%)$					
State	12	11%	184%	557%	114%
Local	6	18%	–	477%	94%
Non-Profit	12	123%	2123%	–	623%
For-Profit	17	94%	34%	-2%	81%
Higher Ed	4	-47%	92%	–	-12%
Tribe	2	–	-21%	0%	-10%
Total	53	64%	659%	258%	202%
Cost per Fiber Mile $\Delta C_{FM}(\%)$					
State	9	82%	163%	–	109%
Local	6	92%	–	–	92%
Non-Profit	11	-3.3%	52%	–	7%
For-Profit	19	11%	-14%	104%	15%
Higher Ed	3	-23%	-1.4%	–	-16%
Tribe	1	–	-44%	–	-44%
Total	49	29%	67%	104%	37%

Cost escalation is derived from proposed and actual results for institutions and fiber miles. Formulas for cost escalation and unit costs are included in Appendix A.

By institution, state projects had 14 percent cost escalation (s.d. 268 percent, N = 12) and 109 percent cost escalation (s.d. 218 percent) for cost per institution and cost per fiber mile. Average cost escalation for cost per institution fell below the stimulus average, but not for cost per fiber mile.

The matrix in Table 1.4 shows missing data for several interactions. By cost per institution (N = 53), there were no broadband stimulus projects by tribal entities with fiber networks, by local institutions with fiber & wireless networks, by non-profit entities with wireless networks, or higher education entities with wireless networks. For cost per fiber mile (N = 40), there were no projects by tribal entities with fiber networks, local entities with fiber & wireless networks, and or wireless networks by any entity type except for-profits.

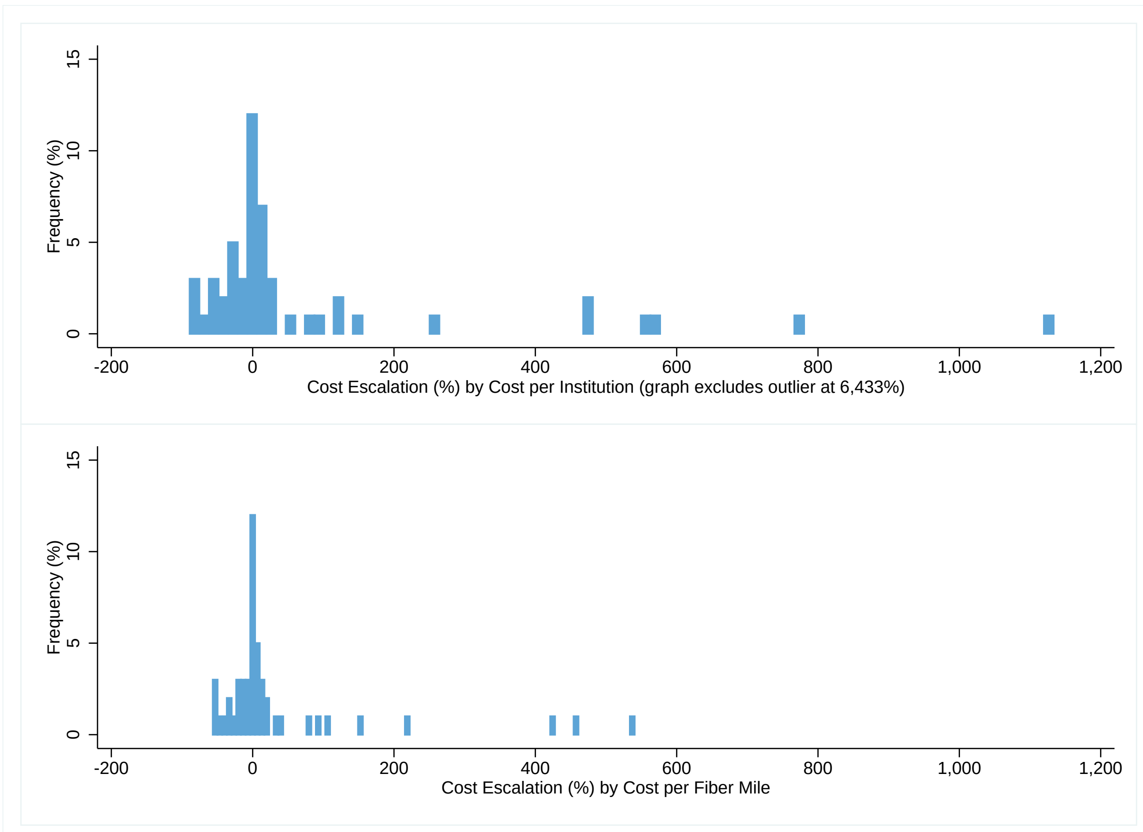

Figure 1.1: Frequency of Cost Escalation $\Delta C_{Inst.}$ (%) and ΔC_{FM} (%).

Frequency analysis for cost escalation based on cost per institution $\Delta C_{Inst.}(\%)$ and cost per fiber mile $\Delta C_{FM}(\%)$ are compared (N = 53) and (N = 49).

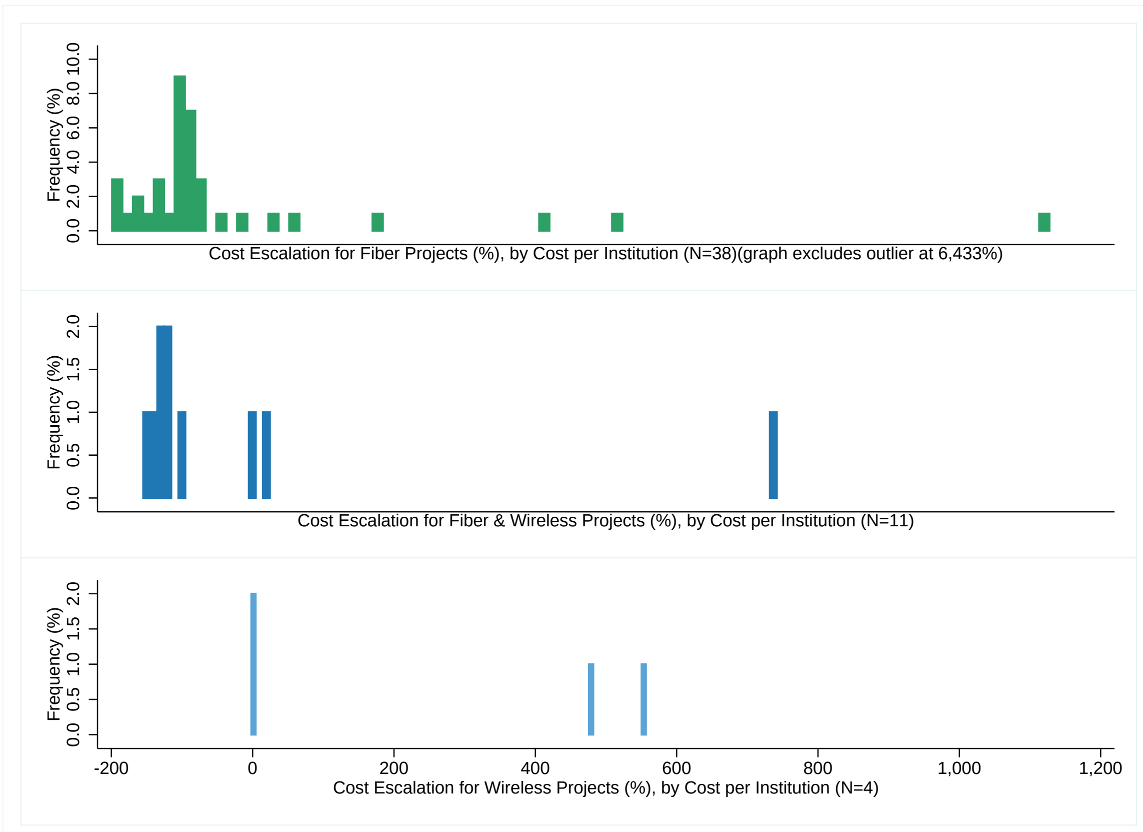

Figure 1.2: Frequency of Cost Escalation $\Delta C_{Inst.}$ (%) by Technology.

The charts here show results for cost escalation based on cost per institution $\Delta C_{Inst.}(\%)$. Frequency analysis for cost escalation based on cost per fiber mile $\Delta C_{FM}(\%)$ is in Appendix A.

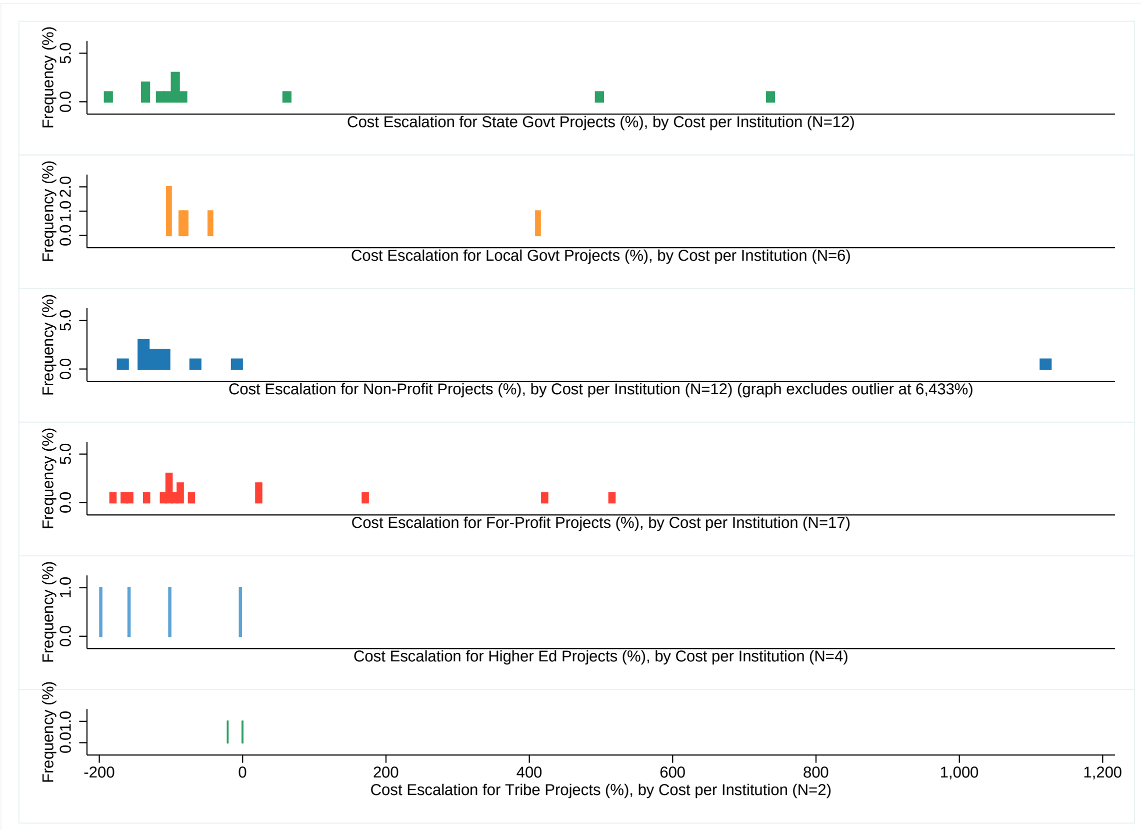

Figure 1.3: Frequency of Cost Escalation $\Delta C_{Inst.}$ (%) by Institution.

The charts here show results for cost escalation based on cost per institution $\Delta C_{Inst.}(\%)$. Frequency analysis for cost escalation based on cost per fiber mile $\Delta C_{FM}(\%)$ is in Appendix A.

1.2.5 Results

Figure 1.1 shows a frequency analysis of cost escalation across projects. The occurrence of cost escalation does not arise more frequently than not. In fact nearly half of the projects missed their costs estimates, but half delivered more connections and fiber miles than expected. This result differs from Flyvbjerg et al. (2003). I cannot reject the null hypothesis that overestimating costs is as common as underestimating costs (H_0 : cost escalation $\Delta C_{Inst.}$ (%) is positive with probability 0.5, p = 1, two-sided test; binomial distribution, 27 projects had cost escalations out of 53 projects; H_0 : cost escalation ΔC_{FM} (%) is positive with probability 0.5, $p < 0.57$, two-sided test; binomial distribution, 22 projects had cost escalations out of 49 projects).

When grantees missed their forecasts, they did so in greater magnitude than those who did not. The magnitude of cost escalation exceeds that of cost overestimates. The probability that cost escalations is larger than cost overestimates is 31.5 and 30.8 percent for cost per institution and cost per fiber mile ($p < 0.02$, non-parametric Mann-Whitney U-test; $p < 0.02$, non-parametric Mann-Whitney U-test).

Figure 1.2 shows a frequency analysis of cost escalation by technology type. I find that technology type does not matter for cost escalation. This result is contrary to Flyvbjerg et al. (2003), where project type did matter. I cannot reject the null hypothesis that the medians of cost escalation are equal.

Median levels of cost escalation are not statistically different in both cost per institution and cost per fiber mile across technology types. I run a one-way ANOVA with Bonferroni correction. For cost escalation $\Delta C_{Inst.}$ (%), the difference between fiber and fiber & wireless projects is not statistically significant ($p < 0.168$), or between fiber and wireless projects (p = 1). For cost escalation ΔC_{FM} (%), the difference in cost escalation is not statistically significant (p = 1).[44]

[44] I also confirm this result with a non-parametric rank test ($p < 0.53$, Kruskal-Wallis non-parametric rank test, N = 38, 11, 4; $p < 0.19$, Kruskal-Wallis non-parametric rank test, N = 40, 8, 1). However, the Kruskal-Wallis test requires 5 or more observations in each group to find a critical value in the chi-squared

Figure 1.3 shows a frequency analysis of cost escalation by institution type. Institution type does not matter for cost escalation. I cannot say the median cost escalation is different in six types of institution. Medians levels are not statistically different in a one-way ANOVA with Bonferroni correction for both $\Delta C_{Inst.}$ (%) and ΔC_{FM} (%) (p = 1).[45]

Table 1.5 shows significant results from Eq. (1.1) which regresses cost escalation on output measures. I find few statistically significant results across three technology types, six institution types, and three outcome variables for cost per institution (directly connected institutions, proposed numbers of directly connected institutions, and total budget) or cost per fiber mile (fiber miles, proposed fiber miles, and total budget). This lack of observable causal effect is consistent with other cost overrun studies such as Flyvbjerg et al. (2004).

From results with statistical significance, some observations can be made. Fiber projects show that a 1 percent increase in the number of directly connected institutions leads to cost escalation $\Delta C_{Inst.}$ (%) decreasing by 0.84 percentage points.[46] Negative coefficients on output variables may show that larger projects are less likely to underestimate costs.

Wireless projects showed positive coefficients on output variables. Cost escalation may arise in larger projects. For a 1 percent increase in the number of proposed institutions, cost escalation by cost per institution $\Delta C_{Inst.}$ (%) increases by 1.52 percentage points. For 1 percent increase in total budget, cost escalation increases by 2.02 percentage points.

State governments showed similar results for cost escalation. For 1 percent increase in the number of directly connected institutions, cost escalation by costs per institution $\Delta C_{Inst.}$ (%) decreased by 0.73 percentage points. For fiber miles, state government projects had positive cost escalation effects from increased proposed fiber miles. The larger the proposed projects, cost escalations were positive. For a 1 percent increase in the number of proposed fiber miles, cost escalations by cost per fiber mile increased by 0.80 percentage points.

distribution. In these comparison groups, there are fewer than 5 observations.

[45]The results are the same under a non-parametric rank test ($p < 0.61$, Kruskal-Wallis non-parametric rank test, N = 12, 6, 12, 17, 4, 2; $p < 0.36$, Kruskal-Wallis non-parametric rank test, N = 9, 6, 11, 19, 3, 1).

[46]In linear-log regression, $\Delta y = (\beta_1/100)\%\Delta x$, where for a 1 percent increase in Δx, y can be expected to increase by $(\beta_1/100)$ units.

Table 1.5: Cost Escalation ΔC (%) Estimates.

Type	$\Delta C_{Inst. or FM}$ (%) =	α	+	β	*Output*	Obs., R^2
Fiber:	$\Delta C_{Inst.}$ =	452	+	-84	$log(Insts.)$	N = 38
		*(232)**		*(45)**		$R^2 = 0.252$
Wireless:	$\Delta C_{Inst.}$ =	-457	+	152	$log(ProposedInsts.)$	N = 4
		*(81)***		*(42)**		$R^2 = 0.410$
Wireless:	$\Delta C_{Inst.}$ =	-3,021	+	202	$log(TotalBudget)$	N = 4
		*(639)***		*(37)***		$R^2 = 0.870$
State Govt:	$\Delta C_{Inst.}$ =	519	+	-73	$log(Insts.)$	N = 12
		*(273)**		*(38)**		$R^2 = 0.206$
State Govt:	ΔC_{FM} =	-389	+	80	$log(ProposedFiberMiles)$	N = 9
		*(188)**		*(33)***		$R^2 = 0.487$
Local Govt:	ΔC_{FM} =	2,711	+	-163	$log(TotalBudget)$	N = 6
		*(1,106)**		*(68)**		$R^2 = 0.684$
Local Govt:	ΔC_{FM} =	1,112	+	-204	$log(FiberMiles)$	N = 6
		*(346)***		*(68)***		$R^2 = 0.747$
Local Govt:	ΔC_{FM} =	661	+	-123	$log(ProposedFiberMiles)$	N = 6
		*(80)****		*(18)****		$R^2 = 0.914$
Non-Profit:	ΔC_{FM} =	185	+	-30	$log(FiberMiles)$	N = 11
		*(53)****		*(9)****		$R^2 = 0.659$
For-Profit:	$\Delta C_{Inst.}$ =	-341	+	95	$log(ProposedInsts.)$	N = 17
		*(146)***		*(38)***		$R^2 = 0.332$

Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Output measures tested against cost escalation for cost per institution $\Delta C_{Inst.}$ are the number of directly connected institutions ($log(Insts.)$), proposed number of directly connected institutions ($log(ProposedInsts.)$), and total budget ($log(TotalBudget)$). Output measures tested tested against cost escalation for cost per fiber mile ΔC_{FM} are the number of new and improved fiber miles ($log(FiberMiles)$), proposed fiber miles ($log(ProposedFiberMiles)$), and total budget ($log(TotalBudget)$). Natural logarithm is used throughout.

Local governments showed negative coefficients on output quantities. For 1 percent increase in total budget, fiber miles, and proposed fiber miles, cost escalation by cost per fiber mile ΔC_{FM} (%) decreased by 1.63 percentage points, 2.04 percentage points, and 1.23 percentage points respectively.

Non-profit and for-profit institutions exhibited similar relationships between outcome measures and cost escalation. For 1 percent increase in the number of fiber miles, cost escalation decreases by 0.30 percentage points in non-profit projects. For 1 percent increase in proposed institutions, cost escalation increased by 0.95 percentage points in for-profit projects.

Figure 1.4 displays scatterplots of cost escalation and outputs for cost per institution $\Delta C_{Inst.}$ (%). Three plots compare cost escalation on dependent variables of total budget, proposed directly connected institutions, and directly connected institutions. The left graphs show technology types and the right graphs show institution types. Data is log transformed for visibility. Appendix A includes frequency analysis for costs per fiber mile $\Delta C_{FM}(\%)$. These results are consistent with related literature that studies cost overruns from outputs levels.

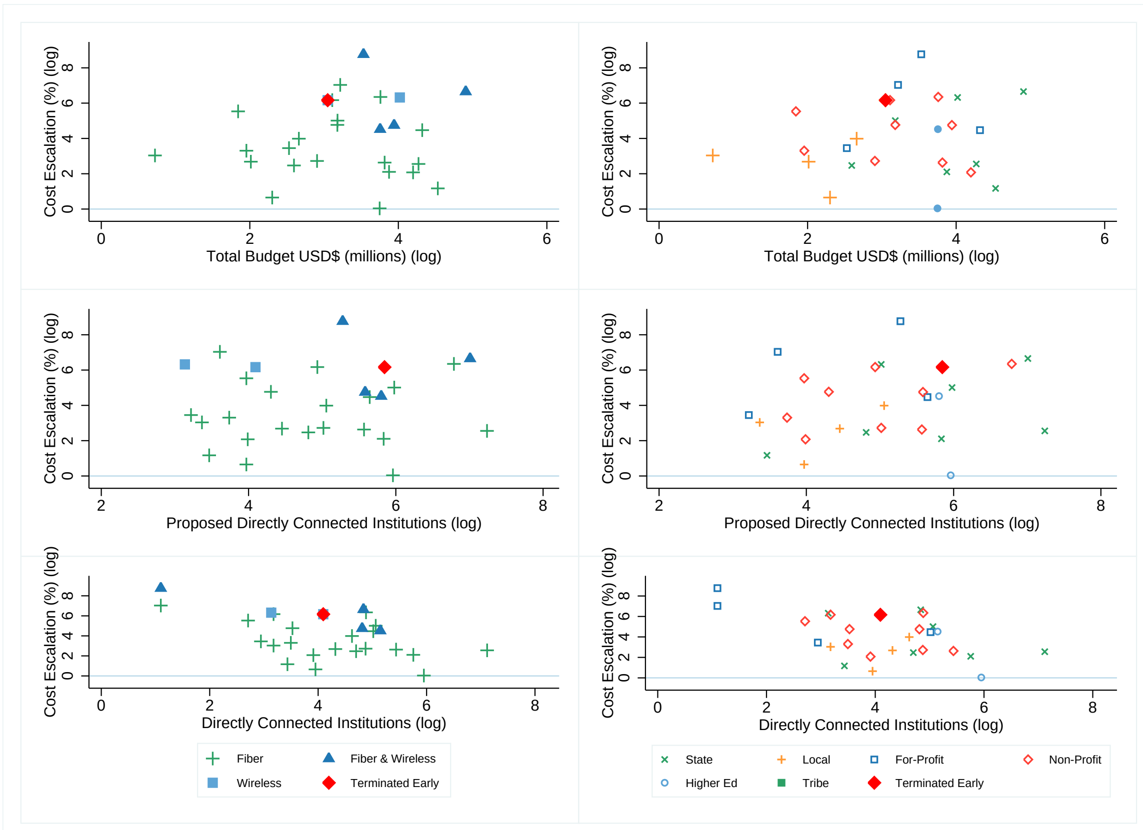

Figure 1.4: Cost Escalation $\Delta C_{Inst.}$ (%) and Outputs.

Scatterplot shows data for positive cost escalations. Negative cost escalations are undefined in a natural log transformation. Frequency analysis for cost escalation based on cost per fiber mile ΔC_{FM} (%) are in Appendix A. The charts here show results for cost escalation based on cost per institution.

1.3 Cost Forecasts

Next, I consider the quality of cost forecasts across projects. After controlling for network characteristics, did proposals predict actual construction? To explore this question, first I discuss cost forecasting for broadband buildout.

1.3.1 Network Characteristics

Grantees built infrastructure in different economic and geographic conditions. Fiber-optic networks are multi-faceted projects. Rural geography causes costs to rise rapidly for projects outside of major cities. Complexity in construction can lead to higher likelihood of cost escalation. Costs also grow exponentially in the 95th percentile of deployment for universal service.[47] To curb exploding costs, federal programs apply per line caps on telephone subsidies to remote residents.[48]

Network characteristics include everything from fiber miles, backbone or lateral strands, active and dark strands, points of interconnection, microwave links, and wireless towers. Fiber-optic cables vary in quantity and quality by backbone and lateral strand count. Strand counts for lateral fiber (12 to 96 strands) differ from backbone fiber (144 to 288 strands). Speeds vary on these lateral (50 megabits per second to 1 gigabits per second) or backbone fibers (10 gigabits per second). Strand count is multiplied by fiber miles to reflect total strand count. The Oklahoma project, for instance, delivered 91,382 total strands of fiber-optic cable while the Iowa project delivered 19,009 total strands. Dark fiber remains dormant until it is lit with routers, equipment, and electricity.[49]

Aerial fiber stretches across utility poles, along roadways, and above residential property. Narrative descriptions from the applications showed an average of 60.6 percent aerial and

[47] CQBAT Cost Model Letter, 2012, p. 2. *See* `https://ecfsapi.fcc.gov/file/7021859948.pdf`.

[48] FCC UCC/ICC Transformation Order, WC Docket No. 10-90, FCC 14-54 (2014). *See* `https://apps.fcc.gov/edocs_public/attachmatch/FCC-14-54A1_Rcd.pdf`.

[49] Final reports and narrative accounts from application files include network characteristics such as square mile area, average price per megabit per second, annual revenues, and number of employees.

39.4 percent buried fiber in the broadband stimulus (N = 13).[50] Buried fiber rests in conduits below roads and on easements for real property.

Speeds vary across networks. Speed tiers, from 1.5 mbps, 50 mbps, 100 mbps, 1 gbps, 10 gbps, and 1 tbps, were offered by broadband builders. Grantees reported maximum advertised speeds and average speeds in menus of broadband service. Average maximum speeds of 16 gigabits per second, and average speeds of 1.1 gigabits per second were reported. Dark strands outnumbered active strands three to one (30,410 dark strands to 11,430 active strands on average per project). One hundred ninety four towers were built and 1,661 new wireless links connect institutions. Tables 1.12 and 1.13 show average network characteristics for 116 broadband projects.

Prices vary by quantity or quality of bandwidth. On each of the speed tiers available, grantees reported prices offered to subscribers. Prices include discounts and one to two-year subsidized rates.[51] However, discounted prices are offered for a limited number of years. Grantees built 10 gigabit backhaul service, 1 gigabit connections to anchor institutions, and 100 mbps services to schools.[52]

Square feet of facility space and service provider agreements may impact cost forecasts as well. Square mile area for network coverage was declared by grantees in their application forms. Table 1.13 shows the average reach of broadband connectivity. Fiber projects were built in smaller areas with an average reach of 6,689 square miles compared to 20,380 square miles. State governments built over larger square areas than local governments, with an average of 31,282 square miles compared to 3,204 square miles.

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[50] *See generally* Nelson County Application, p. 29. The applicant cited average costs of 16 dollars per pole attachment per year with installation of 20 poles per mile.

[51] Price data from grantees is listed in Appendix A. Prices are listed by speed tier to provide some estimate of price by technology and institution. Stimulus grantees explain their price offerings for gigabit backhaul transport and business or school service. Average prices from a sample of broadband projects fall below competitor prices. Government Accountability Office, "Federal Broadband Deployment Programs and Small Business," February 2014. *See* `http://www.gao.gov/assets/670/660734.pdf`.

[52] Applicants provided competitor price data for schools and libraries from AT&T and Fairpoint. Grantees claimed to offer lower prices from 5,000 to 30,000 dollars per month for 10 gigabit backhaul, 650 to 18,518 dollars per month for 1 gbps, 550 to 6,800 dollars per month for 100 mbps, and 500 to 1,000 dollars per month for 10 mbps, and 386 dollars per month for 5 mbps. Some applicants cited industry rates of 12.50 to 62.50 dollars per strand per mile per month, or 100 dollars per month per mbps. *See* Appendix A.

1.3.2 Project Finance

A discussion on risk mitigation may prove useful for cost forecasts. Economists closely study welfare gains in structuring capital-intensive infrastructure projects across public and private entities. Consultants advise federal, state and local governments on sustainable plans to build infrastructure. Deal structures can mitigate risk in infrastructure projects. Public-private partnerships are an important innovation of project finance that shifts risk between public and private entities.

In public-private partnerships, private firms often own and operate facilities, while providing discounts to public entities. Public entities, in turn, provide rights-of-way and tax credits to private builders. Firms structure their capital holdings through debt rather than equity to hedge risk from future economic conditions that may result in declining service revenues or anemic tax receipts.[53]

Public-Private Partnerships

Development economists study outcomes from public-private partnerships. Studies have compared results of public or privately-funded construction where owners and operators bear financial risk in project design, scope, and environment. (Akinci and Fischer, 1998). In one study, highway projects of larger size and longer duration were more likely to incur cost overruns, controlling for contract bidding, environmental costs, and project type.[54] Contract size, contract period, and growth of the project drive the risk of cost overruns. (*Id.*). In procurement auctions for construction contracts, bidding-related variables affects the likelihood of cost overruns. To test whether bid amounts influence the final probability of cost overrun, factors have been measured "lowest bid, second lowest bid, median bid, winning bid, bidding ratios, and bid spread." (*Id.*).

[53] Over 900 providers of fiber broadband offer coverage in the United States. Private lenders require 20 percent equity to issue credit for fiber buildout. Federal programs, as well as the Recovery Act, sought proof of matching funds and equity contributions for buildout. *See* `http://broadbandnow.com/Fiber-Providers.`

[54] Gkritza, Konstantina, and Samuel Labi, "Estimating Cost Discrepancies in Highway Contracts: Multistep Econometric Approach," *Journal of Construction Engineering and Mgmt.,* 134(12): 953-962 (2008).

Markups and underinvestment allow builders recoup losses after contracts are signed. (Akinci and Fischer, 1998). In the telecommunications industry, Laffont and Tirole (1986) measured underinvestment when regulators were unable to adjust price controls dynamically. The public-private partnership literature finely tunes how to structure up-front investments by private firms with future payments by public owners with financing terms to mitigate future economic shocks.[55] Structured finance can mitigate incentives for opportunism. Spiegel (1994) and Spiegel and Spulber (1994) noted that capital structures of regulated firms can mitigate underinvestment. Debt financing, in particular, can mitigate opportunism. Underinvestment can persist, however, if regulators continue to precommit to prices. (*Id.*). Capital structure allows utilities under rate-of-return regulation to partition revenue streams "across different states of nature." (Taggart, 1981, 1985). Higher debt leverage by telecommunications firms can also influence prices charged. Cambini and Rondi (2011) consider evidence from European telecommunication firms where regulatory opportunism lead to underinvestment in buildout. Edwards and Waverman (2006) studied European utilities under regulation where governments were substantially invested. Guthrie (2006) noted "irreversibility of much infrastructure investment" under regulatory regimes as a risk issue in investment theory. Duggan (2002) considered the efficiency of government agencies, private firms, and non-profit organizations in the healthcare context.

Martimort and Pouyet (2008) studied the privatization of utilities in industrial countries

[55] Demand estimation for the service at issue, whether electricity, broadband, highways, subways, or high-speed rail determines the viability of capital investment. Early American papers measured demand for ADSL as price-elastic. Crandall, et al., "The Empirical Case Against Asymmetric Regulation of Broadband Internet Access," *Berkeley Law and Technology Journal,* 17(1): 953–987 (2002). Another study estimated own-price elasticities of demand for ADSL in Japan, finding access demand for ADSL as inelastic, and FTTH and CATV as elastic. Ida, T., and T. Kuroda, "Discrete Choice Analysis of Demand for Broadband in Japan," *Journal of Regulatory Economics,* 29(1): 5–22 (2006). Other scholars find more elastic demand in narrowband internet than broadband internet in Portugal. Pereira, Pedro, and Tiago Ribeiro, "The Impact on Broadband Access to the Internet of the Dual Ownership of Telephone and Cable Networks," *International Journal of Industrial Organization,* 29(2011): 283–293 (2011). Dynamic models of demand for residential broadband can also inform investment decisions. A recent paper considers demand fluctuation in response to changes in broadband prices, with a finding that demand is likely to support investment in fiber-optic buildout in some markets. Nevo, et al., "Usage-Based Pricing and Demand for Residential Broadband," *Econometrica,* 84(2): 411–443 (2016).

in the 1980s and 1990s.[56] Privatization can increase investment because private investors handle uncertainty better than government actors.[57] Traditional public procurement typically separated the public and private sectors. Government designed the project, selected a private builder, but retained ownership and management of assets. (Martimort and Pouyet, at 394). Recently, public-private partnerships have given private sector builders more freedom to design projects and own assets.[58]

Moral hazard incentives between principals and agents explain dynamics in infrastructure investment as well. (Laffont and Martimort, 2002). Ownership by the party that values the benefits the most may be appropriate in cases of incomplete contracts. (Besley and Ghatak, 2001). Hart (2003) considered the ownership question for public-private partnerships with incomplete contracts. He presented a model for ownership structure and the efficiency of public or private provision when a service is defined by incomplete contracts.

Maskin and Tirole (2008) studied public-private partnerships to look at how rules can constrain regulators. They wrote that public officials can misbehave in "'securitizing' public sector liabilities." (*Id.* at 413). Since public officials select projects and private contractors develop and operate the assets, there is disconnect in how officials set costs. Public officials can understate costs, rather than calculate them in full. Rents to contractors can easily balloon in this setting. Public officials "may have preferences that differ from those of a social welfare maximizer." (*Id.*).

Greenstein, McMaster, and Spiller (1995) showed that private investment in telecommunications networks increased with incentive regulations rather than rate-of-return regulations. When risk was shifted to shareholders, underinvestment was less likely. (*Id.*).

[56] They cite the Carter administration as an example of a government that invited private firms into public projects. (*Id.*, at 394, n.4).

[57] *See generally* Alesina, Alberto, et al., "Regulation and Investment," *Journal of the European Economic Association,* 3(4): 791-825 (2005); Arrow, Kenneth, and Robert Lind, "Uncertainty and the Evaluation of Public Investment Decisions," *American Economic Review,* 60(3): 364-378 (1970).

[58] The regulator "takes a more minimalist stance," and lets the private operator build and efficiently manage assets. (*Id.* at 394). Ownership structure is different in a public-private partnership. Martimort and Pouyet write that ownership matters, when "quality attributes of an infrastructure may be hard to specify in advance so that complete contracting with a builder may be difficult or even impossible to write. Ownership provides then incentives to improve quality." (*Id.* at 395).

When shocks occurred in the economy, decisions were guided by shareholders who had more to lose. (*Id.*). Hausman (1997) described demand uncertainty and economic shocks in telecommunications buildout. He wrote that telecom firms make decisions invariably subject to technology and economic change. He warned regulators that policy delay would impose costs on infrastructure buildout.

Net Present Value and Discount Rates

Cost forecasts for fiber-optic buildout include a net present value (NPV) calculation. Net present value incorporates estimates of future revenues. Forecast estimates change, sometimes drastically, depending on the discount rate applied. Stimulus administrators directed applicants to use a 15 percent weighted average cost of capital for project calculations.[59] Universal service models apply a 11.25 percent cost of capital, and an alternative universal service model applies a 9 percent cost of capital.[60] In comparison, submarine cable investors often require cost forecasts to apply a 25 to 33 percent weighted average cost of capital.[61]

An Iowa grantee petitioned to apply a municipal bond rate of 1 percent cost of capital to its NPV estimate. Other applicants sought to value their projects with weighted average costs of capital of 1.5, 3, 3.25, 4, 5, 6, 7, 8, 9, or 10 percent. Maryland and the District of Columbia cited a hurdle rate of 6 percent for their cost of capital.[62] Several

[59] *See generally* State of Louisiana Board of Regents Application, p. 28. Stimulus administrators provided these instructions: "To be completed by for-profit applicants: Rate of Return (without BTOP Funds): Removing potential BTOP funding from your calculations, please submit the net present value of the proposed project over five years both with and without the terminal value of the project. Please conduct these calculations using the following discount rates: 10, 15, 20, 25, 30, 35 and 40 percent. To determine the terminal value of the project, please divide the operating cash flows in Year 5 by the Discount rate minus the Long Term Cash Flow Growth Rate. Please provide the spreadsheets and key assumptions that clearly explain your analysis. Be certain to use the cash flows from operations, and not cash flows impacted by your project's financing. To be completed by for-profit applicants: Rate of Return (with BTOP Funds): Including potential BTOP funding, Please submit the results of the same net present value calculations you conducted to answer the question above."

[60] BAM model uses 11.25 percent, CQBAT uses 9 percent.

[61] The International Telecommunications Union (ITU) cost model recognizes private capital and government or donor-funded weighted average cost of capital at 0 to 5 percent. With a World Bank grant, equity, and commercial loan, the ITU presents broadband projects with 5 percent rates of return on initial investments and 6 percent on incremental investments. Vicious cycles may result for developing countries, however, with the combination of low demand for broadband services and onerous debt repayment liabilities.

[62] Municipal general obligation (GO) bonds vary in performance according to the source of tax revenue. Sewer, water, and electric utility revenues are considered highly stable with low variance. Revenues from

applicants cited denial of loans from banks due to lack of collateral or financial history. Other financing options suggested by grantees included a bond offering at 4 percent with 10 or 15-year fixed rate loans.[63] Types of infrastructure varies in investment risk, whether the technology is cable, wired telecommunications, or wireless telecommunications.[64] For one city, consultants applied a 4 percent discount rate to a 20-year net present value estimate for a fiber-to-the-premises overbuild project.[65]

Several grantees opposed forecast requirements in the stimulus application.[66] Forty-three of the 116 projects revealed their projected rates of return with and without stimulus funds. Rates of return ranged from -94 percent to 47 percent (without stimulus funds), and -22 percent to 90 percent (with stimulus funds). On average, grantees claimed rates of

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high-speed broadband service do not fall into this category with high variance. One grantee wrote that municipalities often have exhausted the market for bond issuance due to over-extended portfolios of debt obligations.

[63]Merit Network proposed a 4 percent bond offering, Appalachian Valley Fiber used a prime rate of 3.25 percent. North Florida Broadband Authority was offered a private loan of prime plus 1 percent with a 5 percent floor. Ocean State Beacon project was denied a 22 million dollar loan for risk. Zito Media and California Broadband Cooperative had loan applications denied due to lack of collateral or financial history.

[64]Betas by Sector (US) for risk are cited in a study on government broadband initiatives. Ellig, Jerry. 2006. "A Dynamic Perspective on Government Broadband Initiatives." *Reason Foundation Policy Study 349.* In 2016, Wireless Telecom has a beta of 1.48, Cable TV 1.23, Telecom Services 0.95. *See* `http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/Betas.html`.

[65]City of Palo Alto Fiber-to-the Premises Master Plan, August 2015. *See* `https://www.cityofpaloalto.org/civicax/filebank/documents/48723`. The city used a price of 0.75 dollars per megabits per second direct internet access in estimates. Project financials necessarily require business realities of overbuild networks where private providers already operate. In discussing the economics of infrastructure, they wrote, "Generally, fiber overbuilds do not offer a high rate of return, which is why there are not many private sector providers clamoring to build fiber networks in markets where customers are already served. Instead, private and public sector entities that opt to overbuild usually consider alternative reasons and benefits for deploying a new network. These entities focus on other value and drivers that make overbuilding make business sense. For example, a municipality may choose to enter the market as an overbuilder for economic development purposes, like serving anchor tenant businesses, school districts, and research parks." (*Id.*).

[66]LA-RICS, Application, p. 40. The grantee wrote, "While we can calculate a Net Present Value (NPV) for this project based on an arbitrary discount rate, we do not think that NPV is an appropriate measure of the value of this project. We do not utilize NPV in prioritizing our projects, as do profit making enterprises that have revenue generating projects competing for the same capital pool. LA-RICS [Los Angeles Regional Interoperable Communications System] is a government entity that answers to the residents and businesses in our jurisdictions; we are not concerned with investors that demand revenue from their investments to be maximized. LA-RICS members are charged with protecting the lives and property within our communities. The investments we make in technology are not quantitatively measured in profits or market share; instead, our investments are evaluated on their ability to enhance the safety of our communities. Implementing LA-SafetyNet will undoubtedly save lives and protect property. Furthermore, the network will be an important tool to help deter crime and prevent terrorism, and it will enhance situational awareness and response times for the entire public safety community. Any NPV calculation will be unable to quantify these benefits LA-SafetyNet will provide. For this reason, we contend that the NPV analysis does not apply to this project."

return of -8 percent without funds, and 16.6 percent with funds (s.d. 19.4 percent and 22.9 percent). Net present value included projected revenue in year 8, net income in year 8, net margins, earnings margins, and debt to asset ratios.

Sixteen of 116 grantees provided bond ratings in unredacted application files. These included a range of Aaa, Aa, Aa-, Aa3, A1, A2, Baa3, and Bbb from different ratings agencies. Average match percentages through equity or alternative grants were 27 percent of total budgets with a standard deviation of 9 percent.

Uptake

Estimates of uptake, or expected subscribership, to households, businesses, and anchor institutions drive revenue predictions in cost forecasts. Actual uptake was not well-documented in final reports for broadband stimulus.

In their letter, seventy-one economists noted demand-side economics of fiber buildout in residential markets. "It will be important not to confuse supply and demand for broadband. About half of all people without broadband say that they are not interested in it." (Concerned Economists, at 4, n.11). A study on the Australian fiber network compared proposed and actual subscribership.[67] The megaproject claimed in 2011 that it could deliver 93 percent uptake, but in 2016, has posted less than 50 percent of target results.[68] The 33 billion dollar network is owned and operated by a government-owned entity, who recently posted a 6.6 billion dollar outlay to buy equity in the company, with a statutory cap of total funding at 22.3 billion dollars.[69] NBN Co Limited plans to raise between 12 and 20 billion dollars in debt financing this year to continue its buildout.[70]

[67] Sorensen, Lucia Gamboa, and Andrew Medina, "The End of Australia's National Broadband Network?" *Technology Policy Institute Working Paper,* (2016).

[68] *Id.*

[69] The Australian national budget includes the broadband network as a liability. *See* `http://budget.gov.au/2016-17/content/bp1/download/bp1.pdf`.

[70] NBN Co Limited planned to be revenue positive in 2021, with 30 percent equity and 13 percent debt financing. *See* `http://www.nbnco.com.au/assets/documents/nbn-co-corporate-plan-6-aug-2012.pdf`.

Vendors and Firm Size

Firm size and vendor size may affect economies of scale for buildout. Some universities cited 19,181 and 27,000 employees, with the smallest grantees with 3, 5, 8, and 9 employees.[71] Invoices included vendor data for all projects (N = 116). Invoices included the number of vendors with payments over 25,000 dollars, vendors with payments under 25,000 dollars, and the total dollar amount paid out to these vendors.

Stimulus funds were not distributed with the price, quantity, or quality discipline of procurement auctions.[72] Applicants may have had a lower chance of winning stimulus funds if costs seemed unreasonably high. Yet price discipline on equipment or parts was only guaranteed if the state or private firm chose to abide by state or federal price schedules. Firm size may also impact performance outcomes in economies of scale. The cost overrun literature cites firm size as a potential factor in forecast error.

Vendors deal wih legal costs to manage rights-of-way, municipal easements, land leases, architectural appraisals, interconnection agreements, pole attachment agreements, railroad crossing permits, conduit usage licenses, and federal and state special permitting. Regulatory requirements may favor large firms who can bear legal and administrative costs.[73] Compliance with federal regulations also required grantees to report impacts on floodplains, wetlands, coastal areas, Brownfield sites, national historic buildings, archaeological sites, and tribal lands.[74]

[71] On average, grantees had 1,235 employees and 897 million dollars in annual revenues.

[72] Eligible costs needed to be (1) reasonable, (2) necessary, (3) allocable, and (4) appropriate. NTIA, Round 1 Workshops. *See* `http://www2.ntia.doc.gov/documents/Infrastructure1_0721.pdf`.

[73] NTIA, "Rights-of-Way Laws by State," 2003. *See* `https://www.ntia.doc.gov/legacy/ntiahome/staterow/rowtableexcel.htm`. Suburban broadband often costs more to build due to zoning restrictions. In New Jersey, the state department of treasury estimates the cost per mile of fiber installation ranges from 184,800 to 501,600 dollars per mile, with contracts set to 152,000 dollars per mile. New Jersey Dept. of Treasury Application, p. 40. Under state procurement law, "Verizon's quote included: Land, Structure, Rights-of-way, Appraisals Architectural and engineering fees Project fees such as municipal construction permits Site work to construct onsite pathways All aspects of fiber provisioning and network documentation while complying with our State's laws on Prevailing Wage Layer 2 and layer 3 network equipment at rates below the WSCA contract (the state uses the Western States Contracting Alliance [WSCA] contract for equipment)." *Id.*

[74] Stimulus grantees commented on property changes according to rules administered by the U.S. Fish and Wildlife Service (FWS), Environmental Protection Agency (EPA), Federal Emergency Management Agency (FEMA), National Oceanic and Atmospheric Administration (NOAA), and U.S. National Park

Other Cost Models

Industry models incorporate network characteristics to forecast costs of broadband buildout. Buildout models guide the 4 billion dollar Connect America Fund, a subsection of the Universal Service Fund.[75] The Connect America Model (CAM) is a cost model that informs the federal universal service program.[76] Other iterations of the model include the Broadband Assessment Model (BAM) and CostQuest Broadband Analysis Tool (CQBAT). These models take into account technology types, population density, vendor prices, and predicted service demand. Hundreds of factors are included, with a dozen technology types, a default 5 percent sales tax rate, and demand prediction model for subscriber uptake.[77] Depreciation and consumer price changes are included, as well as economies of scale for the service providers by employee count. One model includes forward-looking demand prediction, and both incorporate penetration rate models for broadband adoption.[78] Adoption rates are known to be positively correlated with income levels and higher education and negatively correlated with lower education, elderly ages, and rural locations.[79] Fisher-Pry and Gompertz models also forecast technology adoption for demand estimates.[80] These models inform investors of sustainable financing of residential fiber-optic infrastructure.[81]

Service (NPS) and National Register of Historic Places (NRHP).

[75] Middle mile connections to anchor institutions may be considered a different type of buildout goal from residential broadband in the Connect America Fund. FTTH, FTTN, FTTD each constitute different cost structures, along with Docsis 3.0, Broadband over Power Line, LTE and WiMax, and xDSL. The State of Connecticut recently estimated a cost of 3.2 billion dollars to fund fiber-to-the-home for all its residents.

[76] Models are approved by fiber networks and calculated over 8.2 million census blocks.

[77] BAM Model, 2009-2010. *See* `https://transition.fcc.gov/national-broadband-plan/broadband-assessment-model-paper.pdf`.

[78] CQBAT Model, 2012. *See* `https://ecfsapi.fcc.gov/file/7021859948.pdf`.

[79] BAM Attachment, p. 1.

[80] *Id.*

[81] Capital expenditures fell from 71 billion to 64 billion dollars between 2008 and 2009. Investment exceeded pre-crisis levels in 2013 with 75 billion dollars of expenditure. In 2014, providers invested 78 billion dollars, 28 billion dollars of which were spent by wireline providers, 34 billion dollars by wireless providers, and 16 billion dollars by cable providers. USTelecom, 2015. *See* `https://www.ustelecom.org/broadband-industry-stats/investment/historical-broadband-provider-capex`.

In other studies, Cobb-Douglas production functions model inputs to telecommunications buildout. Translog functions are used to predict costs in telecommunications networks.[82] A model that incorporates prices of labor and capital could include public or private cost differences in cost of labor and cost of capital.[83] Telecommunication network maintenance is labor-intensive. For local networks, Verizon employs nearly 40,000 employees and 15,000 outside contractors for on-site maintenance. AT&T employs over 150,000 people, and Comcast over 95,000 people to maintain outside plant, repair infrastructure, and install new equipment.[84]

1.3.3 How Predictive Were Cost Forecasts?

In the case of broadband stimulus, cost modeling may begin with a more basic inquiry. I ask if cost forecasts predicted actual construction. If they did, then the evidence could inform policymakers on the reliability of buildout plans in broadband stimulus. Although broadband networks are dimensional, statistical methods can deal with variation.

In Eq. (1.2), I compare total costs across projects with respect to four outputs of fiber miles, directly connected institutions, indirectly connected institutions, and points of connection. Two sets of categorical predictor variables are type of technology T (fiber, fiber

[82] Bloch, Henry, et al., "Economies of Scale and Scope in Australian Telecommunications," *Review of Industrial Organization,* 18: 219–227 (2001); Christensen, Lauritis, and William Greene, "Economies of Scale in U.S. Electric Power Generation," *Journal of Political Economy,* 84(4): 655-676 (1976). Geographic factors such as topography and population density are the significant drivers of cost for telephone networks. Cubukcu, K. Mert, and Jean-Michel Guldmann, "Geography and the Costs of Local Telephone Networks," *The Annals of Regional Science,* 42(4): 821–842 (2007). A Cobb-Douglas function was recently applied to data center costs. Saha, et al., "A Novel Revenue Optimization Model to Address the Operation and Maintenance Cost of a Data Center," *Journal of Cloud Computing,* 5: 1 (2016). Subsystems within data centers that drive separate costs are "power, ping, and pipe." Patel, Chandrakant D., and Amip J. Shah, "Cost Model for Planning, Development and Operation of a Data Center," *HP Laboratories Palo Alto HPL-2005-107(R.1)* (2005).

[83] A literature on public infrastructure addresses questions of productivity growth from spending source. Productivity growth varies by public, private, and public-private-partnership capital stocks for infrastructure investment, by data from over 143 countries. International Monetary Fund, "Making Public Investment More Efficient: Annex I, Estimating Public, Private, and PPP Capital Stocks," June 2015, at 45. *See* `http://www.imf.org/external/np/pp/eng/2015/061115.pdf`.

[84] Unionized labor is included in older studies. Today over 700,000 employees are unionized in Communications Workers of America and the International Brotherhood of Electrical Workers. *See* `http://www.cwa-union.org/`.

& wireless, and wireless) and type of institution I (state government, local government, non-profit organization, for-profit organization, institution of higher education, and tribe). The vector Γ includes other proposed and actual outputs of i projects. My null hypothesis is that coefficients on categorical variables and outputs is zero.[85]

In Eq. (1.3), I ask whether proposals predict actual outputs across the projects. I control for technology, institution, and total cost. If proposals could not explain actual construction, then no statistical significance should appear in an ordinary least squares regression in four separate linear estimations.

$$TotalCost_i = \beta_1 T_i + \beta_2 I_i + \Omega_i \Gamma_i + \varepsilon_i \tag{1.2}$$

$$Actual_i^j = \beta_1 TotalCost_i + \beta_2 Proposed_i^j + \beta_3 T_i + \beta_4 I_i + \Omega_i \Gamma_i + \varepsilon_i \tag{1.3}$$

Eq. (1.3) also provides a test on whether grantees systematically underbid or overbid for projects.[86] If they offered low bids for networks and underdelivered, then total cost would have a negative effect on actual construction. If they offered low bids but overdelivered, then a positive and significant effect would be seen on the coefficient for total costs after controlling for proposed outputs.

Robust standard errors are applied to deal with heteroskedasticity in the error term. I report normalized beta coefficients after full standardization of the dependent and independent variables. To avoid multicollinearity, one of each categorical variable is omitted from results. Regression results on technology categories should be read with reference to wireless projects built by for-profit grantees.[87]

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[85] I consider total costs of the project, rather than the federal subsidy alone, to reflect the full price of fiber-optic and wireless networks.

[86] I use the term underbid and overbid generally since stimulus funds were not distributed by auction.

[87] UCLA, "Regression with Two Categorical Predictors." *See* `http://www.ats.ucla.edu/stat/stata/webbooks/reg/chapter3/statareg3.htm`.

1.3.4 Data

Table 1.6 shows average total costs by categorical variable. Average network characteristics are listed in Tables 1.12 and 1.13 for reference.

Table 1.6: Average Total Costs.

	Number of Projects	Average	*S.D.*	Min.	Max.
By Technology					
Fiber	85	$35,777,635	*$34,984,538*	$1,331,225	$158,416,520
Fiber & Wireless	22	$49,045,195	*$43,431,799*	$2,051,021	$159,823,296
Wireless	9	$51,263,079	*$66,728,336*	$2,282,589	$217,894,365
Total	116	$39,495,354	*$39,833,429*	$1,331,225	$217,894,365
By Institution					
State Govt.	20	$70,309,051	*$46,253,793*	$13,391,443	$159,823,296
Local Govt.	13	$31,175,560	*$57,228,033*	$2,061,176	$217,894,365
Non-Profit	28	$46,650,467	*$35,326,303*	$4,694,497	$128,958,031
For-Profit	43	$24,626,032	*$23,491,462*	$1,331,225	$94,963,210
Higher Ed	8	$43,140,884	*$39,614,335*	$8,859,615	$128,581,820
Tribe	4	$1,493,555	*$20,933,149*	$2,051,021	$45,902,602
Total	116	$39,495,354	*$39,833,429*	$1,331,225	$217,894,365

Federal stimulus funds were matched with other funds for many Recovery Act projects.

Table 1.7: Total Cost (millions).

	Total Cost (millions)		
	(1)	(2)	(3)
Fiber	-20.069	-49.347	-45.758
	(-0.224)	*(-0.544)*	*(-0.504)*
Fiber & Wireless	-11.872	-35.056	-33
	(-0.117)	*(-0.345)*	*(-0.324)*
State Govt	43.380***	7.738	9.481
	(0.413)	*(0.085)*	*(0.104)*
Local Govt	2.82	17.168	17.281
	(0.022)	*(0.137)*	*(0.138)*
Non-Profit	22.431***	4.334	2.469
	(0.242)	*(0.041)*	*(0.023)*
Higher Ed	18.628	10.399	9.423
	(0.119)	*(0.061)*	*(0.055)*
Tribe	-16.645	-39.06	-35.627
	(-0.077)	*(-0.189)*	*(-0.172)*
Proposed Fiber Miles		0.019***	0.015***
		(0.476)	*(0.379)*
Proposed Directly Connected Insts.		0.004	0.013
		(0.046)	*(0.155)*
Proposed Indirectly Connected Insts.		0.004**	0.003
		(0.201)	*(0.177)*
Proposed Pts. of Interconnection		0.031***	0.054
		(0.236)	*(0.418)*
Actual Fiber Miles			0.012
			(0.111)
Actual Directly Connected Insts.			-0.011*
			(-0.180)
Actual Indirectly Connected Insts.			0.002
			(0.073)
Actual Pts. of Interconnection			-0.025
			(-0.229)
Constant	42.533**	57.194*	52.435
	(.)	*(.)*	*(.)*
Observations	116	49	49
R-squared	0.202	0.704	0.742
Adjusted R-squared	0.151	0.617	0.625

Robust normalized beta coefficients in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The Wireless network indicator for technology, and the For-Profit indicator for institutions are reference variables, which are omitted to avoid multicollinearity.

Table 1.8: Fiber Miles.

	Fiber Miles		
	(1)	(2)	(3)
Total Cost (millions)	4.092*	1.114	0.999
	(0.421)	*(0.121)*	*(0.109)*
Proposed Fiber Miles	0.112*	0.067	0.055
	(0.280)	*(0.182)*	*(0.149)*
Fiber	478.127**	359.537**	341.840**
	(0.543)	*(0.431)*	*(0.410)*
Fiber & Wireless	435.830**	242.151*	217.280*
	(0.443)	*(0.259)*	*(0.233)*
State Govt	-162.006	-197.735*	-168.698
	(-0.184)	*(-0.237)*	*(-0.202)*
Local Govt	-248.745***	-218.918**	-199.782**
	(-0.210)	*(-0.191)*	*(-0.174)*
Non-Profit	40.592	-91.086	-73.478
	(0.044)	*(-0.094)*	*(-0.076)*
Higher Ed	-6.598	27	47.38
	(-0.004)	*(0.017)*	*(0.030)*
Tribe	13.237	-16.78	-5.048
	(0.006)	*(-0.009)*	*(-0.003)*
Proposed Directly Connected Insts.		0.383***	0.427**
		(0.513)	*(0.572)*
Proposed Indirectly Connected Insts.		0.015	0.016
		(0.093)	*(0.097)*
Proposed Pts. of Interconnection		0.348***	0.299*
		(0.290)	*(0.250)*
Actual Directly Connected Insts.			-0.065
			(-0.115)
Actual Indirectly Connected Insts.			0.016
			(0.053)
Actual Pts. of Interconnection			0.073
			(0.073)
Constant	-238.927	-123.487	-121.304
	(.)	*(.)*	*(.)*
Observations	59	49	49
R-squared	0.47	0.742	0.747
Adjusted R-squared	0.372	0.656	0.632

Robust normalized beta coefficients in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Wireless networks and For-Profit institutions are categorical reference variables, omitted to avoid multicollinearity.

Table 1.9: Directly Connected Institutions.

	Directly Connected Institutions		
	(1)	(2)	(3)
Total Cost (millions)	-2.069	-3.773	-2.943
	(-0.129)	*(-0.231)*	*(-0.180)*
Proposed Directly Connected Insts.	1.100***	0.951***	0.960***
	(0.833)	*(0.717)*	*(0.724)*
Fiber	83.899	-58.977	-38.651
	(0.062)	*(-0.040)*	*(-0.026)*
Fiber & Wireless	-66.023	-149.255	-158.046
	(-0.043)	*(-0.090)*	*(-0.095)*
State Govt	165.629	191.989	214.479
	(0.118)	*(0.130)*	*(0.145)*
Local Govt	14.421	108.127	109.451
	(0.008)	*(0.053)*	*(0.054)*
Non-Profit	107.704	-57.525	4.41
	(0.071)	*(-0.033)*	*(0.003)*
Higher Ed	97.539	116.58	170.114
	(0.040)	*(0.042)*	*(0.061)*
Tribe	116.467	33.399	68.544
	(0.034)	*(0.010)*	*(0.020)*
Proposed Fiber Miles		-0.064	-0.079
		(-0.097)	*(-0.120)*
Proposed Indirectly Connected Insts.		0.081	0.068
		(0.281)	*(0.237)*
Proposed Pts. of Interconnection		0.259	0.042
		(0.122)	*(0.020)*
Actual Fiber Miles			-0.209
			(-0.117)
Actual Indirectly Connected Insts.			0.054
			(0.100)
Actual Pts. of Interconnection			0.309*
			(0.174)
Constant	-77.082	48.412	18.296
	(.)	*(.)*	*(.)*
Observations	59	49	49
R-squared	0.662	0.727	0.742
Adjusted R-squared	0.6	0.636	0.624

Robust normalized beta coefficients in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Wireless networks and For-Profit institutions are categorical reference variables, omitted to avoid multicollinearity.

Table 1.10: Indirectly Connected Institutions.

	Indirectly Connected Institutions		
	(1)	(2)	(3)
Total Cost (millions)	7.617	3.562	3.467
	(0.254)	*(0.118)*	*(0.115)*
Proposed Indirectly Connected Insts.	0.286**	0.29	0.263
	(0.538)	*(0.545)*	*(0.494)*
Fiber	472.085*	311.843	271.896
	(0.181)	*(0.114)*	*(0.099)*
Fiber & Wireless	757.337**	386.323	405.425
	(0.255)	*(0.126)*	*(0.132)*
State Govt	-278.764	-495.065	-537.123
	(-0.102)	*(-0.181)*	*(-0.196)*
Local Govt	-296.539	-331.883	-335.096
	(-0.088)	*(-0.088)*	*(-0.089)*
Non-Profit	-631.664	-699.225	-705.495
	(-0.220)	*(-0.219)*	*(-0.221)*
Higher Ed	-427.492	-478.549	-544.119
	(-0.082)	*(-0.093)*	*(-0.105)*
Tribe	-118.2	-147.338	-186.463
	(-0.019)	*(-0.024)*	*(-0.030)*
Proposed Fiber Miles		0.344***	0.356**
		(0.282)	*(0.292)*
Proposed Directly Connected Insts.		0.326	0.005
		(0.133)	*(0.002)*
Proposed Pts. of Interconnection		-0.821*	-0.62
		(-0.209)	*(-0.158)*
Actual Fiber Miles			0.275
			(0.084)
Actual Directly Connected Insts.			0.289
			(0.156)
Actual Pts. of Interconnection			-0.344
			(-0.104)
Constant	-247.911	-22.609	3.627
	(.)	*(.)*	*(.)*
Observations	57	49	49
R-squared	0.482	0.588	0.597
Adjusted R-squared	0.383	0.45	0.413

Robust normalized beta coefficients in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Wireless networks and For-Profit institutions are categorical reference variables, omitted to avoid multicollinearity.

Table 1.11: Points of Interconnection.

	Points of Interconnection		
	(1)	(2)	(3)
Total Cost (millions)	-1.097	-2.552**	-2.18
	(-0.124)	*(-0.278)*	*(-0.238)*
Proposed Pts. of Interconnection	1.073***	1.080***	1.010***
	(0.896)	*(0.904)*	*(0.845)*
Fiber	197.446*	122.259	107.201
	(0.240)	*(0.147)*	*(0.129)*
Fiber & Wireless	221.239*	124.212	128.891
	(0.238)	*(0.133)*	*(0.138)*
State Govt	-55.192	-119.539	-134.256
	(-0.069)	*(-0.144)*	*(-0.161)*
Local Govt	-109.77	-93.915	-95.062
	(-0.096)	*(-0.082)*	*(-0.083)*
Non-Profit	-144.568	-139.459	-141.39
	(-0.161)	*(-0.144)*	*(-0.146)*
Higher Ed	-61.367	-71.229	-95.217
	(-0.039)	*(-0.045)*	*(-0.061)*
Tribe	-60.7	-99.193	-104.399
	(-0.032)	*(-0.052)*	*(-0.055)*
Proposed Fiber Miles		0.035	0.043
		(0.093)	*(0.116)*
Proposed Directly Connected Insts.		0.172**	0.053
		(0.231)	*(0.072)*
Proposed Indirectly Connected Insts.		0	-0.003
		(0.003)	*(-0.017)*
Actual Fiber Miles			0.077
			(0.077)
Actual Directly Connected Insts.			0.101
			(0.180)
Actual Indirectly Connected Insts.			-0.021
			(-0.069)
Constant	-66.401	18.037	22.139
	(.)	*(.)*	*(.)*
Observations	54	49	49
R-squared	0.678	0.721	0.732
Adjusted R-squared	0.612	0.628	0.61

Robust normalized beta coefficients in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Wireless networks and For-Profit institutions are categorical reference variables, omitted to avoid multicollinearity.

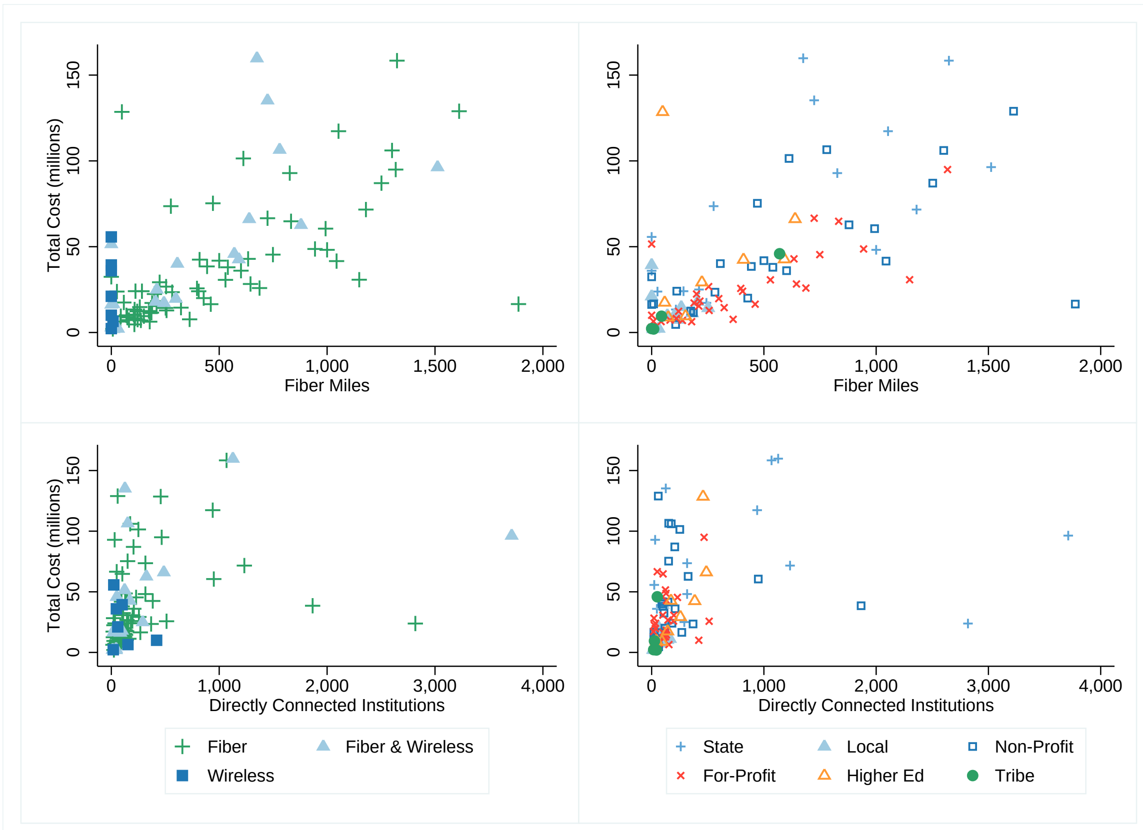

Figure 1.5: Total Cost (millions) and Actual Construction.

Two outputs of construction, fiber miles and directly connected institutions, are shown here compared to total costs by project (N = 116). Appendix A includes plots for other outputs of indirectly connected institutions, points of interconnection, and total strands.

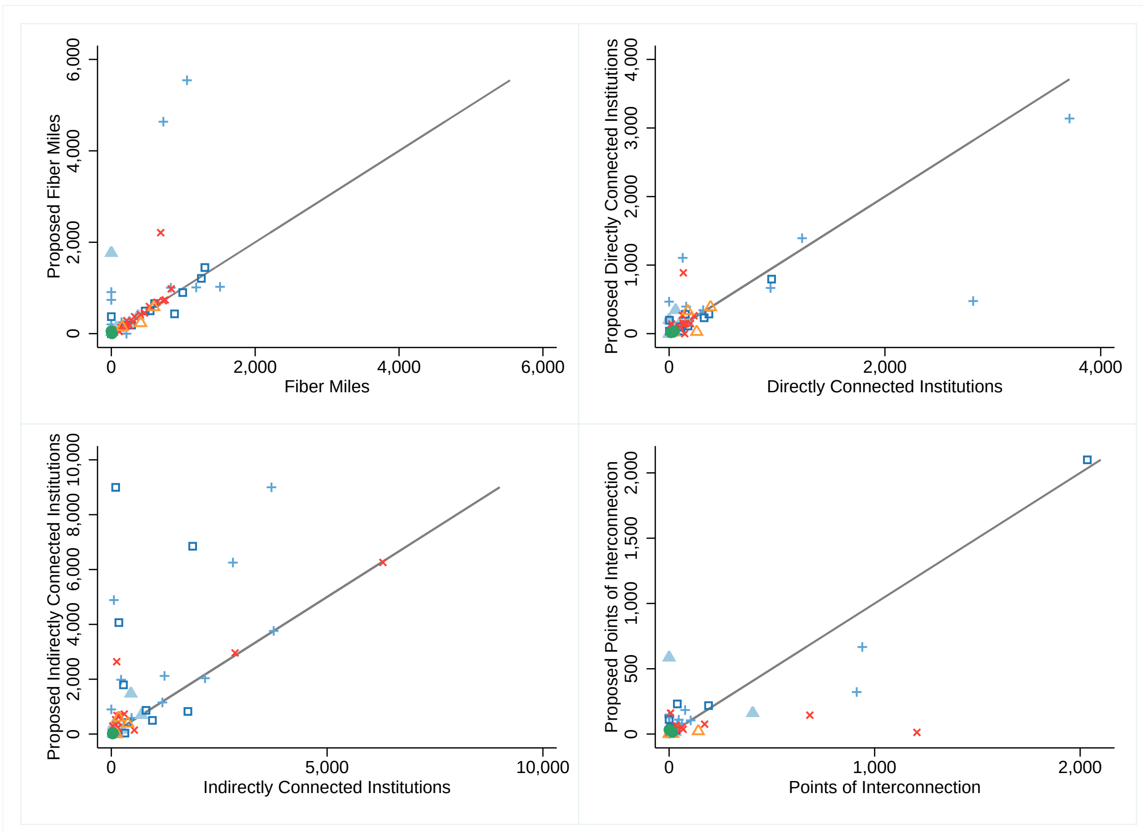

Figure 1.6: Proposed and Actual Construction.

Projects above the 45 degree line indicate cost escalations or cost underestimates. Projects that delivered outputs below the 45 degree line exceeded cost forecasts. Legend for organization type corresponds to Figure 5, for State, Local Non-Profit, For-Profit, Higher Ed and Tribe institutions.

Table 1.12: Average Network Characteristics.

	Directly Connected Insts.	Indirectly Connected Insts.	Fiber Miles	Wireless Links	Wireless Towers	Pts. of Interconnectn	Square Mile Area
By Technology							
Fiber	209	512	394	0	0	146	6,689
	(412)	*(952)*	*(431)*	*(1)*	*(0)*	*(363)*	*(9,937)*
Fiber & Wireless	321	862	349	69	7	102	20,380
	(797)	*(1,131)*	*(401)*	*(123)*	*(9)*	*(225)*	*(30,673)*
Wireless	91	318	1	23	6	29	19,626
	(133)	*(462)*	*(3)*	*(37)*	*(8)*	*(39)*	*(41,405)*
Total	25,634	65,363	41,142	1,734	194	14,887	804,800
Total Fiber	17,754	43,531	33,450	17	0	12,380	280,955
Total Fiber & Wireless	7,058	18,966	7,684	1,514	144	2,244	366,840
Total Wireless	822	2,866	8	203	50	263	157,005
By Institutions							
State Govt	619	1,069	465	48	2	154	31,282
	(1,006)	*(1,232)*	*(518)*	*(130)*	*(6)*	*(297)*	*(40,979)*
Local Govt	70	289	113	8	1	78	3,204
	(52)	*(405)*	*(114)*	*(28)*	*(3)*	*(153)*	*(4,980)*
Non-Profit	217	555	536	5	1	160	9,777
	(372)	*(687)*	*(514)*	*(14)*	*(5)*	*(425)*	*(13,325)*
For-Profit	95	496	291	4	1	110	9,739
	(121)	*(1,155)*	*(341)*	*(14)*	*(4)*	*(318)*	*(18,572)*
Higher Ed	254	303	274	14	2	194	4,062
	(170)	*(133)*	*(241)*	*(35)*	*(4)*	*(379)*	*(2,845)*
Tribe	34	232	156	62	10	4	4,267
	(15)	*(398)*	*(277)*	*(81)*	*(15)*	*(8)*	*(7,252)*
Total	25,634	65,363	41,142	1,734	194	14,887	804,800
Total State Govt	12,378	21,378	9,302	962	48	3,088	375,388
Total Local Govt	905	3,759	1,473	107	19	1,010	35,249
Total Non-Profit	6,074	15,547	15,015	137	27	4,475	127,107
Total For-Profit	4,106	21,331	12,534	164	47	4,747	233,739
Total Higher Ed	2,035	2,422	2,195	115	14	1,550	16,248
Total Tribe	136	926	623	249	39	17	17,068

One hundred sixteen projects include terminated projects. Eighty-five projects were fiber, 22 were fiber & wireless, and 9 were wireless only, as coded by the author. NTIA provided technology and institution counts, but not at a project-level for the infrastructure program. Fiber networks include fiber-optic cables with strand counts ranging from 12 to 488, with aerial or buried installation, and active or dark lit status. Fiber & wireless are hybrid networks with microwave links dependent on a fiber ring or fiber backbone. Direct connections are called "funded" anchor institutions and indirect connections are "potential" anchor institutions in Recovery Act data. Data comes from variables called *MMile_AvgCost*, *MMile_MaxSpeed*, and *MMile_AvgSpeed*. *See* Data Sources, CCI Data Dictionary with Data (2015). Standard deviations are in parentheses.

Table 1.13: Average Network Characteristics.

	Cost Per Mile	Total Strands	Active Strands	Leased Strands	Dark Strands	Max. Speed	Avg. Speed	Avg. Price* Per Mbps
By Technology								
Fiber	$55,751	48,506	1,666	198	1,129	17,538	1,705	$24.56
	($30,798)	*(57,390)*	*(11,779)*	*(1,804)*	*(4,636)*	*(30,655)*	*(2,864)*	*($29.97)*
Fiber & Wireless	$52,702	40,016	2,874	43	7,946	15,587	818	$20.64
	($38,661)	*(45,913)*	*(8,286)*	*(143)*	*(21,525)*	*(30,728)*	*(2,234)*	*($28.81)*
Wireless	$12,718	48	-	-	-	392	117	$463.59
	($5,299)	*(144)*	-	-	-	*(501)*	*(196)*	*($998.03)*
Total	$52,929	5,003,799	204,832	17,788	270,809			
Total Fiber		4,123,005	141,594	16,833	95,995			
Total Fiber & Wireless		880,362	63,238	955	174,814			
Total Wireless		432	-	-	-			
By Institution								
State Govt	$54,023	56,161	1,949	19	3,095	10,509	835	$24.96
	($25,422)	*(63,163)*	*(8,508)*	*(86)*	*(12,746)*	*(23,701)*	*(2,616)*	*($24.52)*
Local Govt	$46,523	18,241	1,486	8	-	4,328	470	$18.69
	($20,178)	*(21,241)*	*(4,171)*	*(29)*	-	*(4,690)*	*(676)*	*($33.87)*
Non-Profit	$52,681	60,927	361	-	1,831	24,447	1,446	$31.72
	($33,889)	*(63,658)*	*(1,702)*	-	*(7,134)*	*(38,111)*	*(2,681)*	*($37.62)*
For-Profit	$43,859	38,747	2,994	389	1,773	16,441	2,120	$173.86
	($24,492)	*(52,147)*	*(16,401)*	*(2,536)*	*(6,022)*	*(30,215)*	*(3,251)*	*($600.00)*
Higher Ed	$84,477	26,093	962	71	10,177	24,020	1,124	$22.59
	($33,502)	*(31,296)*	*(2,720)*	*(202)*	*(28,784)*	*(32,921)*	*(733)*	*($40.35)*
Tribe	$81,824	15,655	-	-	-	2,613	55	$24.48
	($86,818)	*(26,625)*	-	-	-	*(5,085)*	*(37)*	*($0.74)*
Total		5,003,799	204,832	17,788	270,809	16,212	1,431	$68.47
		(54,398)	*(10,694)*	*(1,545)*	*(10,384)*	*(29,900)*	*(2,692)*	*($323.46)*
Total State		1,123,220	38,978	384	61,907			
Total Local		237,137	19,318	104	-			
Total Non-Profit		1,705,956	10,101	-	51,269			
Total For-Profit		1,666,120	128,741	16,729	76,220			
Total Higher Ed		208,746	7,694	571	81,413			
Total Tribe		62,620	-	-	-			

*Average prices are per month per megabit per second, and are coded from narrative accounts of service offerings in the grantee application files. Prices are averaged across all tiers of service. *See* Appendix A. Fifty-nine of the 116 projects included price data in the application files. Average speeds are provided from 73 fiber, 22 fiber & wireless, and 5 wireless projects (N = 100). Maximum speeds are as advertised. Standard deviations are in parentheses.

1.3.5 Results

Table 1.7 shows total costs explained by proposed and actual outputs. Tables 1.8, 1.9, 1.10, and 1.11 show results for four outputs of fiber miles, directly connected institutions, indirectly connected institutions, and points of interconnection.

Table 1.7 shows results from Eq. (1.2). Regression results are presented with reference to the baseline of wireless projects by for-profit grantees. Technology type does not explain total cost. State governments and non-profits show statistically significant positive coefficients in Column (1). Total costs were 43.38 million dollars larger for state governments and 22.43 million dollars larger for non-profits, than for-profits who built wireless networks. Normalized beta coefficients show that state governments (beta = 0.413) have more impact on the size of project budget than non-profits (beta = 0.242).[88] A 1 standard deviation change in the state government categorical variable leads to a 0.413 standard deviation change in total costs.[89]

In Column (2), proposed outcomes predict total costs. Coefficients on proposed fiber miles, proposed indirectly connected institutions, and proposed points of interconnection are statistically significant and positive. The normalized beta coefficient on proposed fiber miles (beta = 0.476) is greater than that of indirectly connected institutions (beta = 0.201) and points of interconnection (beta = 0.236). For each additional proposed fiber mile, total costs increase on average by 19,000 dollars. For each additional indirectly connected institution, total costs increase by 4,000 dollars. For each additional point of interconnection, total costs increase by 31,000 dollars. Institutions do not explain total costs (N = 49, Adjusted $R^2 = 0.617$).

In Column (3), actual outcomes are added and proposed outcomes lose significance on total costs, except for proposed fiber miles. Proposed fiber miles (beta = 0.379) explain

[88]Standardized coefficients scale variables to have a mean of 0 and a standard deviation of 1, for a comparison across different levels. The constant does not have interpretation in a standardized framework.

[89]Some discussion of standardized coefficients has applied to categorical variables, with recommendation to divide by two times the standard deviation. *See generally* Gelman, Andrew, "Scaling Regression Inputs by Dividing by Two Standard Deviations," 2007. I apply the beta function in Stata 12.1.

increases of 15,000 dollars in project budgets. Actual directly connected institutions (beta = -0.180) have statistically significant effects on total costs. A 1 standard deviation change in the number of directly connected institutions leads to a decrease of 0.180 standard deviations in total costs. Larger projects connected more institutions for less cost. For each additional institution, total costs on average were 11,000 dollars smaller. Proposed fiber miles explain more variation in total costs across projects than actually connected institutions. Actual fiber miles do not appear to explain total costs.

Table 8 shows results from Eq. (1.3) for fiber miles. Regression results are presented with reference to the baseline of wireless projects by for-profit grantees. In Column (1), actual fiber miles are predicted by proposed fiber miles. For a 1 unit increase in proposed fiber miles, actual construction delivered 0.112 units of fiber miles (beta = 0.280). Proposed fiber miles fell below actuals across projects, with statistical significance ($p < 0.05$, N = 59, Adjusted $R^2 = 0.37$). Total costs explained actual fiber miles, where for each million dollar increase, 4.092 more fiber miles were delivered (beta = 0.421). Technology and institutions predict actual miles, with fiber and fiber & wireless networks delivering 478.127 and 435.830 fiber miles (beta = 0.543, beta = 0.443) more than for-profit wireless networks. Local governments delivered fewer fiber miles at -248.745 (beta = -0.210).

In Column (2), proposals explain actual fiber miles delivered better than proposed fiber miles. For a 1 unit increase in proposed directly connected institutions, 0.383 fiber miles were delivered (beta = 0.513), and for a 1 unit increase in proposed points of interconnection, 0.348 fiber miles were delivered (beta = 0.290), compared to for-profit wireless networks. Technology and institution types predict construction with fiber networks, fiber & wireless networks, state governments, and local governments explaining actual fiber miles.

In Column (3), other actual outputs are included. If grantees compensated for fiber mile construction with other actual outputs, these coefficients would be statistically significant. Proposed directly connected institutions and proposed points of interconnection explain fiber miles constructed. For a 1 unit increase in proposed institutions, 0.427 fiber miles were constructed (beta = 0.572), and for a 1 unit increase in points of interconnection, 0.299 fiber miles were installed (beta = 0.250).

Proposed fiber miles and total costs do not explain actual fiber miles in Columns (2) and (3). Other elements in the cost forecast, notably proposed institutions and proposed points of interconnection, better predict actual fiber miles than proposed fiber miles. Cost forecasts by grantees may systematically err in anticipating fiber buildout, but may provide tells through other outputs.

Table 1.9 shows results from Eq. (1.3) for directly connected institutions. Regression results are presented with reference to the baseline of wireless projects by for-profit grantees. In Column (1), actual directly connected institutions are predicted by proposed connected institutions. A 1 unit increase in proposed directly connected institutions explains an increase of 1.1 additional institutions (beta = 0.833). Total costs do not explain actual outcomes in institutions connected, nor do technology or institution types.

In Column (2), other proposed outputs could explain the final outcome in institutions but do not show statistical significance. Proposed directly connected institutions still explain the final outcome (beta = 0.717), where a 1 unit increase in proposed institutions leads to 0.951 actual connected institutions. In Column (3), proposed institutions explains actual outcomes (beta 0.724). Actual points of interconnection also correspond to final institution counts (beta = 0.174). For each 1 additional point of interconnection, the model anticipates 0.309 connected institutions.

Table 1.10 shows results from Eq. (1.3) for indirectly connected institutions. Regression results are presented with reference to the baseline of wireless projects by for-profit grantees. In Column (1), proposed institutions explains final performance. For 1 unit increase in proposed institutions, 0.286 institutions are delivered (beta = 0.538) compared to for-profit wireless projects. Technology appears to predict actual construction in this column. Fiber and fiber & wireless networks can explain 472.085 additional institutions and 757.337 additional institutions (beta = 0.181 and 0.255). Institution types do not impact this output (N = 57, Adjusted R^2 = 0.383).

In Column (2), other proposed outputs can predict the actual construction of indirectly connected institutions. For a 1 unit increase in proposed fiber miles, 0.344 additional institutions were connected indirectly (beta = 0.282). For a 1 unit increase in proposed points of interconnection, 0.821 fewer institutions were connected indirectly (beta = -0.209). In Column (3), proposed fiber miles predict the actual number of institutions indirectly connected, with a 1 unit increase leading to 0.356 additional institutions (beta = 0.292).

Proposed indirectly connected institutions and total costs do not explain actual construction in Columns (2) and (3). Proposed fiber miles can help predict indirect connections. Results also show that cost forecasts may systematically overestimate proposed indirect institutions.

Table 1.11 shows results from Eq. (1.3) for points of interconnection. Regression results are presented with reference to the baseline of wireless projects by for-profit grantees. In Column (1), proposed points of interconnection explain actual construction. For a 1 unit increase in proposed points of interconnection, an additional 1.073 points of interconnection are installed (beta = 0.896). Technology type predicts construction, with fiber and fiber & wireless networks installing 197.446 and 221.239 more points of interconnection than for-profit wireless projects (beta = 0.240 and 0.238).

In Columns (2) and (3), proposed points of interconnection explain actual construction. For a 1 unit increase in proposed outputs, actual construction follows with an increase of 1.080 and 1.010 additional points of interconnection (beta = 0.904 and 0.845). Proposed directly connected institutions also predict actual points of interconnection. In Column (2), for an additional proposed institution, 0.172 points of interconnection were also constructed (beta = 0.231). Total cost predicts points of interconnection in Column (2). For an additional million dollars, projects delivered 2.552 fewer points of interconnection (beta = -0.278).

Figure 1.5 graphically depicts the relationship between total cost and two selected outputs, directly connected institutions and fiber miles. Each of the 116 projects are marked by technology and institution category. An upward-sloping relationship between outputs and costs can be seen.

Figure 1.6 compares proposed and actual network characteristics by institution. Figure 1.6 shows outliers in fiber miles and indirectly connected institutions where proposals exceeded actual construction.[90] Correlation between proposed and actual directly connected institutions is 0.796 (N = 59), 0.631 for indirectly connected institutions (N = 57), 0.485 for fiber miles (N = 59), 0.786 for points of interconnection (N = 54). Outputs are shown in a scatterplot matrix in Appendix A. Regression diagnostics confirm the use of linear regression. The normality of residuals is confirmed along with other tests of fitness for the dependent variable.

1.3.6 Discussion

I find that grantees did not systematically underbid for projects after controlling for technology, institution, and budget. Tables 1.8, 1.9, 1.10, and 1.11 show that total costs do not rise with actual construction with controls for proposed quantities. If total cost had positive and significant impact on actual construction, then results would show that grantees overcharged for network outputs. In the other direction, total costs do not fall with actual construction with controls for proposed quantities. If total cost had a negative impact on actual construction, then results would show that grantees systematically delivered more output than initially proposed. In fact, the effect of total cost on actual construction is not statistically significant.

If grantees neither overbid nor underbid for actual construction, this implies that grant

[90]Three projects included Colorado Centennial which proposed 4,637 fiber miles and delivered 724 fiber miles; the State of Connecticut which proposed 5,544 fiber miles and delivered 1,053 fiber miles; and Mississippi South Contact Network which proposed 2,210 fiber miles and delivered 687 fiber miles. *See* Appendix A.

officers may find low-price offers to be cost-effective in infrastructure proposals.[91] Grant officers may be wary of the winner's curse situation where grantees bid too low and cannot deliver promised outputs. However, evidence indicates that grantees on average did not systematically underbid.[92]

Cost forecasts predicted actual construction in some of the four outputs. In some cases, I find that actual outputs are better predicted by proposed quantities other than the particular output at issue. An additional proposed directly connected institution or point of interconnection predicted 0.38 or 0.35 more fiber miles. An additional proposed directly connected institution predicted 0.172 more points of interconnection.

Directly connected institutions and points of interconnection were delivered near target across projects on average. In my model, cost forecasts predict increases of 0.11 fiber miles for each additionally proposed fiber mile, 0.28 indirectly connected institutions for each additionally proposed institution.

Evidence of reliability in cost forecasts for broadband stimulus informs a discussion of how to distribute infrastructure funds. If grantees systematically underestimate fiber miles, for instance, then perhaps compliance measures can target this output quantity. If network outputs are predictable from cost forecasts, then those outputs should take precedence in a request for proposal.

1.4 Grant Review

Finally, I apply statistical analysis to the applicant pool. I ask whether network characteristics were systematically different in accepted and rejected proposals. Administrators read more than 773 applications to select 116 projects.[93] The remaining 657 proposals were

[91] My study is limited to grant proposals that were selected through a ranking and scoring system. A study on cost forecasts of rejected projects that were built without stimulus funds could provide the counterfactual.

[92] This conclusion is predicated on the reliability of actual construction data. Grantees may have overstated their self-reports of actual construction. Grantees that fell short of proposed performance may have redacted their proposal data as well.

[93] The total applicant pool included 239 more applications in the middle mile category which are not found in legacy files through Easy Grant number.

rejected, resulting in a 16 percent acceptance rate.

1.4.1 Application Process

Forty civil servants, with the help of private-sector consultants, distributed 3.4 billion dollars across 116 projects. They read thousands of files, many of which included thousands of pages of documentation. Letters from local, state, and federal politicians, school board members, hospital administrators, and local business owners filled the applications.[94]

Oddly, the agency had never reviewed grants before, prior to the Recovery Act.[95] Senator Richard Shelby noted this fact in an early oversight hearing.[96] The agency quickly signed a contract for 99 million dollars to hire 200 contractors to manage the stimulus program. Indeed, "NTIA ha[d] not previously managed a grant program of BTOP's [Broadband Technology Opportunities Program] size and complexity."

Applicant volume increased in a second round of applications in winter 2010. Applicants promised hundreds and thousands of miles of fiber-optic cable and wireless equipment to those who dearly needed it. Files contained narrative descriptions of shovel-ready projects that would reach Americans who needed broadband. Infrastructure plans varied in size, shape, and region. Applications came from entrepreneurial enterprises and recognizable

[94]The same team read thousands of other applications for digital literacy programs and public computing projects to spend an additional stimulus funds.

[95]The National Institutes of Health reviews grants for 16 billion dollars per year. *See also* Powell, Kendall, "Making the Cut," *Nature,* 467: 383 (2010). Cole, Jonathan R., and Stephen Cole, "Will the Researcher Get the Grant?" *Nature,* 279: 575 (1979). Blank, Rebecca M., "The Effects of Double-Blind Versus Single-Blind Reviewing: Experimental Evidence from the *American Economic Review*," *American Economic Review*, 81(5): 1041–1067 (1991).

[96]Oversight of the Department of Commerce's Broadband Technology Opportunities Program, Hearing Before a Subcommittee of the Committee on Appropriations United States Senate, 111th Cong. 2nd, S. Hrg. 111-698, Jan. 28, 2010 [Oversight Hearing]. Sen. Shelby remarked, "NTIA, with billions of dollars, has been besieged with great proposals, grand proposals. The smallest agency in the Department of Commerce is now tasked with funding 4.7 billion dollars in grants. And yet the administration, Mr. Secretary, overestimated NTIA's capacity to deliver this funding and tasked an agency that does not even have a grant administrating office with disbursing 4.7 billion dollars. Something's got to give." Sen. Shelby noted, "After scrambling to find a way to oversee this program, the Department has tasked grant officers in NOAA [National Oceanic and Atmospheric Administration] and NIST [National Institute of Standards and Technology] to disburse the funding. Further, panels of outside contractors have been hired to review applications. Many of these contractors have never been interviewed in person by anyone at the Department of Commerce and yet are responsible for ensuring that all applicants are qualified." Oversight Hearing, 2010.

municipal governments.

Two volunteer reviewers read each file.[97] The number of reviewers was revised downward from three, after volunteers quit. "The personnel shortage was compounded by a lack of qualified individuals applying to become reviewers, reviewers who dropped out of the process, and the time it took to successfully review the often very lengthy applications (at times over 1,000 pages)."[98] Reviewers with knowledge of fiber buildout scored applications. The agency also went on a roadshow to meet applicants. The agency described best practices to applicants in order to receive good applications.

Administrator Larry Strickling reported to Congress on the agency's progress. The "multi-step review process" resulted in thousands of letters to denied applicants in the first round.[99] To protect Americans from waste, fraud, and abuse, grantees also filed financial readiness statements. The agency took care to shine more light on the applications too. They posted names of cable franchisers and small Internet service providers who applied for stimulus funds. Since enforcement and monitoring costs could overwhelm the review team, they asked the general public to report whether communities were underserved, as claimed in the applications.[100]

Senator Barbara Mikulski warned of the danger of boondoggle projects in an oversight

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[97] The use of volunteer reviewers may have violated the Anti-Deficiency Act. *See infra* OIG Report, 2010. Federal agencies use peer review in different ways to award grants. The National Science Foundation uses three to ten external reviewers, while the National Institutes of Health uses eighteen to twenty external reviewers. Reviews are not blind, as in peer-reviewed journals. Evaluation criteria are descriptive and tailored to the goals of the agency. Hosek et al., "Is There Gender Bias in Federal Grant Programs?" *RAND Corporation, RB-9147, TR-307-NSF* (2005).

[98] Office of the Inspector General, "NTIA Must Continue to Improve Its Program Management and Pre-Award Process for its Broadband Grants Program," *OIG Report No. ARR-19842-1,* 2010 [OIG Report].

[99] Oversight Hearing, 2010. He said, "Of course, those applicants denied in round one will be allowed to apply in round two. We've already announced the funding rules for the second round of funding and we're conducting informational workshops throughout the country. Grant applications for the second round of funding are due March 15. In order to enable full and fair review of all applications and meet our September 2010 deadline, NTIA is consolidating the final two rounds of funding into one and we're making a number of changes to sharpen the focus, to truly inform people what our priorities are and how they can be more competitive."

[100] A list of Internet service providers included hundreds of small cable providers in municipalities around the country. Sham enterprises would be identifiable through a posted list. Transparency could deter private actors who would take advantage of stimulus funds. Hundreds of applications from small businesses filled the queue. Many of the applications were aspirational, with vague and general requests for funds. Some applicants had specific buildout plans, others expressed lofty goals.

hearing. She said, "Now, we know that there is an inherent problem between getting the money out fast and doing the due diligence which this subcommittee is insisting on. And Mr. Secretary, I know you. We don't want to have the boondoggles like what happened at Census, what is going on over at NPOESS [National Polar-Orbiting Operational Environmental Satellite System], what I had at Justice, at the FBI [Federal Bureau of Investigation]. No boondoggles on your watch and no boondoggles on this subcommittee's watch."[101]

The funds needed to be spent quickly, then if possible, efficiently. If grant recipients could not perform their proposed projects, they had a duty under federal law to return the money. Several projects did, in fact return funds, such as the City of Tallahassee. By statute, each state would receive at least one infrastructure project.[102]

An upper limit of 500 million dollars was mandated, but the total number of projects was not limited. The team could have selected a thousand smaller projects, or fewer large projects. Because fiscal stimulus is meant to be "temporary, timely, and targeted," (Concerned Economists, at 1), the Recovery Act set a strict deadline to release the funds by September 10, 2010.

[101] Oversight Hearing, 2010.

[102] Gimpel, Lee and Thorpe (2013) find that Recovery Act funds at the county-level were skewed. Counties received 5.3 times more in the 90th percentile of infrastructure funding than the median county. (*Id.* at 578). Low-income counties did not receive infrastructure, but rather, "medium income takes a positive, statistically significant coefficient in the model for infrastructure spending." (*Id.* at 580). In other words, richer counties received more infrastructure spending than poorer counties under the Recovery Act. With proper econometric controls, they found "unemployment had no statistically significant effect on program allocations." (*Id.*).

Selection Criteria

Grant reviewers applied a merit-based hierarchy of seven priorities to evaluate each proposal.[103] Projects were graded on a scoring system of priorities[104] with guidance on reasonable eligible costs.[105]

Alternative mechanisms were available. Reverse auctions could have applied downward price competition, where sellers of the services compete to offer lower prices.[106] Federal regulators implemented a reverse auction in the Mobility Fund program in universal service reform. Wallsten (2013) reviews the efficacy of auction mechanisms to reform the subsidies. Until a few years ago, local providers did not compete to build telecommunications in rural areas along roadways. Reverse auctions significantly lowered costs for the same infrastructure.

1.4.2 How Different Were the Applications?

In this section, I ask how different were the applications? I conduct empirical analysis on the applicant pool with basic information on network characteristics. My null hypothesis is that applications were not significantly different from each other in terms of network characteristics. I apply non-parametric rank sum tests to the medians of network characteristics, across technology and institution types. Then, I compare averages between the selected projects and the applicant pool.

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[103]Administrators listed seven priorities for selection criteria which included, (1) commitment to anchor institutions, (2) public-private partnerships, (3) economically distressed communities, (4) commitment to community colleges, (5) commitment to public safety entities, (6) last-mile components, (7) over a 30% match in funds. NTIA, Round 2 Workshops. *See* `http://www2.ntia.doc.gov/documents/BTOPSuccessfulApplicationPPT.pdf`.

[104]Scoring by points were based on assessments of project purpose (30), benefits (25), viability (25), budget and sustainability (20). NTIA, Round 1 Workshops. *See* `http://www2.ntia.doc.gov/documents/Infrastructure2_0721.pdf`.

[105]Eligible costs should be (1) reasonable, (2) necessary, (3) allocable, and (4) appropriate. NTIA, Round 1 Workshops. *See* `http://www2.ntia.doc.gov/documents/Infrastructure1_0721.pdf`. *See also* NTIA, Applicant Frequently Asked Questions, May 2010. *See* `http://www2.ntia.doc.gov/files/nofa2_faqs_5_28_10.pdf`.

[106]Fiber-optic networks are built with significant overhead costs in legal and land zoning expertise in each municipality. Network requirements, price schedules, limitations on subcontractors, and state certifications would not slow a reverse auction, but are expected materials for consideration.

If applications were similar in size and scope, this evidence could provide justification for a standardized reverse auction. If applications were so different they could not be priced for fiber miles or institutions, then a subjective grant review could better suit the endeavour. However, if broadband networks have similar features and project budgets, then market mechanisms could be applied.

1.4.3 Data

I coded data from the applicant pool after reading 773 executive summaries from stimulus program files.[107] I coded technology and institution types, along with total cost, fiber miles, and institutions.

Table 1.14 shows the number of applications in each technology and institution category. Of 773 applications, the largest number of applications were in the fiber category from for-profit organizations with 184 applications. Local governments submitted 101 applications for fiber networks, and state governments sent in 37 applications. For-profit organizations submitted 103 applications for wireless networks, while local governments submitted 72. I included a fourth technology category to include legacy equipment because some applicants proposed copper lines, computer terminals, and other networks that did not fall into the main three categories.

Certain types of applications had greater rates of acceptance. Tribes had the highest acceptance rate of 38 percent of 13 applications, across fiber, fiber & wireless, and wireless networks. State governments had a 33 percent rate of award from 60 applications. Non-profit organizations had a 28 percent rate of award with fiber & wireless projects accepted. By technology, fewer wireless projects were accepted at 5 percent, than fiber at 21 percent and fiber & wireless at 23 percent.

Local governments submitted 206 applications. Seven percent of projects were awarded

[107]NTIA notes that not all executive summaries are available for applicants. "Please note that executive summaries are not posted for all applications. Applicants were given the choice of publishing their full executive summary, a redacted executive summary, or no executive summary at all. The executive summaries provided in this database are from those applicants that provided express written permission to publish their summaries." *See* `https://www.ntia.doc.gov/legacy/broadbandgrants/applications/search.cfm`.

across fiber, fiber & wireless, and wireless applications. The average rejected application from local governments had a total cost of 18.5 million dollars to install 119 fiber miles, connect 340 institutions, 162,359 households, 14,533 businesses, over 1,653 square miles. These applications were smaller than the average rejected application, and also smaller than the average awarded application by local governments, which averaged 31.8 million dollars, 329 fiber miles, 373 institutions, 299,484 households, 70,301 businesses, and 3,466 square miles.

Table 1.14: Award Rates.

	Fiber	Fiber & Wireless	Wireless	Legacy	Total
Application Count					
State Govt	37	6	14	3	60
Local Govt	101	30	72	3	206
Non-Profit	79	15	8	1	103
For-Profit	184	43	103	33	363
Higher Ed	20	3	5	0	28
Tribe	5	3	5	0	13
Total	426	100	207	40	773
Award Rate					
State Govt	*32%*	*100%*	*14%*	*0%*	*33%*
Local Govt	*8%*	*7%*	*6%*	*0%*	*7%*
Non-Profit	*29%*	*40%*	*0%*	*0%*	*28%*
For-Profit	*20%*	*12%*	*3%*	*0%*	*12%*
Higher Ed	*35%*	*67%*	*0%*	*0%*	*32%*
Tribe	*40%*	*67%*	*20%*	*0%*	*38%*
Total	*21%*	*23%*	*5%*	*0%*	*16%*

Executive summaries included narrative accounts of technology and institution types. NTIA released an application database that included award status. Some applications did not release executive summaries.

Table 1.15: Average Network Characteristics in the Applicant Pool.

	Total Cost	Fiber Miles	Institutions	Households	Businesses	Square Mile Area
By Technology						
Fiber	$32,223,290	614	1,394	317,203	45,831	8,567
	(49,304,723)	*(1,372)*	*(6,253)*	*(834,646)*	*(151,800)*	*(31,862)*
	426	187	250	257	242	93
Fiber & Wireless	$46,321,112	563	721	370,169	35,452	9,889
	($56,884,143)	*(823)*	*(1,345)*	*(730,723)*	*(93,385)*	*(21,276)*
	100	36	65	64	63	45
Wireless	$33,970,652	888	1,775	350,373	38,846	33,016
	($69,154,775)	*(945)*	*(5,464)*	*(900,056)*	*(117,285)*	*(120,942)*
	207	5	81	99	76	56
Legacy	$8,016,798	40	261	215,239	38,123	5
	($18,141,891)	*(27)*	*(445)*	*(526,453)*	*(107,200)*	*(-)*
	40	4	8	11	9	1
Total	$33,262,393	602	1,340	330,085	42,616	15,849
	($55,694,139)	*(1,281)*	*(5,522)*	*(827,535)*	*(136,281)*	*(69,649)*
	773	232	404	431	390	195
By Institution						
State Govt	$70,917,878	758	1,643	841,285	122,261	34,824
	($89,310,148)	*(602)*	*(2,557)*	*(1,132,644)*	*(192,162)*	*(43,472)*
	60	20	42	38	30	19
Local Govt	$19,470,694	158	345	179,052	22,582	1,925
	($33,752,958)	*(256)*	*(1,191)*	*(595,101)*	*(93,511)*	*(6,158)*
	206	54	100	115	97	80
Non-Profit	$31,499,154	826	3,188	526,084	69,230	8,100
	($39,057,709)	*(1,913)*	*(11,224)*	*(1,095,236)*	*(226,157)*	*(12,095)*
	103	37	52	53	52	25
For-Profit	$ 34,429,565	741	1,436	290,022	36,607	35,070
	($59,370,228)	*(1,427)*	*(5,316)*	*(795,533)*	*(113,580)*	*(122,324)*
	363	108	183	197	187	58
Higher Ed	$44,882,774	493	414	240,931	18,845	2,887
	($53,028,147)	*(639)*	*(415)*	*(485,550)*	*(27,331)*	*(2,804)*
	28	7	18	19	16	7
Tribes	$34,363,940	323	206	12,471	1,875	3,032
	($67,134,988)	*(472)*	*(353)*	*(21,013)*	*(3,525)*	*(5,944)*
	13	6	9	9	8	6
Total	$33,262,393	602	1,340	330,085	42,616	15,849
	($55,694,139)	*(1,281)*	*(5,522)*	*(827,535)*	*(136,281)*	*(69,649)*
	773	232	404	431	390	195

Executive summaries are listed by grant number in program files. The technology type is coded from the descriptions provided by the applicants. Excluded are last mile remote and non-remote applications. Project budget data, fund round, number of applications by applicant, state, tribes in the service area, and years of firm establishment are included in $Totalbudget_Comb$, $Fund_Round$, $No_{Apps}{}_Byprimary$. Households and businesses were often listed as indirect reach of infrastructure projects, as well as square mileage of the network area. Legacy technology includes copper, DSL, Docsis, software, and equipment proposals. Standard deviations are in parenthesis. Number of observations are provided below the standard deviations.

Table 1.16: Average Project in the Applicant Pool.

	Total Budget	Fund Round	Fiber Miles	Insts.	Households	Businesses	Square Miles
Applicant Pool (N = 773)	$33,262,393	1.5	602	1,340	330,085	42,616	15,849
Awarded (N = 116)	$41,732,837	1.6	679	1,895	404,881	56,588	12,035
Not Awarded (N = 657)	$31,674,998	1.5	559	1,127	304,140	37,333	18,033
Awarded Projects							
Fiber	$38,924,065	1.65	699	1,837	329,142	51,031	7,370
Fiber & Wireless	$49,050,973	1.57	548	1,216	515,658	38,414	20,380
Wireless	$49,899,197	1.70	802	4,009	759,514	136,992	18,150
State Govt	$82,789,761	1.80	846	2,091	943,079	141,687	31,282
Local Govt	$31,777,601	1.57	329	373	299,484	70,301	3,466
Non-Profit	$47,607,176	1.62	1,036	3,963	415,160	55,818	11,895
For-Profit	$24,811,625	1.62	518	1,397	282,028	28,891	9,739
Higher Ed	$47,220,255	1.56	327	320	106,383	17,054	4,029
Tribe	$13,722,188	1.60	198	282	9,331	862	4,267
Not Awarded Projects							
Fiber	$30,453,649	1.44	567	1,178	311,904	43,451	9,641
Fiber & Wireless	$45,505,699	1.65	571	485	293,961	33,971	2,895
Wireless	$33,162,096	1.52	1,018	1,496	304,402	23,976	35,862
Legacy	$8,016,798	1.33	40	261	215,239	38,123	5
State Govt	$64,981,936	1.45	595	1,235	739,491	96,858	40,896
Local Govt	$18,573,315	1.66	119	340	162,359	14,533	1,653
Non-Profit	$25,186,550	1.31	390	2,350	625,122	81,648	3,268
For-Profit	$35,790,595	1.41	816	1,447	292,123	38,640	52,951
Higher Ed	$43,775,547	1.74	906	490	338,784	20,635	30
Tribe	$47,265,036	1.38	449	146	14,982	2,889	561

The executive summaries are listed by grant number in program files. The institution type is coded from the descriptions provided by the applicants. Number of observations in the dataset are below the standard deviations in parenthesis. Legacy is a fourth category included in the applicant pool to include software, copper DSL, and older technologies.

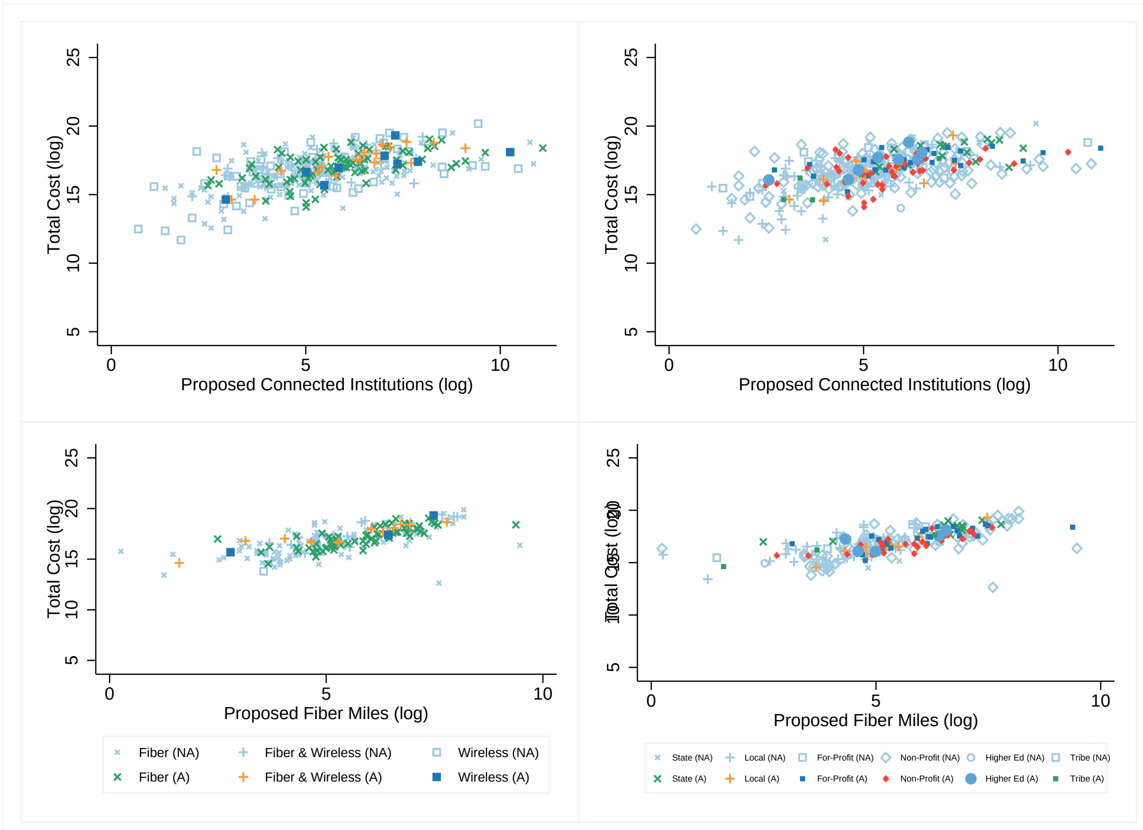


Figure 1.7: Applicant Pool and Awarded Projects.

The left graphs show technology type and the right graphs show institution type represented in the applicant pool. A natural log transformation is applied for visibility.

1.4.4 Results

Applications were not statistically different on network characteristics across technology type. Table 1.15 shows average statistics on network characteristics in the applicant pool. The median number of proposed fiber miles is not statistically different in each of the categories, fiber, fiber & wireless, wireless, and legacy equipment. I apply an ANOVA test with Bonferroni correction to confirm no statistical difference between fiber miles proposed ($p = 1$).[108] Median proposed connections to institutions were not statistically different ($p < 0.16$, Kruskal-Wallis non-parametric rank test, N = 250, 65, 81, 8). Median square mile areas for networks were not statistically different either ($p < 0.13$, Kruskal-Wallis non-parametric rank test, N = 93, 45, 56, 1, $p < 0.23$ and $p < 0.58$ for wireless areas, ANOVA). Median project budgets were different ($p < 0.00$, N = 426, 100, 207, 40).

Applications were statistically different at the institutional level. Networks differed along each of the network characteristics, fiber miles ($p < 0.00$, Kruskal-Wallis, N = 20, 54, 37, 108, 7), community anchor institutions ($p < 0.00$, Kruskal-Wallis, N = 42, 100, 52, 183, 18, 9), square mile area ($p < 0.00$, N = 19, 80, 25, 58, 7), and total budget ($p < 0.00$, Kruskal-Wallis, N = 60, 206, 103, 363, 28, 13).

Table 1.16 shows that awarded projects were larger than rejected projects. Awarded projects had an average project budget of 41,732,837 dollars, offering 679 fiber miles, 1,895 connected institutions, 404,881 households, 56,588 businesses, across 12,035 square miles (N = 116).[109]

Between awarded and rejected projects, the median number of proposed fiber miles is statistically different ($p < 0.00$, Kruskal-Wallis non-parametric rank test, N = 149, 83). Awarded projects proposed an average of 679 miles of fiber (s.d. 1,341), compared to rejected projects with an average of 559 miles of fiber (s.d. 1,250). Fiber miles in awarded

[108] With only four observations in the legacy equipment category, I cannot only rely on a Kruskal-Wallis test ($p < 0.08$, Kruskal-Wallis non-parametric rank test, N = 187, 36, 5, 4).

[109] These numbers differ from the averages in the grantee database. Data in the applicant pool depends on executive summary data, rather than the key metric database.

projects exceeded those of rejected projects with statistical significance ($p < 0.00$, non-parametric Mann-Whitney U-test). The probability that a draw from the proposed fiber miles in the awarded population is larger than a draw from the rejected is 62.5 percent. The median cost was different as well ($p < 0.00$, Kruskal-Wallis, N = 122, 651) and larger in awarded projects ($p < 0.00$, non-parametric Mann-Whitney U-test).

Proposed institutions were statistically different in size ($p < 0.00$, N = 112, 292) and larger ($p < 0.00$, non-parametric Mann-Whitney U-test), by 63 percent probability. Awarded projects proposed 1,895 direct connections (s.d. 6,966), while rejected projects averaged 1,127 direct connections (s.d. 4,853). Square miles were different ($p < 0.00$, N = 71, 124) and larger ($p < 0.00$), by a probability of 72 percent. The average square mileage area for an awarded project was 12,035 square miles (s.d. 22,617), compared to 18,033 square miles (s.d. 85,713) for rejected projects. The probability that the square mile area is larger for the rejected project is 28.7 percent.

I also conduct statistical tests on Table 1.14 to compare the award rates across categories. I can reject the null hypothesis that the median award rate is equal across types of technology. Median award rates are statistically different for fiber, fiber & wireless, wireless, and legacy projects ($p < 0.0016$, Kruskal-Wallis non-parametric rank test, N = 426, 100, 207, 40). I also reject the null hypothesis that median of award rates are statistically different across institutions ($p < 0.0009$, Kruskal-Wallis non-parametric rank test, N = 60, 206, 103, 363, 28, 13).

Topography and custom geographic conditions vary, and with statistical analysis, I estimate averages across network characteristics. Table 1.16 shows the average project sought 33 million dollars to install 602 fiber miles and connect 1,340 community anchor institutions. Across the awarded and rejected populations, proposed networks did not vary by technology as much as they did by institution.

State governments proposed the largest projects. Average awarded and rejected projects had budgets of 82,789,761 dollars and 64,981,936 dollars, for 846 fiber miles and 595 fiber miles respectively. Wireless networks that were rejected, interestingly, proposed the most fiber miles with 1,018 fiber miles. These projects claimed to be able to connect 1,496 institutions over an average area of 35,862 square miles each. Of the wireless networks that were accepted, they did connect the most institutions, with an average of 4,009 institutions, along with 759,514 households, 136,992 businesses, and 802 fiber miles.[110]

Figure 1.7 shows graphical results of total costs and proposed outputs for awarded and rejected projects. Lighter shaded markers represent rejected applications, while the other markers are color-coded. Scatterplots show a positive relationship between total cost and proposed connected institutions, and between total cost and proposed fiber miles.

1.5 Policy Discussion

Of 116 projects, a subset revealed a range of cost forecast quality. Earlier in this article, I found that several grantees delivered less infrastructure than proposed, resulting in cost escalations. Over 773 proposals sent cost forecasts for new broadband networks. Table 1.15 shows proposals for networks with an average of 600 fiber miles to reach 1,000 institutions for a price of 33 million dollars. Broadband projects differed by network characteristics, but not so widely that standard requirements could not be set in a request for proposal in a procurement auction. In the Mobility Fund reverse auction, Wallsten (2013) noted that in areas with multiple bidders, prices were substantially lower to buildout wireless infrastructure. The Mobility Fund was allocated to a different set of areas under a cost-per-road-mile bid system. If costs are systematically underestimated, and later, escalated, then cost discipline through market mechanisms may be appropriate. With smart forecast

[110]Regarding optimism bias, if all 773 proposals were funded as proposed, then for 25.7 billion dollars, applicants offered to build 465,346 new fiber miles, directly connect 1,035,820 institutions, 255,155,705 households, 32,942,168 businesses, over 12,251,277 square miles. The United States is limited to 3.797 million square miles including Alaska, with 116,211,092 households, nearly 100,000 schools, 17,000 libraries, 90,000 municipal governments. If cost escalation occurred in the awarded projects by 202 percent and 37 percent for cost per institution and cost per fiber mile, as my findings indicated above, then Table 1.16 should be read with scrutiny. Cost forecasts may systematically understate costs and overstate outputs. My results infer that half of project budgets could be escalated by costs per institution, and a quarter by cost per fiber mile. Knowledge of optimism bias would caution a reading of Table 1.16 to show that grantees may not accurately deliver these networks.

models, institutions could install gigabit fiber-optic cables with less gold-plating.[111] Rosston and Wallsten (2014) noted that a one-time fund such as broadband stimulus would not provide conditions for a bidding down of prices. yet, administrators of the Universal Service Fund have benefited from learning over time by introducing reverse auctions and other reforms since 1996.[112]

1.6 Conclusion

I find that grantees did not systematically underbid for projects. They did, however, underestimate and overestimate costs with nearly equal frequency, and escalate costs by 202 percent in cost per institution and 37 percent in cost per fiber mile. Cost forecast errors were not explained by budget, technology, or institution. I did not find effects of budget on actual construction which indicates the absence of underbids or overbids. My findings suggest that low-price bids can be cost-effective across project types.

[111] West Virginia spent 5 million dollars on enterprise routers for single Internet connections. Nate Anderson, "Why A One-Room West Virginia Library Runs a $20,000 Cisco Router," *ArsTechnica,* Feb. 25, 2013 "As for that $5+ million the state could have saved, it would have paid for 104 additional miles of fiber."). Edward Wyatt, "Waste Is Seen in Program to Give Internet Access to Rural U.S.," *N.Y. Times,* Feb. 11, 2013.

[112] The Universal Service Administrative Corporation (USAC) operates as a contribution fund facility with annual transactions of over 8 billion dollars. *See* USAC Annual Report, 2015. *See* `https://usac.org/_res/documents/about/pdf/annual-reports/usac-annual-report-2015.pdf`. Nearly 50 billion dollars has been invested over 15 years, at 5.5 to 8.8 billion dollars annually in recent years. Each year, broadband subsidies are sent to 35,000 schools and school districts, 5,000 libraries, hospitals, and thousands of low-income residents. Rather than fund another herculean grant review for broadband stimulus, other mechanisms could provide multiples of savings. Universal service reform could apply industry forecasts for middle mile infrastructure. Grantees could bid for contracts to install lateral fiber directly to buildings for 50,000 dollars per building. Grantees that fail to build would be obligated to return funds.

Chapter 2: Effects of the Discount Matrix on E-rate Funds from 1998-2012

2.1 Introduction

Improving high-speed broadband access to community anchor institutions such as schools and libraries is a public policy goal of the ConnectEd initiative (Federal Communications Commission [FCC], 2013). Federal funding of broadband infrastructure, however, invites scrutiny on the means and efficacy of the distribution of such funds. For community anchor institutions, the critical question is how public money is disbursed and whether grant criteria serve statutory goals.

Under E-rate reform efforts of 2014, policymakers are evaluating the distribution criteria of funds for broadband deployment to these community anchor institutions. Schools and school districts continue to request increased funding levels to improve broadband connectivity through the E-rate program (Funds for Learning [FFL], 2013). In FY2013, the Universal Service Administrative Company (USAC) processed 46,198 applications for nearly $5 billion in support requests (FCC, 2013).

With large investments in broadband infrastructure to schools, the problem remains on how to evaluate such projects. Vague requirements to improve speeds and upgrade connections can be an invitation for rent-seekers, waste, and fraud (Rosston Wallsten, 2013). Defining cost-effective broadband speed remains an open question, whether acceptable download speed is 4 mbps or 100 mbps or 1 gbps (FCC, 2013; FCC, 2012; New America Foundation [NAF], 2013). Thus, simply increasing funds for upgraded connections may lead to economically inefficient results without adequate evaluation. Real limitations exist for central administrators to determine which broadband projects are more efficient to pursue, and then, to measure broadband speeds actually delivered (NAF, 2013). This is a systematic weakness in federal broadband application and grant mechanisms (Rosston Wallsten, 2013; Comments of 71 Economists, 2009).

This article contributes to analysis of federal broadband projects, particularly the E-rate program. Table 2.1 shows that for fifteen years, the E-rate program, formally known as the schools and libraries universal service support mechanism (FCC, 2013), has distributed a total of $34 billion in priority 1 and 2 funds, including $13.8 billion to schools and libraries for broadband capacity through upgraded networks and internal equipment purchases (USAC Advanced Search Tool, 2013). An important question is whether funds have led to cost-effective broadband deployment and improved educational outcomes. The intermediate question is whether funds have been distributed in a reasonable manner to satisfy broadband priorities across the states over fifteen years. Empirical analysis can help efforts to evaluate the program by measuring effects of the discount matrix on fund distribution.

Table 2.1: E-Rate Funds Aggregated by Service Type 1998-2012.

Service Type	E-rate Funds 1998-2012
Priority 1 Telecommunications	$15,575,746,684
Priority 1 Internet Access	$4,297,768,108
Priority 2 Internal Connections	$13,796,627,176
Priority 2 Internal Connections Management	$1,194,943,636
Total	$34,865,085,604

Source: USAC Advanced Search Tool (2013).

2.2 Universal Service and E-Rate for Schools and Libraries

The E-rate program was created in 1998 by Section 254(h) of the Telecommunications Act of 1996 as a schools and libraries universal service support mechanism. The Federal-State

Joint Board on Universal Service set an annual funding cap for spending by the E-rate program to $2.25 billion in 1997, with inflation indexing set in 2010 (FCC, 2013).

Since 1998, $34 billion in priority 1 and priority 2 funds have been distributed through an application and funding commitment process (USAC Advanced Search Tool, 2013). Tens of thousands of public and private schools and school districts in the United States have received these funds under a schedule of priority 1 (telecommunications and internet access) and priority 2 (internal connections and internal connections management) services. Figure 2.1 and Figure 2.2 present data aggregated from the USAC Advanced Search Tool (2013). Figure 2.1 presents a simple time series of funds by year and service type. Figure 2.2 presents a simple time series of the number of unique recipients of funds by year and service type.

Figure 2.2 shows the number of recipients for internal connections priority 2 funds, compared with the rising number of recipients of priority 1 funds. Priority 2 internal connections funds constitute nearly half of E-rate fund outlays as seen in Table 2.1 and Figure 2.1, directed to a limited number of recipients annually. These statistics highlight the importance of further investigation of this particular category of E-rate funding.

2.2.1 Evaluation of the E-Rate Program.

The E-rate program is currently under review for reform through a July 2013 notice of proposed rulemaking administrative proceeding (FCC, 2013). E-rate reform raises the question of how to evaluate the current state of connectivity in American schools. Broadband in schools has been evaluated from different viewpoints. One view is that schools have access to sufficient Internet speeds, and the other view is that schools are falling behind the cutting edge. FCC (2010) reviewed the E-rate program after ten years from 1998 to 2008. As of 2008, 95% of survey respondents had terrestrial broadband connections, where 3% had dial-up access and 2% satellite connections (FCC, 2010). In fact, 46% of urban respondents had fiber optic connections along with 38% of rural respondents (FCC, 2010). High-speed

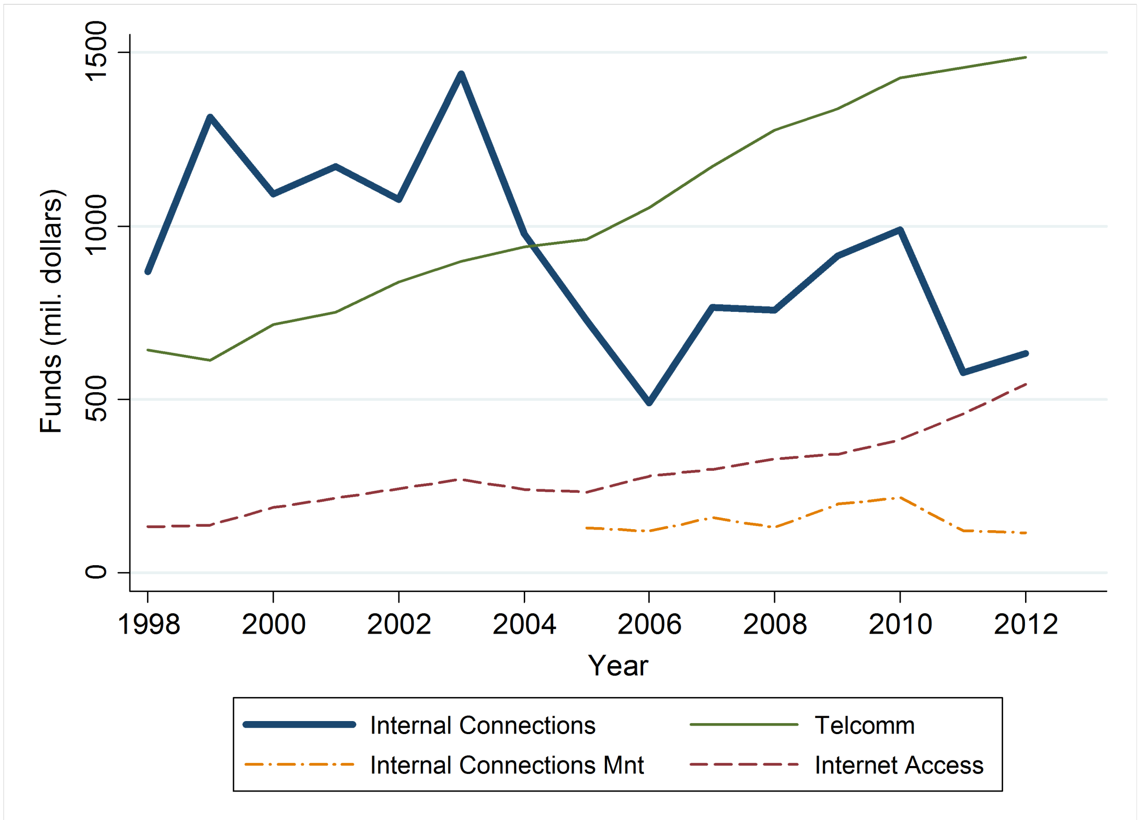


Figure 2.1: E-Rate Funds by Year and Service Type.

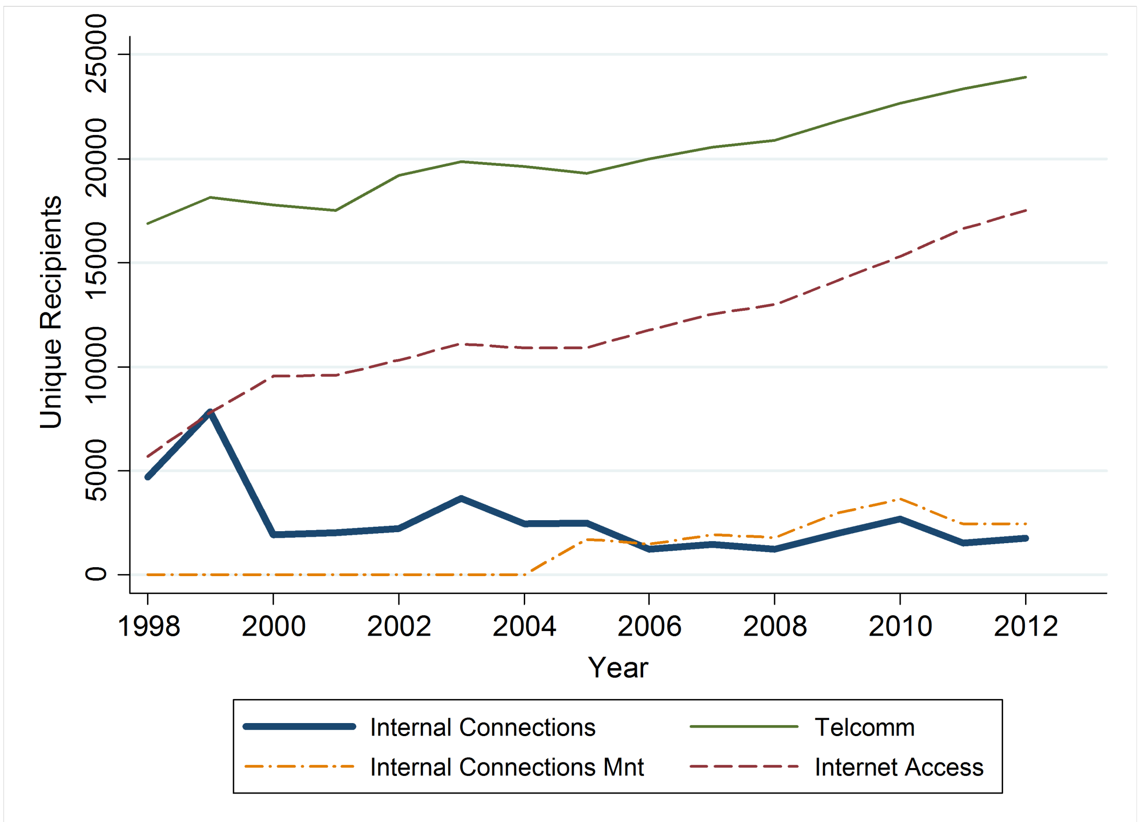


Figure 2.2: E-Rate Recipients by Year and Service Type.

Internet had reached schools and libraries, where 55% of survey participants reported average broadband speeds greater than 3 mbps (FCC, 2010). FCC (2010) reported that 11% had access to 3 to 6 mbps, 8% had 6 to 10 mbps, 14% had 10 to 25 mbps, 12% had 25 to 100 mbps, and 10% of respondents reported having download speeds of 100 mpbs. Recently, FCC (2014) has highlighted, however, that Wi-Fi capacity is lagging in 60% of schools, with no allocation in the current E-rate program for Wi-Fi technologies.

2.2.2 E-Rate Discount Matrix: Income-Based Criteria for Priority 2 Funds

Income-based criteria are used to fulfill E-rate priority 2 funding requests which depend on available roll-over funds after priority 1 funding requests are fulfilled. Income-based need is based on the National School Lunch Program (NSLP) which defines which students are eligible for free or reduced lunch (FCC, 2013). An E-rate "discount rate" is calculated from a matrix which accounts for NSLP eligible students and urban or rural locale of schools and school districts. Table 2.2 presents the E-rate discount matrix. This calculated E-rate discount rate is an income-based measure with extra weight afforded to rural schools below the 49% eligibility level for NSLP (USAC, 2013b).

Table 2.2: E-Rate Discount Matrix for Priority 2 Funds.

Income-Based Criteria % of students eligible for the National School Lunch Program	Calculated E-rate Discount Rate Urban Location	 Rural Location
Less than 1%	20%	25%
1% to 19%	40%	50%
20% to 34%	50%	60%
35% to 49%	60%	70%
50% to 74%	80%	80%
75% to 100%	90%	90%

Source: USAC (2013a).

USAC requests applicants to calculate an E-rate discount rate based on school address.

USAC (2013b) explains the formula. First, schools determine their status as urban or rural schools as determined by U.S. Department of Education locale code. USAC also offers guidance on urban and rural locale assignments. USAC provides list of counties per state based on Metropolitan Statistical Area (MSA) data (USAC, 2003). The data is further specified by census tract demarcations between urban and rural locale. Then, schools calculate the percentage of its students who are NSLP eligible, which is the simple ratio of NSLP eligible students divided by total students. That percentage is then used to determine the E-rate discount rate from the matrix in Table 2.2. For urban and rural schools with at least 75% NSLP eligible students, the calculated discount rate for priority 2 funds is 90%. For urban and rural schools with at least 50% NSLP eligible students, the calculated discount rate for priority 2 funds is 80%. Below those levels above 1% NSLP eligible students, rural schools have a 10% advantage in discount rate over urban schools. Below 1% NSLP eligible students, rural schools have a 5% advantage in discount rate over urban schools.

For school districts, the overall discount rate is the weighted average discount rate of all schools in the district, using the number of students in each school as the weight (USAC, 2013b). This allows for the discount rate to be calculated in finer granularity than the 10% bands demarcated in the discount matrix. Each fourth quarter, a discount rate threshold is announced. This cutoff applies to priority 2 fund requests. Applicants with discount rates above the threshold are eligible for funds, and applicants below the threshold are not. This announcement occurs after schools and school districts have submitted applications for the fiscal year. A historical account of announced discount rate thresholds per fiscal year includes announcements of 70%, 20%, 82%, 86%, 81%, 70% (with a $420 million roll-over), 81%, 80%, 86%, 81% (with a $650 million roll-over), 86% (with a $600 million roll-over), 77% (with a $900 million roll-over), 20% (with a $1.15 billion roll-over estimated), 88% (with a $500 million roll-over), 90% (with a $1.05 billion roll-over) in fiscal years 1998 to 2012 respectively (State E-rate Coordinators Alliance, 2013). With threshold announcements mostly remaining above 80%, E-rate fund recipients have rarely benefited from the 10%

rural benefit from 60% to 70% in the 35% to 49% band, from 40% to 50% in the 1% to 19% band, and the 5% rural benefit from 20% to 25% in the Less than 1% band.

2.2.3 Questions from the FCC Proposed Rulemaking

In the 2013 E-rate reform proceeding, FCC asks whether the discount rate is the appropriate mechanism for the distribution of priority 2 funds. In several paragraphs of the reform proceeding, FCC (2013) asks for comment on the use of the discount rate matrix for internal connection funds, and for the question of modifying the discount matrix entirely. Some commenters have proposed limiting priority 2 funds to below 70% or 80% discount rate going forward (FCC, 2013, para. 118). FCC (2013) also asks for comment on other adjustments to the discount rate matrix, such as extending the lowest band from 20% to 10%, and reducing the top bands to 85%, 75%, or 65% (FCC, 2013, para. 124).

The effect of the discount rate on allocation of the fund is a central question for E-rate reform (FCC, 2013). FCC asks whether disparate impacts on allocation would arise if they lowered all discount rates in the matrix, if the bands were delineated in 5% rather than 10% bands, or if there were fewer bands in larger delineations (FCC, 2013, para. 124).

The allocation of E-rate funds on rural schools is also an important question for E-rate reform, and FCC asks for comment on a proposal to use the NSLP percentage with a 20% increase for non-urban areas, and 25% increase for rural areas (FCC, 2013, para. 125). In a separate section, FCC notes different proposals on how to weigh rural schools more or less than urban schools (FCC, 2013, para. 133-134). In particular, FCC (2013) asks for comment on the effects of the matrix, where in the top two bands of 80% and 90%, rural schools do not have a benefit compared to urban schools.

FCC also asks whether per-school and per-student metrics for fund commitments should be developed for analysis of the E-rate program (FCC, 2013, para. 135). FCC seeks comment on appropriate per-student and per-building limits, if at all, for priority 2 funds (FCC, 2013, para. 138-144), and potential effects of such limits on the distribution of the fund. FCC also asks about the need for detailed data with identifiers for schools under urban-centric locale codes (FCC, 2013, para. 54).

2.2.4 Scope of Priority 2 Internal Connections Funds

Priority 2 funds are specifically meant to support "internal connections" and "internal connections management." Internal connections are equipment and connection upgrades that are listed as eligible services by USAC (2013c). USAC (2013c) describes "components located at the applicant site" which include connections "within, between or among instructional buildings which comprise a school campus or library branch, but do not include services that extend beyond." This equipment is internal to sites, and do not extend beyond campuses.

Internal connections funds are important for broadband connectivity, compared to the priority 1 payments. These "internal connections" are defined in detail. USAC (2013c) lists components that can be purchased and installed in schools in an extensive list, ranging from cabling components, network interface cards, LAN access points, wireless LAN controllers, Voice over IP components, cable modems, email servers, DNS servers, network software, and server storage (USAC, 2013c).

Cable and connectors include copper, fiber, coax, twisted pair, and the components necessary such as jacks, panels, faceplates, and wire managers, conduit and raceway. Circuit cards and components include network interface cards, processors, and processor terminator cards. Data distribution includes access points in LAN environments, hubs, multiplexers as part of LAN network switches, routers, wireless LAN controllers, and voice and VOIP components. Servers and computers as servers fall into this category, when used as a conduit for information rather than source. This category also includes remote access components, terminal servers, web servers, a monitor per eligible server, and KVM switches. Priority 2 funds are also eligible to be spent on storage devices such as hard disks, DVD, CD drives, and storage for operating systems. Telephone components are also included for Private Branch Exchange (PBX), Key System (KSU), voice mail, wireless VOIP equipment, Automatic Route Selection (ARS), E911 reader board voice compression module, voice interface card, switchboard/attendant console, and intercom systems (USAC, 2013c).

The wide range of equipment eligible for purchase with priority 2 internal connections funds raises the issue of fraud and abuse. If measurement and performance metrics are not well-defined, the opportunity for superfluous expenditures is quite possible. The scope of the E-rate program has been the subject of Congressional oversight hearings and hundreds of audits by a parade of government agencies: Government Accountability Office, Federal Communications Commission Office of Inspector General, Department of Justice Antitrust Division and National Criminal Office, Department of Education Office of Inspector General, Department of Interior Office of Inspector General (Bureau of Indian Affairs), USAC Internal Audit Division, and Defense Contract Audit Agency (DCAA). Fraud, waste, abuse, procurement irregularities, false claims, kickbacks, and criminal charges have been features of the fund as much as its successes (Problems with the E-Rate Program, 2005). Lack of inventory controls on equipment such as wireless laptops and equipment was a major concern for the New York City Department of Education audit (U.S. Department of Education Office of Inspector General [DOE OIG], 2004). Controls for information technology equipment spending have been requested repeatedly by different offices of inspector general.

A look into the records of two districts with the largest aggregate funds in this category provides a better view on the broadband technologies actually purchased. New York City Department of Education has been audited for its purchases of computer equipment for Internet access by the Department of Education Office of Inspector General (DOE OIG, 2004). Los Angeles Unified School District's internal connections funds are documented as well for review, where funds have been spent on LAN upgrades and PDX phone upgrades in school buildings (Los Angeles Unified School District, 2006).

Priority 2 funds are of particular interest due to their role in enhancing connectivity through equipment upgrades through internal connections. The question for policymakers is how the discount matrix and threshold announcement procedure has affected the distribution of priority 2 internal connections funds. FCC asks whether distribution has fulfilled the goals of the E-rate program to expand connectivity in an "economically reasonable" manner (FCC, 2013). Given these important questions on the effects of these criteria on the distribution of the fund, this article provides a data set of fifteen years of state-level aggregates from 1998 to 2012. Particular attention is afforded to priority 2 internal connections, rather than priority 1 funds. Funds that have contributed to equipment upgrades may have more direct relation to broadband deployment goals than priority 1 service payments.

In an effort to reform priority 2 fund commitments, USAC implemented the "two-in-five" rule in 2003 to extend eligibility to a wider range of applicants (FCC, 2013, para. 144). The rule, however, did not result in more equitable access, since "because requests for priority two funding exceed the E-rate funding cap, there is wide-spread agreement that a relatively small number of applicants, those that qualify for the highest discount rates, receive priority two funding over and over again, while other applicants seldom qualify for priority two funding" (FCC, 2013, para. 144). The issue of how to distribute priority 2 funds has raised the question on whether to use the priority 1 and priority 2 system at all (FCC, 2013, para. 146-148). FCC (2013, para. 149-151) asks how a "simplified allocation system" that eliminates the discount matrix could distribute E-rate funds. The analysis that follows provides some estimates on how the discount matrix has distributed funds in its current structure.

2.3 Related Literature

Jayakar and Park (2009) provide a comprehensive literature review of other papers that have evaluated the E-rate program on state-level aggregates. They cite Hudson (2004) which investigates E-rate funds for three years from 1998 to 2001. Hudson's analysis shows a disproportionate share of funds per population and outperformers with a wide range of potential reasons. The analysis pointed to Alaska, New Mexico, and New York as particular examples. Jayakar and Park (2009) also cite Panagopoulos (2005) for a regression on data from 2002.

Panagopoulos (2005) uses state-level aggregates of funds as the dependent variable of an ordinary least squares regression and isolates population as the only predictive predictor of support. Jayakar and Park (2009) estimated the impact of demographics and poverty rates in school districts on E-rate funding the state of Pennsylvania from two years of 1999 and 2004. Their hypothesis was that the complex application procedure may disadvantage schools that lack expertise and administrative resources. They found the reverse, that E-rate funds were positively correlated with poverty rate and percentage of minority students.

Prior studies do not separate priority 1 and priority 2 funds for analysis. The distinction between priority 1 and priority 2 funds has particular importance, however. Priority 1 funds are allocated to maintain existing telecommunications and internet access services and payments, while priority 2 funds are used to upgrade broadband capacity for equipment purchases. For the purposes of broadband deployment and expansion of high-speed connectivity, the distribution of priority 2 funds is of particular relevance. The discount matrix, based on income-based criteria, then becomes an independent variable of interest.

2.4 Empirical Strategy

The ordinary least squares (OLS) regression method provides estimates of effects of distribution criteria on the internal connections fund. One way to organize the total distribution of funds from 1998 to 2012 is through state-level aggregation. State-level aggregation has been used in related literature to evaluate E-rate fund distribution (Jayakar and Park, 2009; Panagopoulos, 2005; Hudson, 2004).

Four regression equations estimate the effect of the discount matrix on internal connection funds by state. Eq. (2.1) estimates the effect of the average discount rate of recipients on aggregate internal connections funds. Eq. (2.2) estimates the effect of the number of National School Lunch Program students on aggregate internal connections funds. Eq. (2.3) and Eq. (2.4) estimate the effect of schools and students by locale type. These OLS regressions provide simple estimates on the distribution of funds based on student populations of each state.

$$InternalConnFunds_i = \beta_0 + \beta_1 AvgDiscountRate_i + \varepsilon_i \tag{2.1}$$

$$InternalConnFunds_i = \beta_0 + \beta_1 NSLPStudents_i + \varepsilon_i \tag{2.2}$$

$$InternalConnFunds_i = \beta_0 + \beta_1 CitySch_i + \beta_2 SuburbSch_i + \beta_3 TownSch_i + \beta_4 RuralSch_i + \varepsilon_i \tag{2.3}$$

$$InternalConnFunds_i = \beta_0 + \beta_1 CitySt_i + \beta_2 SuburbSt_i + \beta_3 TownSt_i + \beta_4 RuralSt_i + \varepsilon_i \tag{2.4}$$

Treatment groups provide more detailed comparisons. The first treatment group estimates effects on all 50 states and the District of Columbia. The second group estimates effects from a smaller sample of 48 states excluding New York, California, and Texas. The third estimates effects in FY2010 alone. The quasi-experiment of FY2010 is described below.

2.5 Variables and Data

Table 2.3 provides a description of the variables in Eq. (2.1)-(2.4) with data sources. Table 2.4 provides descriptive statistics of the dataset. Data is available in Table B.1, B.2, B.3 in Appendix B.

The next sections describe variables in greater detail, including internal connections funds from 1998 to 2012, the discount rate of fund recipients, National School Lunch Program student populations, the treatment group that excludes data from New York, California, and Texas, urban and rural student and school locales, and a quasi-experiment from FY2010.

Table 2.3: Variable Type, Description, and Sources.

Type	Variable	Description	Source
Dependent variable	Internal Connections Funds	Priority 2 funds for internal connections from 1998 to 2012. Does not include funds for internal connections management, or priority 1 funds for telecommunications or internet access.	USAC Advanced Search Tool, 2013
Independent variables	Average Discount Rate	Simple average of discount rate of recipients of internal connections funds, across fifteen years.	USAC Advanced Search Tool, 2013
	NSLP Students	Simple average of nine-month participation levels per state FY 2009 to FY2013.	USDA Food and Nutrition Service, 2014
	City Locale	Number of schools/students in a territory inside an urbanized area and inside a principal city.	NCES, 2013
	Suburb Locale	Number of schools/students in a territory outside a principal city and inside an urbanized area.	NCES, 2013
	Town Locale	Number of schools/students in a territory outside an urban cluster.	NCES, 2013
	Rural Locale	Number of schools/students in a census defined rural territory.	NCES, 2013

2.5.1 Internal Connections Funds Aggregated from 1998-2012.

The dependent variable is internal connections funds per state, aggregated from the USAC Advanced Search Tool (2013) from 1998 to 2012. The USAC Advanced Search Tool (2013) was used to collect 750 Search Commitment Applicant Reports named "1998-AK.csv" to "2012-WV.csv." Files were combined in Stata for 1.5 million records of unique funding commitments with discount rates, addresses, types of service (priority 1 telecommunications, priority 1 internet access, priority 2 internal connections, and priority 2 internal connections management), types of recipient (school, school district, library, school and library consortium), wave numbers, and funding request numbers (FRN) from 50 states and the District of Columbia over fifteen years.

Table 2.4: Descriptive Statistics.

Variables	Obs.	Mean	Std. Dev	Min	Max
Internal Connections Funds	51	271,000,000	542,000,000	764,962	2,660,000,000
Average Discount Rate	51	0.76	0.05	0.63	0.86
NSLP Students	51	608,455	681,746	47,176	3,339,322
City Schools	51	637	866	42	5,098
Suburban Schools	51	689	857	-	4,274
Town Schools	51	281	226	-	1,079
Rural Schools	51	718	524	-	2,897
City Students	51	311,268	503,429	9,112	2,887,523
Suburban Students	51	354,976	479,533	-	2,533,393
Town Students	51	115,677	95,020	-	496,548
Rural Students	51	252,936	238,731	-	1,319,276

2.5.2 Average Discount Rate of Internal Connections Funds Recipients.

The independent variable in Eq. (2.1) is the average discount rate of recipients of internal connections funds. From separate FRN records, unique recipient data were aggregated by recipient name in each state. Recipient name and state pairs were grouped due to the large number of recipients with similar names in different states, e.g., “Parkview Library” which exists in Maine and Massachusetts. Spelling changes and abbreviations were de-duplicated. This process yielded unique recipients aggregated across fifteen years. The dataset was sorted by a few thousand of the largest fund recipients and checked for spelling duplicates by state and funding category. Some unique recipients remain fragmented where names are listed as “ – School” in some years, and “ – School District” in other years. Aggregation by address did not yield better results as address variations were more prevalent than location names across years. This database includes 47,975 unique recipients. Average internal connection funds recipient discount rate is a simple average of these recipients. The discount rate for priority 2 recipients is not distinct from the discount rate for priority 1 recipients, which are not restricted by income-based criteria. Figure 2.3 shows a scatterplot of state-level aggregates of priority 2 internal connections funds by average discount rate of recipients.

2.5.3 National School Lunch Program Students

The independent variable in Eq. (2.2) is the National School Lunch Program student participation per state. These data were compiled through a simple average per state from FY 2009 to FY 2013 provided by the U.S. Department of Agriculture food program (USDA Food and Nutrition Service, 2014). Participation data are nine-month averages with summer months excluded. The NSLP student population variable in Eq. (2.2) serves to provide a comparison with Eq. (2.1) on the discount rate metric due to the similarity in discount rate and NSLP criteria. Table 2.5 provides a comparison of the eligibility bands for E-rate funds and NSLP categories listed by the Department of Education.

Table 2.5: National School Lunch Program Categories Compared to the E-Rate Discount Matrix.

E-rate Discount Matrix % of students eligible for NSLP	NCES NSLP Data % of students eligible for NSLP
Less than 1%	10% or Less
1% to 19%	10% or Less, 11%-25%
20% to 34%	11-25%, 26-50%
35% to 49%	26-50%
50% to 74%	51-75%
75% to 100%	76-100%

Source: NCES (2010).

Figure 2.4 shows a scatterplot of funds and NSLP students in each state. Figure 2.3 and Figure 2.4 show similar results, which is not surprising given Table 2.5 which compares the E-rate discount matrix and NSLP eligibility categories.

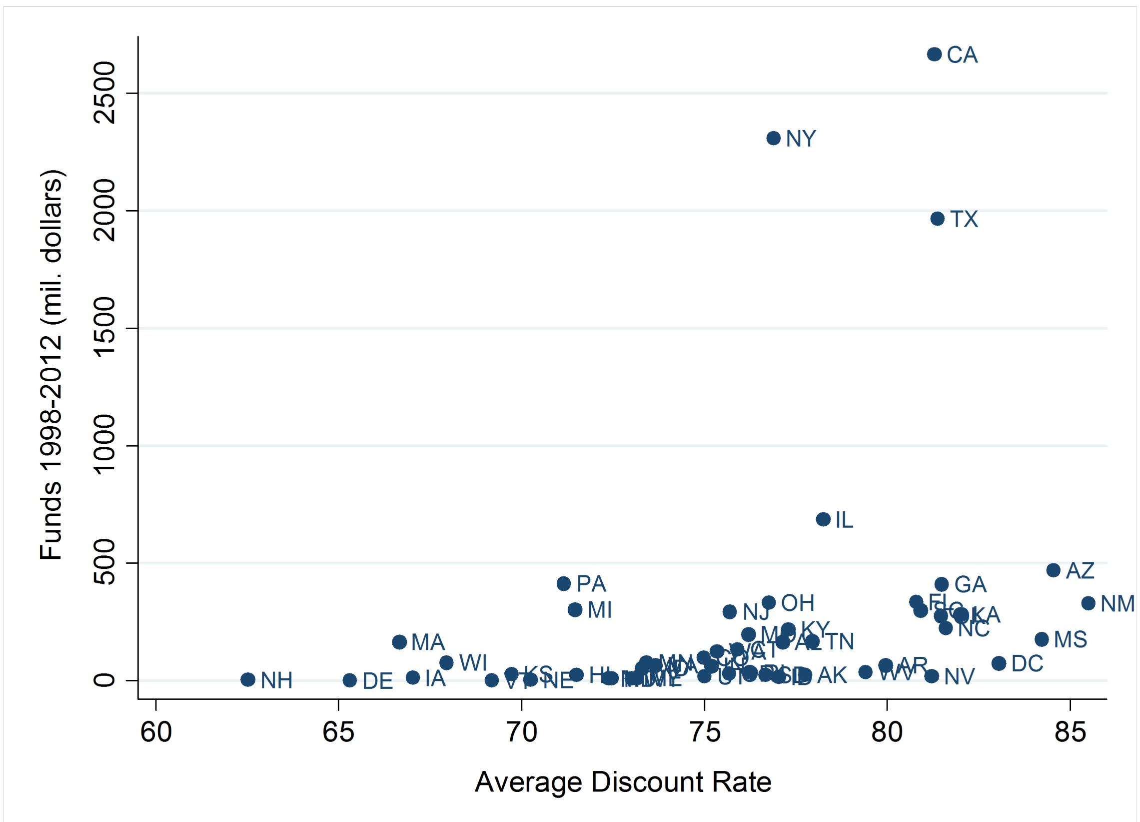


Figure 2.3: Average Discount Rate of Recipients and Internal Connections Funds by State.

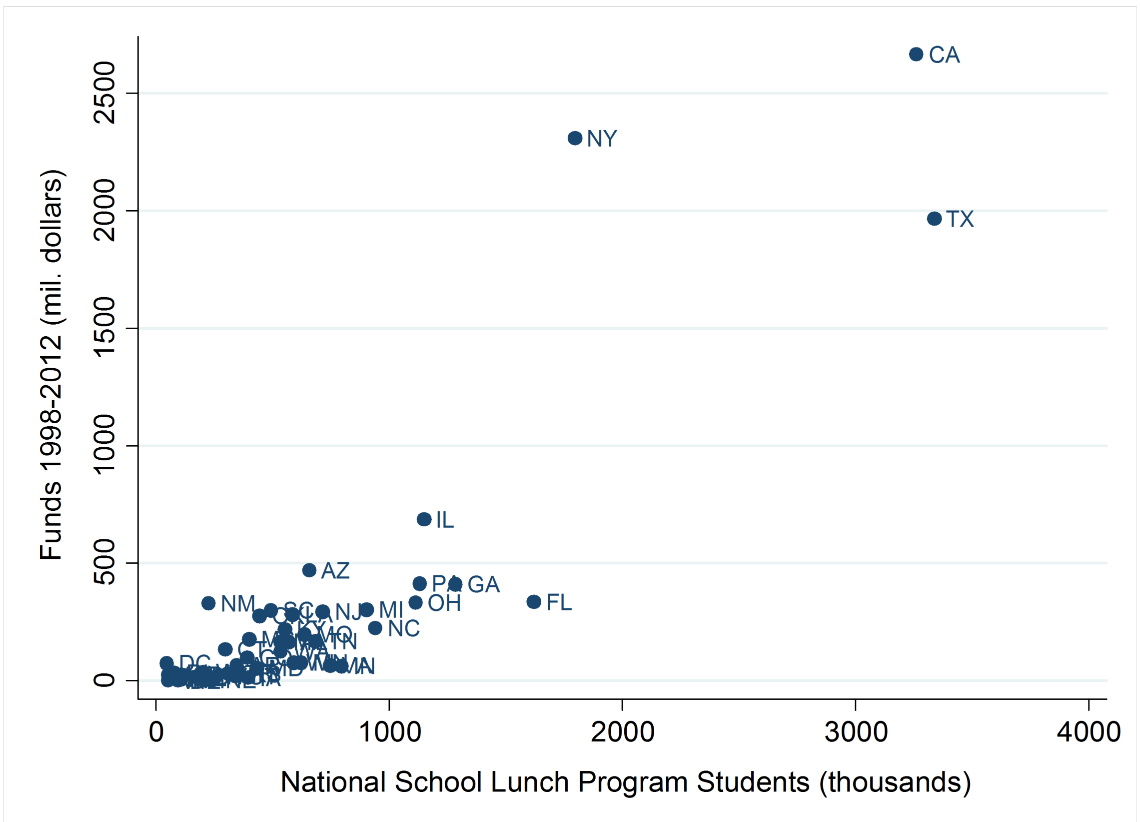


Figure 2.4: Internal Connections Funds and NSLP Students by State.

2.5.4 Funds excluding New York, California, and Texas

Treatment groups include and exclude the effects of New York, California, and Texas. The reason for excluding these three states is the large share of funds that have been allocated to those states between 1998 and 2012. Figure 2.3 shows the aggregate amount of priority 2 internal connections funds awarded to recipients in New York, California, and Texas. Figure 2.4 shows these highly populated states have large school districts with many students in the National School Lunch Program. Data from the USAC Advanced Search Tool (2013) show that over fifteen years, New York City Department of Education accounted for nearly $1.7 billion in funds, Los Angeles and San Diego City Unified School District for $738 million and $114 million, and Dallas, Houston, and Laredo Independent School Districts for $145, $141, and $89 million.

Table 2.6 shows per-school and per-student levels of funds from 1998 to 2012 by state. New York, California, and Texas together have received nearly the same amount of funds as the other 48 states combined, with per-student and per-school levels two to three times the national average. E-rate has distributed nationally on average, $116,313 per school and $261 per student in internal connection funds. New York students, on average, have been allocated $358,001 per school and $753 per student. Recipients in the three largest states on average have been allocated $251,399 per school and $471 per student. The remaining 48 states on average have been allocated $75,340 per school and $180 per student over the last fifteen years. The number of National School Lunch Program students in each state is an important influence in funding commitments, and the per-NSLP student estimate is provided as well. Table B.3 in Appendix B gives state-level data. The E-rate program has distributed to New York, for instance, the equivalent of $1,285 per NSLP student within the state, compared to $302 per NSLP student in the remaining 48 states. This may be explained if New York, for instance, has a higher percentage of NSLP students in schools with 75% to 100% eligible NSLP student populations. In the discussion section below, Figure 2.5 may help explain this outcome, where 75% to 100% eligible NSLP student populations are found in cities in greater numbers.

Table 2.6: Internal Connections Funds for Treatment Groups Per-Student and Per-School.

State	DR	Internal Connections Funds (1998-2012)	Students	Schools	Per Student Est.	Per NSLP Student Est.	Per School Est.
NY	77	$2,309,109,125	3,066,230	6,450	$753	$1285	$358,001
CA	81	$2,664,352,718	6,531,209	12,035	$408	$816	$221,384
TX	81	$1,966,417,575	5,142,705	9,120	$382	$589	$215,616
NY, CA, TX	80	$6,939,879,418	14,740,144	27,605	$471	$826	$251,399
48 States	76	$6,856,747,760	38,037,509	91,011	$180	$302	$75,340
50 + DC	76	$13,796,627,176	52,777,653	118,616	$261	$445	$116,313

Sources: USAC Advanced Search Tool (2013), NCES (2013a, 2013b), USDA Food and Nutrition Service (2014). DR signifies average discount rate of priority 2 internal connection fund recipients.

2.5.5 Schools and Students by Locale

The independent variables in Eq. (2.3) and Eq. (2.4) are city, suburb, town, and rural schools and students in each state. These data were combined from data on public and private schools and students from the National Center for Education Statistics (NCES) Common Core of Data (CCD) (National Center for Education Statistics [NCES], 2013a; 2013b). NCES/CCD data is collected through fiscal and nonfiscal survey components from the 2011-2012 year. Locale type is derived from the NCES twelve-category locale code, aggregated into four types, where the code is based on the school's physical address, and location relative to urban areas (NCES, 2013b, pp. A-2-A-4). Locations of 87,756 public schools and 30,862 private schools are presented, for a total of 118,618 schools across 50 states and the District of Columbia (NCES, 2013a, Table 2.4). Across the United States, 32,482 schools (27%) are listed in city locales, 35,144 schools (30%) in suburbs, 14,356 schools (12%) in towns, and 36,636 schools (31%) in rural locales (NCES, 2013a, 2013b). A total of 52,768,384 students in elementary and secondary schools are represented by 15,874,648 students (30%) in city schools, 18,103,750 students (34%) in suburb schools, 5,899,502 students (11%) in town schools, and 12,899,747 (24%) in rural schools (NCES, 2013a, 2013b). State-level data is available in Table B.2.

Comparison of E-rate funds through state-level aggregation and a simple distribution of schools and students by locale in Eq. (2.3) and (2.4) may not be necessary if USAC provided locale codes for each funding recipient. While funding request numbers are available, different numbers are assigned to the same recipient and for separate payments each year. However, even if USAC provided locale identifiers for E-rate recipients, the locale of each school would still need to be matched with fund commitments. Since school districts, such as Los Angeles Unified School District or New York City Department of Education, contain hundreds of schools in potentially different locales, per-school data would be the next best dataset. Given the data available, state-level aggregates are analyzed, similar to the related literature.

2.5.6 Quasi-Experiment from FY2010

A quasi-experiment from FY2010 provides a comparison on estimated effects of the discount rate and locale on internal connections funds. In that particular year, the FCC made available funds to all discount levels through an ex post waiver procedure, essentially allowing all requests from schools above the minimum discount rate of 20% to be fulfilled for internal connections fund requests (FCC, 2011). The order responded to a petition to release $850 million in unused funds carried over from the prior year. Without the discount rate threshold, a prediction is that the discount rate should not have a significant effect on the level of internal connection funds in FY2010.

A concern with a quasi-experiment of FY2010 is that the announcement of the lower discount rate occurred after applications had been submitted. This raises an endogeneity issue. Applicants with lower discount rates, perhaps from non-urban school districts, may not have applied for funds in FY2010. Districts with higher income populations may not have bothered to submit applications. Thus, data from FY2010 could infer a discount rate effect in fund requests due to discount rate applications that reflected expectations of historical threshold levels.

However, the applicant pool of priority 2 funds may reflect a wide range of recipients with various discount rates. Annually, over 20,000 schools and school districts submit Form 471s to USAC for priority 1 E-rate funds. Figure 2.2 presents priority 1 recipients by year for telecommunication and internet access applications. This level of subscription to the E-rate program suggests that if school districts have administrative resources to file Form 471s, then the cost to file an additional priority 2 request may be only marginally more expensive. If the marginal cost of filing a priority 2 application is small compared to the expected value of receiving funds, even at a small probability, then schools and school districts have an incentive file applications consistently. There also exists a chance that thresholds will be changed in the future. Even after announcement, the threshold decision is subject to revision through a petition process. Petitions have been filed each year asking FCC to lower the threshold. In fact, FCC reversed its announcement for FY2010 in response to one such petition (FCC, 2011).

The discount rate threshold level has also exhibited historical variance that may provide applicants reasonable expectations that priority 2 applications could be worth the effort to prepare. In the discussion above, the threshold dipped as low as 20% in 1999, 70% in 2003, 77% in 2009, and 80% in 2005. Thus, estimates from FY2010 are included below with the presumption that applications included a wide range of discount rates that year.

2.6 Results

Table 2.7 shows regression results from Eq. (2.1) with different treatment groups. The coefficient estimates the effect of the discount rate on internal connections funds by state.

For each percentage point increase in the average discount rate of recipients, say, from 85% to 86%, the model estimates funds per state increased by $32.1 million. With the exclusion of three largest recipient states, for each percentage point increase in the discount rate of recipients, funds per state increased by $13.7 million. This result provides a measure

Table 2.7: Estimates of Discount Rate on Internal Connection Funds.

	Priority 2 Internal Connections Funds by State 1998-2012	
	(1)	(2)
	All States	Excluding NY, CA, TX
Discount Rate (%)	32,133,151	13,688,899
	(2.60)*	(4.18)**
Constant	-2,167,348,019	-892,280,188
	(2.46)*	(3.68)**
R^2	0.1	0.22
N	51	48

Robust standard errors in parentheses. ** $p < 0.05$, * $p < 0.1$.

of the discount rate on total funds. From the treatment that excludes New York, California, and Texas, this implies that a difference of 10% in discount rate would amount to a $137 million difference in total internal connection funds. Or, from Table B.1 in Appendix B, a state like New Hampshire with a 63% average discount rate of recipients would receive $137 million less in internal connection funds over fifteen years than a state like Maine with a 73% average discount rate of recipients. The same regression was run on data from FY2010 only, and shows no statistically significant effect of the discount rate on the internal connections funds. This result confirms the prediction that the discount rate would not have a significant effect in a year when discount rate was waived. Estimates from the discount matrix and the discount rate itself are not as helpful, however, as per-student and per-school estimates.

Table 2.8 shows regression results from Eq. (2.2). The coefficient estimates the increase in internal connections funds for each NSLP student by state. As opposed to the discount rate of the recipient school district or school, the number of NSLP students allows for a per-student estimate of funding levels per state.

For each additional student in the National School Lunch Program, priority 2 internal connections fund increased $700, and excluding New York, California, and Texas, $315.

Table 2.8: Estimates of NSLP Students Per State on Internal Connection Funds.

	Priority 2 Internal Connections Funds by State 1998-2012	
	(1)	(2)
	All States	Excluding NY, CA, TX
NSLP Students	699.99	314.51
	(7.11)**	(6.04)**
Constant	-155,392,777.21	-5,445,491.09
	(3.92)**	(0.26)
R^2	0.78	0.56
N	51	48

Robust standard errors in parentheses. ** p < 0.05, * p < 0.1.

The results are statistically significant, with an R2 of 0.78 and 0.56. The number of NSLP students in each state impacts the levels of funding, but to a larger degree when including the three largest recipient states.

The treatment group effect in Column (2) highlights the difference in concentration of fund recipients, despite the number of NSLP students nationwide. Estimates from the data including all states gives one perspective of the range of E-rate priority 2 fund recipients, but without the leading school districts, the allocation of funds looks quite different.

Table 2.9 shows regression results from Eq. (2.3) and Eq. (2.4) for years 1998 to 2012. Regressions with the number of students and schools by locale per state are run for a treatment group with all 50 states and the District of Columbia, and one with 48 states excluding New York, California, and Texas. Locale of school and students on funds per state provides estimates of which student populations received E-rate priority 2 funds under the discount matrix criteria.

The effect of student and school locale on internal connections funds is not statistically significant, except for city schools and students. Columns (1) and (2) show that city populations appear to affect distribution to states by $1,082 per city student and $684,835 per

Table 2.9: Estimates by Locale on Internal Connection Funds.

	Priority 2 Internal Connections Funds by State 1998-2012			
	(1)	(2)	(3)	(4)
	All States		Excluding NY, CA, TX	
	Per Student	Per School	Per Student	Per School
City	1,081.92	684,835.40	328.06	176,517.10
	(5.36)**	(6.88)**	(1.17)	(1.36)
Suburb	-29.53	-67,238.54	118.65	52,774.19
	(0.28)	(1.16)	(1.33)	(1.22)
Town	234.69	-375,548.05	645.27	263,422.78
	(0.46)	(0.93)	(1.51)	(0.96)
Rural	-242.58	65,939.96	-10.93	-36,380.50
	(0.94)	(0.47)	(0.05)	(0.33)
Constant	-21,561,334.15	-60,930,428.64	-17,647,732.85	-8,207,983.98
	(0.73)	(2.16)*	(0.95)	(0.36)
R^2	0.88	0.86	0.6	0.57
N	51	51	48	48

Robust standard errors in parentheses. ** $p < 0.05$, * $p < 0.1$.

city school. This estimated effect of city populations exceeds per-student and per-school estimates from Table 2.6 above. Recall that national averages of internal connections funds were calculated above at $261 per student and $116,313 per school without respect to locale type. Suburb, town, and rural population effects are not statistically significant.

City population effects are not statistically significant in Columns (3) or (4) with the exclusion of New York, California, and Texas. The magnitude of the effect falls to $328 per city student and $176,000 per city school. These coefficients lack statistical significance, but are closer in magnitude to national averages from Table 2.6. These results imply that large allocations of priority 2 internal connections funds to these three states may account for the effect of city populations on internal connection funds.

Table 2.10 presents regression results from Eq. (2.3) and Eq. (2.4) for FY2010 alone, the quasi-experiment of lifting the discount rate criteria and fulfilling all priority 2 funding requests.

Columns (1) and (2) show that in FY2010, distribution estimates amount to $77 per

Table 2.10: Estimates by Locale on Internal Connection Funds in FY2010.

	Priority 2 Internal Connections Funds by State 1998-2012			
	(1)	(2)	(3)	(4)
	All States		Excluding NY, CA, TX	
	Per Student	Per School	Per Student	Per School
City	77.91	50,932.52	20.52	18,325.78
	(3.68)**	(3.70)**	(1.24)	(2.14)*
Suburb	-32.36	-20,308.40	-0.31	-1,501.47
	(1.63)	(1.71)	(0.05)	(0.45)
Town	-44.76	-95,089.20	-6.52	-14,241.94
	(0.82)	(2.06)* (0.25)	(1.01)	
Rural	70.46	54,455.54	26.55	7,555.72
	(1.74)	(1.9)	(3.66)**	(1.27)
Constant	-5,999,786.33	-11,383,144.56	1,250,550.58	1,593,733.66
	(1.48)	(1.65)	(1.15)	(1.14)
R^2	0.84	0.79	0.58	0.47
N	51	51	48	48

Robust standard errors in parentheses. ** $p < 0.05$, * $p < 0.1$.

city student and $50,932 per city school. Regressions that exclude New York, California, and Texas confirm a similar story in FY2010, that states received an estimated $20 per city student and $18,325 per city school with statistical significance. Suburb, town and rural population effects generally lack statistical significance, but some coefficients are notable. In one case, Column (3) shows an estimated effect of $26 per rural student. In FY2010, perhaps the waiver had a statistically significant effect on fund distribution to states with rural populations.

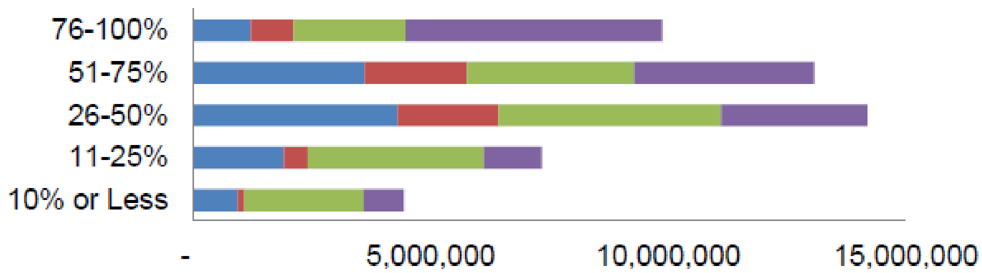
2.7 Discussion

Distribution of priority 2 funds depends on the discount matrix and, implicitly, National School Lunch Program student populations per state. Since the E-rate threshold announcement depends so heavily on NSLP eligibility of school districts and schools, the results above invite closer analysis of NSLP student data.

NSLP student data can be examined by urban or rural locale. Figure 2.5 presents NCES (2010) data on NSLP student populations by locale. NCES (2010) data is not available at the state-level and was not used in regression Eq. (2.2) above which used USDA (2014) data. NCES (2010) data includes a total of 48,933,094 NSLP students from fall 2010, while USDA (2014) data used in Eq. (2.2) gives a total of 31,031,200 over FY2009 to FY2013 in the 50 states and District of Columbia. The Department of Education or Department of Agriculture does not appear to publish National School Lunch Program student enrollment per state by locale data.

Figure 2.5 shows that a majority of students attending schools in the 76-100% student eligibility category are from city locales. In contrast, the majority of students in rural locales are found in the 51-75% and 26-50% eligibility categories. This data does not provide information on whether those students are predominantly located in New York, California or Texas. However, if the E-rate discount matrix is used to commit priority 2 funds to school districts with high percentages of NSLP-eligible students, then simple statistics can estimate which students and which states are being awarded funds as a consequence of distribution criteria.

NSLP student distribution by locale informs reform efforts for the E-rate discount matrix. If E-rate funds are distributed according to the discount matrix, much of the effect will be driven by locale demographics of NSLP students. These regressions provide estimates of fund distribution since NSLP data by state by locale is unavailable. From NSLP data alone, the predominance of priority 2 funds to high discount rate recipients can be expected to go to city students attending schools with 76-100% eligibility. This prediction arises simply from the locale distribution of students in the NSLP categories. If E-rate reformers intend to distribute E-rate funds to schools and students in rural, town, or suburb locations, adjustments to the discount matrix criteria need to be made. Perhaps, for instance, an increased rural benefit in the discount matrix of 10% to 15% at all levels, including the 80% and 90% discount rate levels, would enable priority 2 funds to reach additional NSLP students in non-urban locales.



	10% or Less	11-25%	26-50%	51-75%	76-100%
Rural	940,579	1,910,880	4,310,271	3,615,187	1,220,314
Town	142,494	503,519	2,120,711	2,153,786	897,390
Suburb	2,512,308	3,711,522	4,691,219	3,515,302	2,353,805
City	840,721	1,213,738	3,070,715	3,796,444	5,412,189

Figure 2.5: Distribution of Elementary and Secondary Enrollment Eligible for National School Lunch Program by School Locale.

Source: NCES (2010).

2.8 Conclusion

This study identified the distribution of priority 2 internal connections funds from 1998 to 2012, and estimated the effects of the discount matrix and National School Lunch Program student population by state. Regressions provided per-student and per-school estimates for funds based on urban and rural locale. The study also tested a quasi-experiment of FY2010 when USAC waived the discount matrix for priority 2 fund commitments. Empirical inquiry into USAC's distribution of funds by discount rate and locale can assist in efforts to reform the E-rate program. Further analysis could simulate potential discount rate reforms as requested by FCC (2013). Data analysis could also investigate adjustments to the discount matrix based on underlying NSLP data (FCC, 2013).

Chapter 3: Is There a Coupon Divide? A Study of Technology Adoption in the Digital Television Transition of 2005

3.1 Introduction

The Digital Television Transition and Public Safety Act of 2005 mandated a national transition from analog to digital television broadcasts.[1] In this study, I investigate drivers of participation in a federal program for subsidized converter boxes.

Curiously, I find that broadband adoption explains participation rates in the coupon program. After controlling for other factors, such as redemption rates, over-the-air television households, demographics, and income, my results show an effect from broadband adoption at the zip code level. The study raises an endogeneity problem, since many coupon requests were made by online form. Broadband adoption may have facilitated coupon requests, but the alternative could be true as well. Coupon seekers could have adopted broadband to search for deals, savings, and opportunities.

Data on participation rates show an interaction between consumers and government directly, and consumers and their broadband, indirectly. My study adds to the digital divide literature because it suggests a research question. Is broadband adoption driven by a consumer preference to seek coupons and deals?

[1] P.L. 109–171, 120 Stat. 21, Title III of the Deficit Reduction Act of 2005, Feb. 8, 2006. *See also,* DTV Delay Act, P.L. 111–4, 123 Stat. 112, Feb. 11, 2009 (extending the deadline from February to July 2009).

3.2 Coupons for TV Converter Boxes

Coupons for converter boxes looked like pre-paid credit cards worth 40 dollars each. Figure 3.1 shows the physical coupon. Over 33 million coupons were mailed to households with 1.34 billion dollars in value.[2]

The coupon program relied on households to first, become aware of the subsidy, second, to request coupons, and third, to travel to a participating store to redeem the converter box. To prevent fraud and waste, the U.S. Department of Commerce anticipated coupon requests, formulated eligibility requirements, and designed waivers and program extensions.[3]

Figure 3.2 shows the online form for coupon requests. Table 3.1 shows that 59 percent of coupon requests were made through the online form, while 38 percent were made over the telephone, and 3 percent by paper mail.[4] Appendix C includes an image of the paper form.

The Commerce Department specifically targeted television markets through two different campaigns.[5] They sent information about the program to nursing homes, elderly populations, underserved and low-income populations, and areas with households that relied on over-the-air broadcasts.[6] Local television stations also donated time to inform viewers of the free program.[7]

Device manufacturers that built converter boxes adhered to technical standards. Over 190 boxes from foreign and domestic manufacturers were certified by federal staff for the coupon program.[8] Over 2,300 retailers in 34,000 locations sold converter boxes and accepted

[2]With a budget of 160 million dollars for program overhead (Kruger, 2009), NTIA distributed 1.34 billion dollars worth of coupons, totaling 22.25 million coupons to households with analog-only and multichannel-video televisions, and 11.25 million coupons to analog-only households. The program received an additional 650 million dollars of support from the Recovery Act of 2009 (IBM, 2009, p. 3).

[3]NTIA, 2009a; IBM, 2009.

[4]NTIA, 2009b.

[5]IBM, 2009.

[6]NTIA, 2009a; NTIA, 2009b; Nielsen, 2008.

[7]GAO, 2008. Public service advertisements worth 5 million dollars informed vulnerable households (GAO, 2008). Broadcast stations donated to the federal government 1.4 billion dollars in free air time for public service announcements (NTIA, 2009b, p. 14).

[8]The Federal Communications Commission (FCC) assisted the program with a laboratory staff who conducted 300 tests on each certified converter box (NTIA, 2009b, p. 9). The FCC lab had never before

the federal coupons.[9]

Figure 3.1: Coupons for two TV Converter Boxes.

Source: FrugalDad, Apr. 30, 2008, `http://daddyforever.com/2008/04/30/digital-tv/` (last accessed March 15, 2017).

Table 3.1: Formats of Coupon Requests.

	Requests	% Total
Fax	137,009	0%
Mail	1,089,428	3%
Phone	13,070,075	38%
Website	20,504,268	59%
Total	34,800,780	100%

3.2.1 Who Would Want a TV Converter Box?

Who would want one of these subsidized converter boxes? The direct reason is to keep an over-the-air projection television functional through the analog to digital transition. But participation in the coupon program could have been driven by interest in free coupons themselves.

performed so many tests on electronics devices before this program. (NTIA, 2009b, p. 9).

[9] *Id.*

Figure 3.2: Online Form for the Coupon Program.

Source: Discount Coupons, `http://discouucoupon.info/tv-converter-box-discount-coupons/` (last accessed March 15, 2017).

The share of households that relied solely on over-the-air television was less than 10 percent in 2009. The share of households watching broadcast-only television had fallen from 14 percent in 2005.[10] The year after the transition, 9.6 percent of households relied exclusively on over-the-air television.[11] A few years after the digital transition, the number of over-the-air television households increased slightly to 9.8 percent in 2013.[12]

Over-the-air television households could have watched television content through other

[10] FCC, 2009b, para. 108. Cable systems had 56 percent penetration among American households in 2005 (FCC, 2009b, para. 40-41).
[11] FCC, 2012, para. 211. Cable systems had 45 percent penetration among American households in 2010 due to the rise in households subscribing to alternative distribution systems such as satellite television (FCC, 2012, para. 70).
[12] FCC, 2015, para. 8.

means. New flat-screen digital televisions were made with embedded digital antennas. Some of these households may have decided to upgrade their televisions. For several holiday seasons, flat-screen televisions were big ticket items with 115 billion dollars spent on 220 million units in 2011.[13] Sales of flat-panel televisions grew from 2005 to 2009, growing from 29,060,000 to 32,100,000 units sold annually between 2008 and 2009.[14] Americans tossed out their old televisions during those years as well. In 2009, 28 percent of electronic products collected for recycling were projection televisions.[15]

Cable and satellite television also offered more channels than over-the-air television. Netflix and over-the-top television came on the market in 2009 as well. Video content was a small share of internet traffic in 2009 (Atkinson, et al., 2011), and by 2010, over-the-top streaming video competed with existing television services (Flint, et al., 2015). Nielsen started to measure over-the-top television viewership in 2010. Less than 25 percent of broadband traffic was internet video at the time, which grew to more than 60 percent of peak period traffic in 2014 (Sandvine, 2014).[16]

Mobile phones and smartphones entered the home in 2009 as well. Media consumption increased, rather than decreased, with a proliferation of more screens.[17] At this time in technology history, questions arose on whether additional screens would take away viewership from other channels. The opposite was in fact the case.

One-third of the coupons were allocated to households that relied solely on over-the-air televisions. The other two-thirds of the coupons were requested by households connected to cable or satellite service.[18] The Commerce Department set aside 11.25 million coupons

[13] Economist, 2012.

[14] EPA, 2011, p. 11.

[15] EPA, 2011, p. 19. The EPA estimated the average age of projection televisions collected for recycling was 8 to 20 years old (EPA, 2011, p. 16).

[16] In 2014, Netflix constituted a share of 32.39% aggregate peak traffic, YouTube with 13.35%, HTTP with 8.47%, BitTorrent with 5.03%, Facebook with 2.94%, and Amazon Prime with 2.37% (Sandvine, 2014, p. 6, tbl. 2).

[17] Nielsen, 2009; Pew Research Center, 2012a.

[18] The coupon allocation was based on household self-reports without monitoring, auditing, or enforcement by the Commerce Department. No data exists on error rates on the distribution of coupons to households with analog-only televisions.

to analog-only households, and 22.25 million coupons to households with analog-only or multichannel-video televisions.[19]

The Commerce Department, with the help of consultants, estimated projected demand for the converter box coupons. For several years, and decades, before the transition, the impact of a digital switch had been discussed in Washington. Changes in technology with the introduction of the iPhone in 2007 and Netflix in 2009 accelerated the need for broadcasters to adapt to new video offerings.

3.2.2 Legislative History

Congress held dozens of hearings before and after enacting the Digital Television Transition Act of 2005. Subcommittees in the House and Senate considered case studies of other countries that had already switched from analog to digital television. In 2001, during a hearing on a digital transition, Senator John McCain expressed concerns on the political economy of broadcast television. He quoted *New York Times* columnist William Safire on the incentives of broadcasters, Congress, and the American public. "In terms of ripping off the taxpayers with not a peep from the media, nothing compares with the broadcasters' lobby. This phalanx of freeloaders has stolen the free use of great chunks of the most valuable natural resource of the information age: the digital television spectrum owned by the American people."[20]

Safire, in his opinion column, called the broadcasters, "spectrum squatters," who received a giveaway from Congress and the White House, who in turn, benefited from broadcaster support. He wrote, "When a few of us suggested that this national resource be opened to competitive bidding rather than given away, the broadcasters insisted that the airwaves were their entitlement. With a gift of the new spectrum, they promised to deliver

[19] NTIA, 2009a; NTIA, 2009b.

[20] Transition to Digital Television, Senate Hearing 107-1103, 107th Congress, First Session, Mar. 1, 2001, `https://www.gpo.gov/fdsys/pkg/CHRG-107shrg87414/html/CHRG-107shrg87414.htm`, quoting, Safire, William. Spectrum Squatters, N.Y. Times, Oct. 9, 2000, `http://www.nytimes.com/2000/10/09/opinion/essay-spectrum-squatters.html`.

free TV broadcasts on high-definition television. The Republican Congress and Clinton White House promptly doubled the broadcasters' bandwidth – a freebie estimated then at $70 billion, now worth far more."

Four years later, the Digital Television Transition Act was signed into law, and eight years later, in 2009, the final switch was made from analog to digital broadcasts. The transition started, however, twenty years earlier, when in 1985, a Japanese standard for high-definition television first made its way to the United States (Hart, 2009). American stations did not take to the digital standard for several presidential administrations and dozens of sessions of Congress. After decades of delay, broadcasters managed to keep their spectrum in the public interest, modifiable only through Congressional legislation. Proposals were floated for auctions to the high-definition spectrum (*Id.*, p. 16), but licenses to these frequencies failed to materialize in the 1990s. Transmissions remained in trust with the stations under prior allocations.

3.3 Related Literature

Studies on participation rates in food stamp programs may have relevance for this study.[21] Those studies use regression methods to compare participation rates, redemption rates, and demographic and income drivers for engagement in the coupon programs. Peer effects also affect participation rates in food stamp programs.[22]

The marketing literature measures participation rates in retail coupon programs by format of coupon and types of coupon savings.[23] In 2014, Americans had access to 329 billion coupons, of which 2.9 billion were redeemed. The average face value of coupons was $1.56, and average time for redemption was 2.2 months.[24] Non-food coupons exceeded

[21] *See generally,* Matthews, James R. (2001). Food Insecurity Issues: An Analysis Based on California WIC Data, Journal of Food Distribution Research, March 2001.

[22] QJE article on peer effects in WIC benefits.

[23] *See generally,* Inmar, 2014 Coupon Trends, 2013 Year-End Report, `http://go.inmar.com/rs/inmar/images/Inmar_2014_Coupon_Trends_Report.pdf`.

[24] *Id. at 20.*

food coupons by nearly 50 percent, while food coupons had higher rates of redemption.[25] Marketers claim that 96 percent of shoppers have used a coupon in the last 3 months, and 74 percent of survey participants say using a coupon makes them feel smarter.[26] Types of coupons studied include inserts, direct mail, instant redeemable, electronic checkout, on package, in package, shelf pad, shelf dispenser, handout, electronic kiosk, bounceback, military, print at home, online only, print or online, among others.

Studies of broadband adoption find reasons for the digital divide. The digital divide is a persistent gap between adoption and availability of high-speed broadband. In 2009, 63 percent of American homes had adopted broadband subscriptions (Horrigan, 2009). Broadband adoption rates rose to 72.4 percent in 2011.[27] Adoption rates lagged availability where 93 percent and 96 percent of homes had access to 3 mbps of download speeds in wired and wireless broadband.[28]

Explaining the digital divide then and today remains a critical research question. The top reason offered by survey respondents for not subscribing to broadband at home was not availability, price, or usability. Lack of relevance topped the reasons for disinterest in broadband adoption.[29]

International studies have measured drivers of broadband adoption in New Zealand (Howell, 2015), and South Korea (Park et al., 2015). Some studies focus on mobile broadband availability (Prieger, 2013), and demographic factors such as race (Prieger, et al., 2008). Other studies find specific obstacles to broadband adoption (Katz, et al., 2014).

The Government Accountability Office developed a model to estimate demographic drivers of broadband adoption in the United States with holding company data at the zip code level.[30] The agency relied on survey data on broadband adoption, with data on

[25] *Id. at 23-24.*
[26] *Id.* at 43.
[27] NTIA/ESA, 2013a.
[28] *Id.*.
[29] *Id.*, p. 43.
[30] GAO, 2006, tbl. 2.

per capita income, race, education, age, children, household size, occupation, and urbanicity.[31] The model incorporated FCC Form 477 data on the number of broadband providers to the household. The model reported a negative coefficient for adoption likelihood for individuals aged 50 and older, residing in rural locations.[32] The model reported a positive coefficient for adoption likelihood for households with children, in larger households, in suburban locations.[33]

A literature on e-Government and the digital divide covers the effects of low broadband adoption on civic engagement through information technology (Hanafizadeh, et al., 2013). For a history of the digital television transition since the 1980s, Hart (2009) provides an account of legislative and technological progress leading up to the Digital Television Transition Act of 2005.

3.4 Empirical Strategy

To investigate drivers of participation in the converter box program, I use ordinary least squares regression. I test a null hypothesis that participation rates cannot be explained by coupon redemption rates, technology, demographic, or income variables. If coefficients on the independent variables are different from zero with statistical significance, then I can reject my null hypothesis. To handle heteroskedasticity in the error term, I use robust standard errors. I transform the variables with the natural logarithm to assist in linear regression. For regression diagnostics, see Appendix C. I use normalized beta coefficients to standardize the scale units of the independent variables.[34]

$$lnPRATE_z = \alpha_z + \beta_1 lnRRATE_z + \Delta_z \mathbf{B}_z + \Theta_z \mathbf{D}_z + \Phi_z \mathbf{I}_z + State + \varepsilon_z \tag{3.1}$$

[31] *Id.*.
[32] *Id.*, tbl. 6.
[33] *Id.*.
[34] *See generally,* King, Gary (1986). How Not to Lie with Statistics, American Journal of Political Science, 30(3): 666-687.

Eq. (3.1) shows the dependent variable as participation rate in the coupon program. Participation rate, $lnPRATE_z$, is the number of coupon requests divided by population in each zip code.[35] Independent variables include redemption rate, $lnRRATE_z$, which is the number of coupons redeemed per zip code divided by requests per zip code. Broadband variables in vector $\mathbf{B}_z$ include availability and adoption rates inferred from the number of holding companies per zip code (Kolko, 2010). The percentage of households that do not subscribe either to cable television or alternative distribution systems (ADS) such as satellite television are included in an over-the-air television variable. Over-the-air television penetration is tracked in television markets by over 200 designated market areas as denoted by by d. Demographic variables in vector $\mathbf{D}_z$ include population density, median age, and number of dependents per capita. Income variables in vector $\mathbf{I}_z$ include income per capita and cost of living by location affordability. Location affordability is a share of housing and transportation costs as a percentage of median income. State fixed effects are included for each of 53 jurisdictions (including Washington, D.C., Puerto Rico, and Guam).[36]

3.5 Data

Tables 3.2 and 3.3 present descriptive statistics and data sources for dependent and independent variables in Eq. (3.1). Over 55,000 zip codes are reduced to 25,482 zip code tabulation areas (ZCTAs) due to data limits in the converter box dataset, holding companies dataset, and zip code to ZCTA relationship file.

[35]The participation rate is not divided by households, due to inclusion of a control variable for number of dependents per capita.

[36]Check for inclusion of Puerto Rico, did not include in one of the DMA tables.

Table 3.2: Descriptive Statistics

Variable	Obs.	Mean	S.D.	Min.	Max.
Participation Rate (Zip Code)	25,482	0.214	0.168	0.000	18.500
Redemption Rate	25,481	0.550	0.100	0.000	0.917
Predicted Broadband Adoption	25,482	0.343	0.057	0.222	0.422
Implied Broadband Availability	25,482	0.817	0.134	0.530	1.000
Over-the-Air TV Households	25,482	0.132	0.051	0.040	0.373
Population Density	25,482	0.001	0.002	0.000	0.057
Median Age	25,482	40.868	6.249	18.800	80.900
Dependents per Capita	25,482	0.277	0.148	0.000	17.750
Location Affordability Index	25,482	0.562	0.060	0.384	0.956
Income Per Capita	25,482	$53,488	$39,210	$5,002	$2,368,676
Holding Companies	25,256	9.146	4.313	2.000	31.000

3.5.1 Converter Box Coupons by Zip Code

The Commerce Department released zip code data on the TV converter box coupon program.[37] Data from the converter box program is presented by requests and redemptions.[38] Zip code data has deficiencies, but is the smallest granularity provided for this program. Zip codes as denoted by the U.S. Postal Service can "belong to multiple districts and multiple states."[39] Zip codes demarcate actual mail routes for mail carriers, which are lines, compared to polygons.[40] Since the Commerce Department collected coupon requests by postage address, I converted these zip codes into zip code tabulation areas (ZCTA) to map demographic and income data with polygons.[41]

[37]The data is available online for information purposes without a warrantee on its reliability (NTIA, 2010a).

[38]The two datasets include Coupons Redeemed by ZIP5 (NTIA, 2010c; NTIA, 2010d), and Coupons Requested by ZIP5 (NTIA, 2010b).

[39]Sunlight Foundation, 2012.

[40]*Id.*, 2012.

[41]I use zip code and ZCTA interchangeably after mapping zip codes to ZCTAs and dropping zip codes outside the Census Bureau relationship file.

Table 3.3: Data Sources

Variables	Source
Dependent Variable	
Participation Rate (Zip Code)	NTIA (2010b), Census Bureau (2015d; 2015e; 2015f)
Independent Variables	
Redemption Rate	NTIA (2010c), NTIA (2010b)
Predicted Broadband Adoption	FCC (2005), Kolko (2010)
Implied Broadband Availability	FCC (2005), Kolko (2010)
Over-the-Air TV Households	Nielsen (2007)
Median Age	IRS (2010)
Population Density	Census Bureau (2015d; 2015e; 2015f)
Dependents per Capita	IRS (2010)
Location Affordability Index	HUD (2017)
Income per Capita	IRS (2010)
Holding Companies	FCC (2011)

3.5.2 Participation Rates by Zip Code

Participation rates are calculated by dividing the number of requested coupons with the population in each zip code.[42] Participation rates are calculated by zip code. In some cases, population from the Internal Revenue Service dataset differs from the Census Bureau.

In a separate listing of participation rates at the designated market area (DMA) level, the Commerce Department published a table with different methodology than I use in this study.[43] For a comparison, see Table 3.3. The Commerce Department participation rates are based on 2008 Nielsen data on a market share of 60 percent of over-the-air households in each television market. These participation rates differ from those used in the regression analysis on a zip code level. Table 3.3 compares participation rates through aggregations across zip codes and averaged across zip codes.

[42]Population per ZCTA is the variable *ZPOP* in Internal Revenue Service (IRS) files.
[43]NTIA, 2010.

3.5.3 Redemption Rates by Zip Code

Redemption rates are calculated by dividing the number of redeemed coupons by the number of requested coupons in each zip code. This coupon program showed consistent redemption rates with general retail coupon redemption rates.[44]

3.5.4 Over-the-Air TV Households by Designated Market Area (DMA)

Over-the-air television households are generated by Nielsen Media Research. I use data from DMA Household Universe Estimates from September 2006, which includes percentage of households in each designated market area with cable subscriptions and alternative distribution system (ADS) subscriptions from November 2006. ADS are satellite distribution networks for television content. Over-the-air households are estimated as television households that do not have cable or ADS subscriptions.[45]

3.5.5 Designated Market Areas (DMA) by Zip Code

Yahoo YQL Web Service offers a resource with named places in the world through Yahoo! GeoPlanet. Designated market areas (DMA) are included as place types for locations in the United States. I ran queries to match zip codes to DMAs.[46]

3.5.6 Predicted Broadband Adoption by Zip Code

Kolko (2010) generated a model for predicted broadband availability and adoption rates at the zip code level. His model depends on two data sources. He used FCC Form 477 data on holding companies from December 2005 and broadband adoption survey data from Forrester Research in the Technographics Benchmark series. The Forrester survey asked 60,000 households in December 2005 about technology behaviors and adoption (*Id.* at

[44] GAO, 2008.

[45] The calculation is *(1 - Cable and/or ADS household %)*.

[46] In Java, I ran this query: 'select * from geo.places.belongtos where member_woeid in (select woeid from geo.places where placetype="Zip Code" and text="22201") and placeTypeName="28"'.

136).[47] Kolko emphasized that his model cannot be used to predict how broadband adoption would change with increases or decreases in the number of holding companies by zip code. The number of holding companies in each zip code is not exogenous to broadband supply or demand. (*Id.* at 138, n.19).

3.5.7 Implied Broadband Availability by Zip Code

With FCC data, Kolko (2010) generated estimates for availability of broadband by the number of holding companies by zip code. His paper applied a probit regression model to estimate broadband availability from the number of holding companies in each zip code. In my model, I apply his estimates to holding company data from 2011 for each zip code.[48] Holding company data has been criticized for its reliability in broadband statistics, since it does not reflect providers, but reflects subscribership.[49]

3.5.8 Population Density, Median Age, and Dependents by ZCTA

The U.S. Census Bureau provides demographic data for Zip Code Tabulation Areas (ZCTAs) through the Urban Area Relationship Files.[50] Population density is calculated as the population per ZCTA divided by the total land area of the ZCTA.[51] Median age is from the Demographic Profile dataset.[52] Dependents per capita is the number of dependents from

[47] Surveys were conducted by mail and in English. (Kolko, 2010, n.14).

[48] FCC, 2013.

[49] FCC, 2013.

[50] Census Bureau, 2015d; 2015e; 2015f. These files include the ZCTA5 zip codes by 2010 Zip Code Tabulation Area, the variable *ZPOP* (2010 population of the 2010 ZCTA), *ZHU* (2010 housing unit count of the 2010 ZCTA), *ZAREA* (total area of the 2010 ZCTA), and *ZAREALAND* (total land area of the 2010 ZCTA). The Census Bureau also provides statistics on urban populations in defined Urban Areas. This urban to rural population statistic could have been useful for regression analysis, but there are reasons for my decision to exclude analysis. Urban Areas have boundaries around metropolitan cities that overlap several zip codes and different congressional districts. Since the U.S. Census Bureau demarcation of Urban Areas differs from both zip codes and congressional districts, they were not used in this analysis.

[51] I generate a new variable *ZDENSITY* as a population density for ZCTAs calculated as *ZPOP* divided by *ZAREALAND*.

[52] I apply the variable *hd01_s020*. I also tested population age data by ZCTA, not included in this report. The U.S. Census Bureau provides population data by ZCTA through the Profile of General Population and Housing Characteristics: 2010 (DP-1) dataset on the 2010 Demographic Profile from the 2010 Census with All 5-Digit ZIP Code Tabulation Areas within the United States and Puerto Rico. Five-year age bands are demarcated by percentage of total population in each zip code, such as under 5 years, 5 to 9 years, 10 to

the IRS database divided by the population per ZCTA.[53]

3.5.9 Average Gross Income by ZCTA

The Internal Revenue Service publishes tax data by zip code. These tax files from 2010 provide a host of information on tax filings per zip code, including adjusted gross income, total tax forms filed, prepared tax filers, joint filers, and number of dependents claimed. Data at the zip code level provides the number of dependents in each zip code and total number of households.

3.5.10 Location Affordability Index by County

The U.S. Department of Housing and Urban Development generates cost of living data through an index of location affordability. The smallest available area is at the county-level. I map county-level data from the Location Affordability index to zip code using a Census Bureau relationship file. I use the costs of housing and transportation as a percentage of income for the median income family.[54] The Location Affordability Index depends on a simultaneous equation model to account for local amenities, income scaling, housing characteristics, tenure split, and other factors such as car and household owners, gross rent, selected monthly ownership costs, transit percent to work, transit renters, block density, household owners and renters, retail jobs, job density, and median income.[55]

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15 years, up to 80 to 84 years, and 85 years and over. Median age in a zip code is also available in this dataset, along with average household size, average family size, and households with individuals under 18 and over 65 years old. The Demographic Profile dataset contained 33,124 ZCTAs. These ZCTAs exceeded the 25,977 ZCTAs that matched those in the coupon program database, and 7,151 ZCTAs were dropped from the coupon database.

[53] I apply the variable *n2* (check this).

[54] I apply the variable *ht*. The agency notes that other metrics such as monthly rent or selected monthly ownership costs are not well-correlated with costs of living across localities.

[55] Data and Methodology: Location Affordability Index Version 2.0, `http://www.locationaffordability.info/LAPMethodsV2.pdf`. The index depends on several federal data sources including U.S. Census American Community Survey (ACS), U.S. Census TIGER/Line Files, U.S. Census Longitudinal Employment-Household Dynamics (LEHD) Origin-Destination Employment Statistics (LODES), National Transit Database, and the Consumer Expenditure Survey. Location Affordability Index, About, `http://www.locationaffordability.info/About_Data.aspx`.

3.5.11 ZCTAs by County

Relationship files provided by the U.S. Census Bureau are used to match zip code tabulation areas (ZCTAs) and counties. Several zip codes span multiple counties. For the Location Affordability Index, in the case where some zip codes are mapped to several counties, a simple average cost of living index was collapsed from counties to zip codes.[56]

3.6 Results

After running the regression from Eq. (3.1) on zip code level data, I find that broadband adoption explains participation rates. In Table 3.4, independent variables are presented in descending magnitude of robust normalized beta coefficient.[57]

In column (1), coupon redemption rates are regressed on participation rates. The the R-squared value is 0.419, before including other variables. I find that redemption rate, on its own, explains most of the variance in participation rates. A one percent increase in redemption rate leads to a 2.102 percent increase in participation rate. Redemption rate has a normalized beta coefficient of 0.647.

The positive effect of redemption rates on participation rates means that zip codes with more participants were more likely to redeem the coupons. In other words, redemption rates are higher in zip codes with more coupon seekers. If there was no effect on redemption rate, then coupon requests and redemptions would be unrelated. This positive relationship could indicate peer effects, which is beyond the scope of this study.

In columns (2) to (4), results show the impact of additional independent variables in

[56]There are other limitations on ZCTA data. "ZCTAs are generalized area representations of U.S. Postal Service (USPS) ZIP Code service areas. Since ZCTAs are not [sic] exact representations of the USPS' ZIP Code delivery areas they should not be used for mailing purposes." (U.S. Census Bureau, 2015c).

[57]Normalized beta coefficients do not necessarily mean the variable is more important than others, but scaled variance helps to adjust for value differences. See `https://www3.nd.edu/~rwilliam/stats1/x92.pdf`. A caveat on normalized beta coefficients is that they depend on variables having distributions that resemble each other. For skew and kdensity of the independent variables, see Appendix C. Many variables are on a 0 to 1 scale, such as participation rate, redemption rate, predicted broadband adoption, implied broadband availability, and over-the-air television household penetration rates.

the multivariate regression. The coefficient on broadband adoption remains positive with a normalized beta coefficient of over one.

In column (5) after including state fixed effects, the independent variables have coefficients different from zero with statistical significance at the 1 percent level. I can reject my null hypothesis that broadband, demographic, and income variables have no effect on participation rates in the coupon program. A one percent increase in redemption rate explains a 1.879 percent increase in participation rate. Redemption rate has a normalized beta coefficient of 0.578, which is larger than normalized beta coefficients on the other variables. A one percent increase in predicted broadband adoption leads to a 2.671 percent increase in participation rate. Predicted adoption has a normalized beta coefficient of 0.699, which has the largest magnitude among the other variables. A one percent increase in implied broadband availability leads to a 2.679 percent decrease in participation rate. Implied availability has a normalized beta coefficient of -0.695.[58] A one percent increase in population density leads to a 0.80 percent decrease in participation rate. Population density has a normalized beta coefficient of 0.278. A one percent increase in over-the-air television households explains a 0.232 percent increase in participation rate. Over-the-air television households has a normalized beta coefficient of 0.143. A one percent increase in median age leads to a 0.798 percent increase in participation rate. Median age has a normalized beta coefficient of 0.193. A one percent increase in dependents per capita explains a 0.256 percent increase in participation rate. Dependents per capita has a normalized beta coefficient of 0.107. A one percent increase in percentage of median income spent on housing and transportation, as denoted by location affordability index, leads to a 0.683 percent decrease in participation rate. Location affordability has a normalized beta coefficient of -0.108. A one percent increase in percentage of income per capita leads to a 0.436 percent decrease in participation rate. Income per capita has a normalized beta coefficient of -0.257.

[58] Implied broadband availability is negatively correlated to predicted broadband adoption, see Appendix C. This is due to the model generated by Kolko (2010).

3.7 Discussion

Why would broadband adoption explain participation rates in the coupon program? After controlling for other variables at the zip code level, an effect from broadband adoption on coupon participation remains statistically significant. My model has not addressed the endogeneity problem, however.

If there is correlation between coupon seekers and broadband adopters, which behavior drives the other? Is broadband adoption driven by a preference to seek coupons and deals? Or does broadband adoption facilitate the search for coupons or deals?

The first option may be more likely. Individuals who seek deals would adopt technology to assist their behaviors. In this particular program, we know that 59 percent of coupon requests were made online and 38 percent by telephone. Since many coupons were requested by telephone, the hypothesis that broadband increased coupon requests seems less likely. More data on request format would help to answer this question.

So, coupon seekers might have adopted broadband to amplify their underlying preferences for deals and savings. Many households could have redeemed a converter box to keep a second or third television in operation for marginal gains in video screens.

But my results show that richer households were not the ones seeking coupons on their own. My regression results show that income negatively affected participation rates, so the richer the zip code, the less likely coupons were requested. Location affordability also had a negative coefficient. As cost of living in a zip code increased, coupon participation goes down. Median age and dependents per capita had positive coefficients. Zip codes with older householders and larger families participated in the program at higher rates than other zip codes.

My results seem to indicate a coupon divide that identifies a population with lower cost of living, lower income, older age, and more dependents. A coupon divide may correspond to the digital divide in an anecdotal way, but empirical analysis raises the possibility of a consumer behavior explanation not readily defined by simple categories of demographics or income.

3.8 Conclusion

Individual decisions to adopt converter boxes, or broadband, come from preferences that may be explained by demographics, income, or technology. By zip code, I find that coupon seekers and broadband adopters are statistically correlated. My study invites further empirical work on the digital divide and consumer preferences.

Table 3.4: Participation Rates by Designated Market Area

DMA Rank	DMA	Participation Rate (ZCTA)	Participation Rate (NTIA)	OTA %	Cable %	ADS %
175	LAKE CHARLES, LA	41.4%	33.2%	8.5%	73.6%	28.3%
135	WAUSAU, WI	40.7%	45.5%	20.3%	58.3%	42.4%
208	ALPENA, MI	38.8%	32.4%	11.2%	69.9%	30.8%
70	GREEN BAY, WI	38.8%	46.9%	22.5%	67.4%	33.1%
137	COLUMBIA, MO	38.6%	37.3%	14.2%	65.0%	36.0%
107	FT. WAYNE, IN	37.8%	49.1%	22.5%	57.0%	43.9%
201	ST. JOSEPH, MO	37.8%	33.6%	12.7%	73.5%	27.7%
171	QUINCY, MO, IA	37.0%	43.8%	15.1%	54.6%	46.9%
87	HARLINGEN, TX	36.9%	70.8%	37.3%	64.8%	36.1%
181	JONESBORO, AR	36.5%	32.7%	10.3%	64.0%	37.2%
91	SOUTH BEND, IN	35.9%	48.1%	23.3%	57.2%	43.5%
...						
1	NEW YORK, NY	10.7%	22.4%	6.1%	85.5%	16.3%
28	SAN DIEGO, CA	10.5%	17.9%	8.7%	89.9%	10.7%
13	SEATTLE, WA	10.5%	17.0%	13.3%	80.9%	19.6%
155	ODESSA, TX	10.2%	18.0%	9.1%	82.0%	19.5%
30	HARTFORD, CT	9.5%	15.3%	5.5%	87.0%	13.7%
98	EL PASO, TX	9.5%	65.5%	31.9%	72.9%	28.3%
195	EUREKA, CA	9.5%	16.7%	14.9%	81.2%	19.7%
210	GLENDIVE, MT	8.6%	13.6%	6.5%	81.5%	19.1%
120	SANTA BARBARA, CA	7.9%	13.7%	8.0%	73.2%	27.8%
71	HONOLULU, HI	4.6%	8.8%	5.5%	95.3%	5.2%
207	JUNEAU, AK	3.3%	5.3%	7.9%	76.3%	25.3%

Participation Rate (ZCTA) shows a simple average of participate rates across zip codes in a designated market area. Participation Rate (NTIA) shows data from a report entitled, “Final Household Participation by DMA, Ratio of Authorized Household Participation to Total Households by Coupon Dashboard Market Area (cDMA),” NTIA (2010). Participation Rate (NTIA) are the sum of all coupons divided by a population of 60 percent of over-the-air households, based on 2008 Nielsen data. My regression analysis uses Participation Rate (ZCTA). This chart excludes Puerto Rico, which had the highest % household participation at 101.29% and 1,258,477 requested coupons. Other Sources: Nielsen (2009). Rank of Designated Market Areas. Nielsen (2007). Over-the-air households. For comparison, the table also shows the over-the-air households in each television market (OTA), the number of Wired Cable Subscriptions (Cable) from the variable *WiredCableSubHH* and Alternative Distribution System Subscriptions (ADS) from the variable *ADSSubHH*. This chart is available with data from over 200 television markets in Appendix C.

Table 3.5: Drivers of Participation in the Coupon Program

	Participation Rate (log)				
Variables (log)	(1)	(2)	(3)	(4)	(5)
Redemption Rate	2.102***	2.168***	2.132***	2.053***	1.876***
	[0.647]	[0.667]	[0.657]	[0.633]	[0.578]
Predicted Broadband Adoption		5.116***	4.057***	4.227***	2.671***
		[1.339]	[1.062]	[1.107]	[0.699]
Implied Broadband Availability		-4.693***	-4.159***	-4.141***	-2.679***
		[-1.216]	[-1.078]	[-1.074]	[-0.695]
Population Density			0.059***	0.093***	0.080***
			[0.207]	[0.323]	[0.278]
Over-the-Air TV Households			0.226***	0.241***	0.232***
			[0.139]	[0.148]	[0.143]
Median Age				0.775***	0.798***
				[0.188]	[0.193]
Dependents per Capita				0.293***	0.256***
				[0.123]	[0.107]
Location Affordability Index				0.158***	-0.683***
				[0.025]	[-0.108]
Income per Capita				-0.456***	-0.436***
				[-0.269]	[-0.257]
State Fixed Effects	No	No	No	No	Yes
Constant	-0.435***	4.130***	4.139***	7.176***	5.056***
	[.]	[.]	[.]	[.]	[.]
Observations	25,473	25,473	25,473	25,466	25,466
R-squared	0.419	0.434	0.466	0.542	0.617

Robust normalized beta coefficients in brackets. *** p<0.01, ** p<0.05, * p<0.1.

Appendix A: Appendix for Chapter 1

Table A.1: Broadband Stimulus Projects.

	Entity and Project Name	Institution	Technology	State
1	Los Angeles Regional Interoperable Communications System Authority The Los Angeles Public Safety Broadband Network: LA-SafetyNet	Local	Wireless	CA
2	Executive Office State Of West Virginia West Virginia Statewide Broadband Infrastructure Project-"Middle Mile"	State	F,W	WV
3	Information Technology, Maryland Department Of One Maryland Broadband Network	State	Fiber	MD
4	Centennial Board Of Cooperative Educational Services Colorado Comm Anchors Broadband Consortium Connecting CO's Middle Mile	State	F,W	CO
5	Keystone Initiative For Network Based Education & Research Pennsylvania Research and Education Network (PennREN)	For-Profit	Fiber	PA
6	University Of Arkansas System Arkansas Healthcare, Higher Ed, Pub Saf, Research Integr Broadband Initiative	Higher Ed	Fiber	AR
7	Information Technology, Dept Of Access Connecticut: Expanding the State's Education & Public Safety Network	State	Fiber	CT
8	Northwest Open Access Network NoaNet BB Infrastructure Project	For-Profit	F,W	WA
9	MCNC North Carolina Rural Broadband Initiative	For-Profit	Fiber	NC
10	California Broadband Cooperative, Inc Digital 395 Middle Mile	For-Profit	Fiber	CA
11	University Corporation For Advanced Internet Development United States Unified Community Anchor Network (U.S. UCAN)	For-Profit	Fiber	MI
12	Central Management Services, Illinois Department Of Illinois Broadband Opportunity Partnership East Central Region	State	F,W	IL
13	State Of Louisiana Board Of Regents Louisiana Broadband Alliance - Infrastructure Project	State	Fiber	LA
14	Horizon Telcom, Inc. Connecting Appalachian Ohio Middle Mile Consortium	Non-Profit	Fiber	OH
15	Finance, Oklahoma Office Of State Oklahoma Community Anchor Network (OCAN)	State	Fiber	OK
16	Merit Network Inc REACH Michigan Middle Mile Collaborative II	For-Profit	Fiber	MI
17	Trillion Communications Corp. South Central Alabama Broadband Commission (SCABC - CCI)	Non-Profit	Fiber	AL
18	Executive Office Of The State Of Mississippi Mississippi Education, Safety and Health Network	State	F,W	MS
19	Northwest Open Access Network State of Washington Broadband Consortium	For-Profit	Fiber	WA
20	Virgin Islands Public Finance Authority viNGN Comprehensive Community Infrastructure Program	State	Fiber	VI
21	Motorola, Inc San Francisco Bay Area Wireless Enhanced Broadband Project (BayWEB)	Non-Profit	Wireless	CA
22	Massachusetts Technology Park The Massachusetts Broadband Institute MassBroadband 123	State	Fiber	MA
23	Cvin, Llc The Central Valley Next Generation Broadband Infrastructure Project	Non-Profit	Fiber	CA
24	Northern Illinois University Inc Illinois Broadband Opportunity Partnership Northwest Region	Higher Ed	F,W	IL
25	Bluebird Media, L.L.C. Northern Missouri Ultra-High Capacity Middle Mile	Non-Profit	Fiber	MO
26	University System Of New Hampshire Network New Hampshire Now	For-Profit	F,W	NH
27	Onecommunity Transforming NE Ohio: From Rust Belt to Tech Powerhouse, An Ohio Middle Mile Consortium Project	For-Profit	Fiber	OH
28	Department Of Information Technology New Mexico Statewide Interop Radio Comm Internet Transp Sys (SIRCITS)	State	Wireless	NM
29	Govnet Llc SACCNet - Arizona Critical Middle Mile	Non-Profit	F,W	AZ
30	Treasury, New Jersey Department Of The State of New Jersey Broadband Network	State	Fiber	NJ
31	Ion Hold Co.,Llc ION Upstate New York Rural Broadband Initiative	Non-Profit	Fiber	NY
32	Vermont Telecommunications Authority Vermont Fiber Link	State	Fiber	VT
33	Navajo Tribal Utility Authority Navajo Nation Middle/Last Mile Proj: Quality Broadband for the Navajo People	Tribe	F,W	AZ
34	Delta Communications, L.L.C. Illinois Broadband Opportunities Partnership - Southern	Non-Profit	Fiber	IL
35	Com Net, Inc. GigEPAC–GigE PLUS Availability Coalition	Non-Profit	Fiber	OH
36	University Of Wisconsin System Building Community Capacity through Broadband	Higher Ed	F,W	WI
37	University Of Hawaii Systems Ke Ala–Ike: Connecting Hawaii's Comm Colleges, Univ, Schools & Libraries	Higher Ed	Fiber	HI
38	North Georgia Network Cooperative Inc North Georgia Network	For-Profit	Fiber	GA
39	Merit Network Inc. REACH Michigan Middle Mile Collaborative	For-Profit	Fiber	MI
40	Opencape Corporation OpenCape Corporation Middle Mile Project	For-Profit	F,W	MA
41	North Florida Broadband Authority Ubiquitous Middle Mile	Local	Wireless	FL
42	MCNC	For-Profit	Fiber	NC

Table A.1: Broadband Stimulus Projects.

	Entity and Project Name	Institution	Technology	State
	Building a Sustainable Middle-Mile Network for Underserved Rural NC			
43	Sho-Me Technologies L.L.C.	For-Profit	Fiber	MO
	MoBroadbandNow 'Sho-Me MO' Middle Mile Project			
44	Bristol Virginia Utilities Board	Local	Fiber	VA
	Southwest Virginia Middle Mile Project			
45	Peoples Telephone Cooperative Inc.	For-Profit	Fiber	TX
	East Texas Medical and Educational Fiber Optic Network			
46	Executive Office Of Commonwealth Of Pennsylvania Office Of Administration	State	Wireless	PA
	Cmwth of PA Broadband Middle Mile Proj: Enhancing Connectivity in N. PA			
47	Florida Rural Broadband Alliance	For-Profit	F,W	FL
	Florida Rural Middle Mile Networks - Northwest and South Central Regions			
48	Critical Hub Networks, Inc.	Non-Profit	F,W	PR
	Puerto Rico Bridge Initiative			
49	Ocean State Higher Ed Economic Development Administrative Network.	For-Profit	Fiber	RI
	Beacon 2.0			
50	Biddeford Internet Corp. (D.B.A. Gwi)	Non-Profit	Fiber	ME
	Three Ring Binder			
51	Troy Cablevision, Inc.	Non-Profit	Fiber	AL
	Southeast AL SmartBand Rural Broadband for Econ Dev & Energy Mgmt			
52	Board Of Trustees Of The University Of Illinois	Higher Ed	Fiber	IL
	Urbana-Champaign Big Broadband Below Ground UC2B Middle Mile, Last Mile			
53	State Of Wisconsin Department Of Administration	State	Fiber	WI
	Wisconsin's Education and Library Broadband Infrastructure Build-out			
54	Zayo Bandwidth, Llc	Non-Profit	Fiber	IN
	Indiana Middle Mile fiber for Schools, Communities & Anchor Institutions			
55	Appalachian Valley Fiber Network	Non-Profit	Fiber	AL
	Appalachian Valley Fiber Network ("AVFN")			
56	Contact Network, Inc.	Non-Profit	Fiber	MS
	South Central Mississippi Broadband Infrastructure Project			
57	South Dakota Network, Llc	Non-Profit	Fiber	SD
	Project Connect South Dakota Delivering 10 MB for Community Anchor Inst			
58	District Of Columbia Government	State	F,W	DC
	"DC-CAN" - DC Community Access Network			
59	Nevada Hospital Association	For-Profit	Fiber	NV
	Nevada Broadband Telemedicine Initiative			
60	Iowa Health System	For-Profit	Fiber	IA
	Iowa Healthcare Plus Broadband Extension Project			
61	Utopia	State	Fiber	UT
	Utah Telecomm Open Infrastructure Agency Community Partnership Project			
62	Enventis Telecom, Inc.	Non-Profit	Fiber	MN
	Greater Minnesota Broadband Collaborative			
63	Iowa Communications Network	State	Fiber	IA
	Bridging the Digital Divide for Iowa's Communities			
64	E.N.M.R. Telephone Cooperative	For-Profit	Fiber	NM
	Extending the Middle Mile: ENMR-Plateau Middle Mile CCI Project			
65	Valley Telephone Cooperative Inc.	Non-Profit	Fiber	TX
	Rio Grande Valley Fiber Network			
66	Charlotte, City Of	Local	Wireless	NC
	CharMeck Connect			
67	Mid-Atlantic Broadband Cooperative	For-Profit	Fiber	VA
	Middle Mile Expansion for Southern Virginia			
68	Ronan Telephone Co	Non-Profit	F,W	MT
	Montana West			
69	Education Networks Of America, Inc.	Non-Profit	Fiber	IN
	Broadband Access & Equity for Indiana Community Anchor Institutions			
70	Zayo Bandwidth, Llc	Non-Profit	Fiber	MN
	Connect Anoka County Community Broadband Network			
71	Columbia County Georgia It	Local	F,W	GA
	Columbia County Community Broadband Network (CCCBN)			
72	University Of Utah	Higher Ed	Fiber	UT
	Utah Anchors: A Community Broadband Project			
73	Region 18 Education Svc Ctr	State	F,W	TX
	Connect Southwest Texas			
74	Plumas Sierra Rural Electric Cooperative	Non-Profit	Fiber	CA
	Plumas-Sierra Telecommunications (PST) Mild Mile Fiber Project			
75	Adams County Communications Center, Inc.	For-Profit	F,W	CO
	ADCOM 911/DIA Regional Broadband Public Safety Network			
76	Enmr Telephone Cooperative, Inc. Dba Enmr-Plateau	For-Profit	Fiber	NM
	ENMR-Plateau Middle Mile			
77	Nebraskalink, Llc Connecting Nebraska Communities	Non-Profit	Fiber	NE
	A High-Speed Broadband Network for All of Nebraska			
78	Iniciativa Tecnológica Centro Oriental, Inc. (Inteco, Inc.)	For-Profit	F,W	PR
	Construction of Broadband Infrastructure Central East Region of Puerto Rico			
79	Dcn, Llc	Non-Profit	Fiber	ND
	DCN's CCI Broadband Project			
80	Dekalb County Government	Local	Fiber	IL
	DeKalb Advancement of Technology Authority Broadband			
81	Contact Network, Inc.	Non-Profit	Fiber	MS
	Mississippi Delta Broadband Infrastructure Project			
82	Oconee, County Of	Local	Fiber	SC
	Oconee FOCUS (Fiber Optics Creating Unified Solutions)			
83	North Central New Mexico Economic Development District	State	Fiber	NM
	REDI Net			
84	Vermont Telephone Company, Inc	Non-Profit	Fiber	VT

Table A.1: Broadband Stimulus Projects.

	Entity and Project Name	Institution	Technology	State
	Vermont Broadband Enhanced Learning Link (VT BELL)			
85	Mid-Atlantic Broadband Cooperative	For-Profit	Fiber	VA
	Middle Mile Expansion for Eastern Virginia			
86	Nexus Systems, Inc.	Non-Profit	Fiber	LA
	Louisiana 'Piney Hills' Parishes Broadband Infrastructure Project			
87	Deltacom, Inc.	Non-Profit	Fiber	TN
	East Tennessee Middle Mile Fiber Broadband Project			
88	Citizens' Telephone Co-Operative	For-Profit	Fiber	VA
	NRV-ROAN (New River Valley Regional Open Access Network)			
89	Clackamas, County Of	Local	Fiber	OR
	Clackamas Broadband Innovation Initiative			
90	Lane Council Of Governments	Local	Fiber	OR
	Oregon South Central Regional Fiber Consortium Lighting the Fiber			
91	It&E	Non-Profit	Wireless	GU
	Next Generation Network - Middle Mile Infrastructure Plan			
92	Rockbridge, County Of	Local	Fiber	VA
	Connecting the Dots: Rockbridge Broadband Initiative			
93	Texas A & M University	Higher Ed	Fiber	TX
	Texas Pipes			
94	Pyramid Lake Paiute Tribe	Tribe	Fiber	NV
	Pyramid Lake Paiute: Natukwena Nagwesenoo			
95	Board Of Regents Of University Of Wisconsin System	Higher Ed	Fiber	WI
	Metropolitan Unified Fiber Network (MUFN)			
96	Jkm Consulting, Inc.	Non-Profit	Fiber	AL
	Project BEAR (Broadband for East Alabama Region)			
97	Zito Media Communications Ii, Llc	Non-Profit	Fiber	PA
	Northeastern Ohio and Northwestern Pennsylvania Fiber Ring Project			
98	Carver, County Of	Local	Fiber	MN
	Carver County Open Fiber Initiative (CCOFI)			
99	Silver Star Telephone Company, Inc.	Non-Profit	Fiber	WY
	Expanding Greater Yellowstone Area Broadband Opportunities			
100	Bloomingdale Communications Inc	Non-Profit	Fiber	MI
	Van Buren County Fiber Ring			
101	Virginia Tech Foundation, Inc.	For-Profit	Fiber	VA
	Allegheny Fiber: Extending VA's Open Access Fiber Backbone to Ridge & Valley			
102	Onwav Inc.	Non-Profit	Wireless	TN
	Five County Broadband Interconnected Training Access			
103	Silver Star Telephone Company, Inc.	Non-Profit	Fiber	WY
	Delivering Opportunities: Investing in Rural Wyoming Broadband			
104	Bend Cable Communications, Llc	Non-Profit	Fiber	OR
	Central Oregon Fiber Alliance			
105	Level 3 Eon, Llc	Non-Profit	Fiber	TX
	Expanding broadband access across Texas			
106	Hardy Telecommunications, Inc.	For-Profit	Fiber	WV
	Hardy AnchorRing			
107	Level 3 Eon, Llc	Non-Profit	Fiber	CA
	Expanding broadband access across California			
108	First Step Internet, Llc	Non-Profit	F,W	ID
	Central North Idaho Regional Broadband Network Expansion			
109	Level 3 Eon, Llc	Non-Profit	Fiber	FL
	Expanding broadband access across Florida			
110	Nelson County Virginia	Local	F,W	VA
	Nelson County Virginia Broadband Project			
111	Nez Perce Tribe	Tribe	Wireless	ID
	Nez Perce Reservation Broadband Enhancement			
112	Page County Broadband Authority	Local	Fiber	VA
	Page BBA Broadband Project			
113	Ute Indian Tribe	Tribe	F,W	UT
	Uintah and Ouray Reservation Fiber Optic Infrastructure Project			
114	Level 3 Eon, Llc	Non-Profit	Fiber	GA
	Expanding broadband access across Georgia			
115	Level 3 Eon, Llc	Non-Profit	Fiber	TN
	Expanding broadband access across Tennessee			
116	Level 3 Eon, Llc	Non-Profit	Fiber	KS
	Expanding broadband access across Kansas			

Table A.2: Results from Broadband Stimulus Projects.

	Term. Early	Total Budget	ARRA Awarded	ARRA Invoiced	Fiber Miles	Directly Connected Institutions	Indirectly Connected Institutions
Los Angeles Public Safety	0	217,894,365	154,640,000	154,640,000	0	0	454
State of West Virginia	0	159,823,296	126,323,296	102,087,005	675	1127	2206
State of Maryland	0	158,416,520	115,240,581	115,240,581	1324	1068	1068
Colorado Centennial	0	135,300,777	100,635,190	95,098,536	724	126	3763
Keystone PennREN	0	128,958,031	99,660,678	99,660,678	1612	59	2320
University of Arkansas	0	128,581,820	102,131,393	102,131,393	49	458	458
State of Connecticut	0	117,318,786	30,031,849	28,140,589	1053	940	2172
NoaNet WA	0	106,546,591	84,347,997	83,294,206	780	152	278
MCNC North Carolina	0	106,091,969	75,757,289	74,820,476	1301	175	175
California Digital 395	0	101,435,997	81,148,788	81,148,788	612	251	251
UCAN Michigan	0	96,793,607	62,540,162	62,540,162	0	0	0
State of Illinois	0	96,382,028	61,895,282	61,124,979	1512	3711	3711
Louisiana Board of Regents	1	95,016,532	80,596,415	736,611	0	0	1249
Ohio Horizon	0	94,963,210	66,474,247	66,474,247	1318	467	3424
State of Oklahoma	0	92,907,816	73,998,268	70,391,553	827	31	1185
Merit REACH MI 2	0	87,049,114	69,639,291	66,546,435	1252	206	206
Trillion Alabama	0	86,256,980	10,572,567	10,572,567	29	0	418
State of Mississippi	1	83,987,788	70,055,000	32,112,483	0	0	226
State of Washington	0	75,307,089	54,452,347	42,211,243	471	151	282
Virgin Islands Public Auth.	0	73,610,586	58,888,469	40,863,456	276	316	316
Motorola SF	1	72,483,637	50,593,551	3,596,862	0	0	150
Mass Tech Park	0	71,645,444	45,445,444	45,445,444	1180	1233	1233
Central Valley CA	0	66,599,667	46,619,757	46,619,757	724	50	6293
No. Illinois University	0	66,173,301	46,114,026	46,114,026	639	487	487
Bluebird Northern Missouri	0	64,803,350	45,145,250	45,145,250	833	102	176
University System of NH	0	62,750,571	44,480,992	43,389,184	879	325	1775
NE Ohio OneCommunity	0	60,532,495	44,794,046	36,888,075	993	950	1885
State of New Mexico	0	55,700,000	38,699,997	28,806,126	0	23	23
Arizona GovNet	0	51,561,929	39,274,877	19,726,923	0	123	383
State of New Jersey	1	49,547,690	39,638,152	1,102,555	0	0	60
Rural NY ION	0	48,673,735	38,938,988	38,938,988	944	128	128
VT Telecom Authority	0	48,177,760	33,393,402	28,646,378	1000	316	316
Navajo AZ	0	45,902,602	32,190,067	32,015,304	570	50	828
S. Illinois Delta Comm	0	45,395,020	31,515,253	31,515,253	749	230	300
Ohio Com Net	0	42,904,268	13,483,004	13,483,004	634	132	2868
University of Wisconsin	0	42,726,744	29,884,914	29,884,914	591	172	172
University of Hawaii	0	42,466,000	33,972,800	32,848,287	409	384	384
North Georgia Network	0	41,863,171	33,490,537	33,490,537	500	94	94
Merit REACH MI	0	41,611,526	33,289,221	33,289,221	1044	146	433
OpenCape Mass	0	40,161,393	32,072,093	32,072,093	306	91	670
N. Florida Authority	0	39,369,676	30,142,676	30,142,676	0	100	1476
MCNC Rural NC	0	38,512,091	28,225,518	28,225,518	444	1866	1866
Sho-Me Missouri	0	38,000,000	26,600,000	26,600,000	540	101	101
Southwest VA Bristol	0	36,220,536	22,698,010	22,698,010	370	0	125
East Texas Peoples	0	36,031,695	28,825,356	28,825,356	601	209	209
State of Pennsylvania	0	35,980,017	28,784,014	28,784,011	0	47	98
Florida Rural	0	34,149,665	23,693,665	21,890,835	0	3	804
Puerto Rico Critical Hub	0	33,125,409	25,682,370	25,682,370	0	1	2074
Rhode Island Beacon	0	32,476,991	21,739,183	21,739,183	0	110	953
Biddleford Maine	0	30,758,722	24,606,978	24,598,663	1149	100	100
Troy Cable Alabama	0	30,688,821	26,068,284	24,516,074	529	198	198
University of Illinois	0	29,280,837	22,534,776	21,385,087	224	256	294
State of Wisconsin	1	28,722,959	22,978,367	36,610	0	0	0
Indiana Zayo	0	28,274,326	19,099,460	17,840,980	645	21	9
Appalachian Valley AL	0	26,730,258	21,286,914	21,072,529	254	145	166
Mississippi South Contact	0	25,906,278	93,855,029	93,727,981	687	195	919
South Dakota Network	0	25,715,303	20,572,242	20,572,242	397	512	512
Wash. DC-CAN	0	25,033,000	17,457,764	17,457,764	211	291	291
Nevada Hospital	0	24,971,267	19,643,717	10,242,135	389	3	315
Iowa Health System	0	24,102,285	14,746,630	13,298,131	112	181	1681
Utopia Utah	0	24,071,690	16,229,321	15,847,428	142	158	470
Minnesota Enventis	0	24,032,053	16,822,437	14,766,945	405	34	34
Iowa Communications	0	23,867,544	16,230,118	15,462,714	26	2818	2818
New Mexico ENMR	0	23,515,451	16,460,815	16,460,815	282	369	369
Rio Grande TX	0	22,425,509	15,697,856	15,697,856	200	24	165
Charlotte Charmeck NC	1	21,092,443	16,702,490	4,176,421	0	60	60
S. Virginia Coop	0	20,055,363	16,044,290	15,051,341	428	118	118
Montana Ronan	0	19,738,925	13,796,640	12,342,400	299	33	33
Indiana ENA	1	18,351,465	14,257,172	-	0	0	0
Zayo Colorado	0	18,278,375	12,794,862	11,178,382	215	131	131
Columbia County GA	0	18,002,131	499,386	499,386	205	99	150
University of Utah	0	17,495,691	13,401,096	12,558,622	58	142	298
Southwest TX Region 18	0	17,279,343	11,946,728	11,377,051	244	63	63
Plumas Sierra CA	0	17,212,800	13,770,240	13,770,240	189	17	17
Adams County CO	0	16,678,760	12,137,422	8,383,103	9	20	22
ENMR New Mexico	0	16,564,907	11,252,066	11,226,454	1887	269	269
Nebraska Link	0	16,496,952	11,547,866	11,547,866	461	101	101
Puerto Rico INTECO	0	16,343,675	12,931,174	12,931,174	0	84	330
North Dakota DCN	0	15,401,653	10,781,157	10,781,157	210	124	124
DeKalb County IL	0	14,830,204	11,864,164	11,529,172	132	78	97
MS Delta Contact	0	14,480,584	20,725,022	20,725,022	323	132	534

Table A.2: Results from Broadband Stimulus Projects.

	Term. Early	Total Budget	ARRA Awarded	ARRA Invoiced	Fiber Miles	Directly Connected Institutions	Indirectly Connected Institutions
Oconee County SC	0	14,306,764	7,804,181	7,527,006	252	102	102
New Mexico REDI	0	13,391,443	10,565,792	10,565,792	108	110	110
Vermont Bell	0	12,861,126	9,002,788	6,868,907	256	124	125
Eastern VA	0	12,529,059	10,023,247	8,744,759	174	19	19
Nexus Louisiana	0	12,343,984	9,163,384	9,163,384	120	108	108
DeltaCom East TN	0	11,731,815	8,322,868	8,322,868	44	2	271
New River Valley VA	0	11,560,803	9,237,760	8,874,782	186	57	57
Clackamas County OR	0	11,292,386	5,995,600	5,995,600	180	163	249
Lane Council OR	0	10,439,035	8,325,530	8,322,577	104	139	217
Guam Next Gen	0	10,062,992	8,039,792	8,039,792	0	420	420
County of Rockbridge VA	0	9,995,752	9,604,840	9,604,840	70	52	53
Texas A & M University	0	9,543,061	6,550,775	6,550,775	151	44	123
Pyramid Lake Tribe NV	0	9,502,006	7,070,006	5,376,783	44	25	25
University of Wisconsin	0	8,859,615	5,106,373	5,106,373	74	92	206
East Alabama JKM	0	8,199,737	6,269,197	6,269,197	110	49	76
Zito OH and PA	0	7,671,130	6,136,904	6,136,904	363	66	146
Carver County MN	0	7,494,500	11,584,467	11,584,467	122	75	700
Silver Star Yellowstone WY	0	7,234,820	5,608,179	5,608,179	82	41	41
Bloomingdale MI	0	7,058,092	5,646,473	5,351,851	137	33	33
Virginia Tech	0	6,925,000	5,540,000	5,482,285	106	2	2
Five County TN	0	6,501,995	5,184,447	4,819,335	8	154	154
Silver Star WY	0	6,346,571	5,063,623	5,063,623	42	50	50
Oregon Bend Cable	0	6,312,522	4,418,765	4,418,765	178	15	15
Level 3 TX	1	6,237,051	4,677,788	2,260,609	0	0	0
Hardy WV	0	4,694,497	3,201,760	3,201,760	107	63	63
Level 3 CA	1	4,389,325	3,291,994	1,096,611	0	0	0
North Idaho First Step	0	2,992,029	2,393,623	1,958,452	0	44	635
Level 3 FL	1	2,755,000	2,066,250	835,356	0	0	0
Nelson County VA	0	2,283,308	1,826,646	1,826,646	31	13	23
Nez Perce Tribe ID	0	2,282,589	1,569,109	1,152,117	0	18	31
Page County VA	0	2,061,176	1,648,941	1,367,021	7	24	53
UTE Indian Tribe Utah	0	2,051,021	1,418,266	1,418,266	9	43	42
Level 3 GA	1	1,903,080	1,427,310	553,449	0	0	0
Level 3 TN	1	1,727,650	1,295,737	585,126	0	0	0
Level 3 Kansas	1	1,331,225	998,419	464,949	0	0	0
Total (116 Projects)	13	4,581,461,018	3,353,279,589	2,939,023,079	41,142	25,634	65,363

Table A.3: Cost Escalation ΔC (%) by Project.

	$\Delta C_{Inst.}$	ΔC_{FM}	Prop. Insts.	Actual Insts.	Cost per Inst.	Prop. Fiber Miles	Fiber Miles	Cost per Fiber Mile	Term. Early
Florida Rural	6433%		196	3	11,383,222	0	0		0
Nevada Hospital	1133%		37	3	8,323,756		389	64,193	0
Colorado Centennial	778%	540%	1106	126	1,073,816	4637	724	186,880	0
Ohio Com Net	573%	9%	888	132	325,032	688	634	67,672	0
State of New Mexico	557%		151	23	2,421,739	0	0		0
Rio Grande TX	479%	-17%	139	24	934,396	166.3	200	112,128	0
Charlotte Charmeck NC	477%		346	60	351,541		0		1
Oregon Bend Cable	253%		53	15	420,835		178	35,464	0
Utopia Utah	150%	77%	395	158	152,352	250.74	142	169,519	0
Minnesota Enventis	118%	3%	74	34	706,825	418	405	59,338	0
Arizona GovNet	116%		266	123	419,203		0		0
University of Wisconsin	92%	-1%	331	172	248,411	582.99	591	72,296	0
State of Washington	87%	5%	283	151	498,722	496	471	159,888	0
Oconee County SC	54%	-3%	157	102	140,262	245	252	56,773	0
Eastern VA	32%	-2%	25	19	659,424	170	174	72,006	0
Bloomingdale MI	27%	0%	42	33	213,882	137.5	137	51,519	0
Page County VA	21%	460%	29	24	85,882	39.2	7	294,454	0
Zayo Colorado	15%	33%	151	131	139,530	286	215	85,016	0
Carver County MN	15%	-1%	86	75	99,927	120.6	122	61,430	0
S. Illinois Delta Comm	14%	-1%	262	230	197,370	740.4	749	60,608	0
Mass Tech Park	13%	-14%	1392	1233	58,107	1012.4	1180	60,716	0
New Mexico REDI	12%	37%	123	110	121,740	148	108	123,995	0
VT Telecom Auth.	8%		342	316	152,461		1000	48,178	0
Central Valley CA	8%	-1%	54	50	1,331,993	720	724	91,988	0
State of Oklahoma	3%	22%	32	31	2,997,026	1005	827	112,343	0
County of Rockbridge VA	2%	91%	53	52	192,226	134	70	142,796	0
University of Hawaii	1%	-43%	388	384	110,589	235	409	103,829	0
Wash. DC-CAN	0%		291	291	86,024	0	211	118,640	0
Nebraska Link	0%	-2%	101	101	163,336	452.75	461	35,785	0
MS Delta Contact	0%	15%	132	132	109,701	373	323	44,832	0
Nez Perce Tribe ID	0%		18	18	126,811	56	0		0
Sho-Me Missouri	-1%	-7%	100	101	376,238	500	540	70,370	0
Five County TN	-2%	104%	151	154	42,221	16.3	8	812,749	0
Clackamas County OR	-3%	0%	158	163	69,278	180	180	62,735	0
New River Valley VA	-5%	0%	54	57	202,821	185.5	186	62,155	0
East Alabama JKM	-6%	-56%	46	49	167,342	48	110	74,543	0
State of Illinois	-15%	-32%	3138	3711	25,972	1026	1512	63,745	0
NE Ohio OneCommunity	-16%	-9%	796	950	63,718	900	993	60,959	0
UTE Indian Tribe Utah	-21%	-44%	34	43	47,698	5	9	227,891	0
New Mexico ENMR	-22%	-33%	287	369	63,728	189	282	83,388	0
Troy Cable Alabama	-26%	13%	147	198	154,994	595.2	529	58,013	0
Southwest TX Region 18	-27%	-20%	46	63	274,275	194	244	70,817	0
University System of NH	-29%	-51%	232	325	193,079	434	879	71,389	0
State of Connecticut	-29%	426%	667	940	124,807	5544	1053	111,414	0
Adams County CO	-35%	156%	13	20	833,938	23	9	1,853,196	0
MCNC North Carolina	-36%	11%	112	175	606,240	1448	1301	81,546	0
Montana Ronan	-48%	-14%	17	33	598,149	257.35	299	66,016	0
Texas A&M University	-52%	-3%	21	44	216,888	147	151	63,199	0
Silver Star Yellowstone WY	-61%	9%	16	41	176,459	89.39	82	88,230	0
Rhode Island Beacon	-66%		37	110	295,245	372	0		0
Silver Star Rural WY	-76%	-10%	12	50	126,931	37.74	42	151,109	0
Iowa Communications	-83%	-53%	476	2818	8,470	12.1	26	917,982	0
University of Illinois	-89%		28	256	114,378		224	130,718	0
MCNC Rural NC				1866	20,639		444	86,739	0
State of West Virginia				1127	141,813		675	236,775	0
State of Maryland				1068	148,330		1324	119,650	0
South Dakota Network				512	50,225		397	64,774	0
N. Illinois University				487	135,879		639	103,558	0
Ohio Horizon				467	203,347		1318	72,051	0
University of Arkansas				458	280,746		49	2,624,119	0
Guam Next Gen				420	23,960		0		0
Virgin Islands Public Auth.				316	232,945		276	266,705	0
ENMR New Mexico				269	61,580		1887	8,778	0
California Digital 395				251	404,127		612	165,745	0
East Texas Peoples Telco		10%		209	172,400	659	601	59,953	0
Merit REACH MI 1		-3%		206	422,569	1210	1252	69,528	0
Mississippi South Contact		222%		195	132,853	2210	687	37,709	0
Iowa Health System				181	133,162		112	215,199	0
NoaNet WA				152	700,964		780	136,598	0
Merit REACH MI				146	285,010		1044	39,858	0
Appalachian Valley AL		-28%	0	145	184,347	182	254	105,237	0
University of Utah				142	123,209		58	301,650	0
Lane Council OR				139	75,101		104	100,375	0
Rural NY ION				128	380,264		944	51,561	0
North Dakota DCN		-19%		124	124,207	169.5	210	73,341	0
Vermont Bell				124	103,719		256	50,239	0
Southern Virginia Coop				118	169,961		428	46,858	0
Nexus Louisiana				108	114,296		120	102,867	0
Bluebird Northern Missouri		18%		102	635,327	981	833	77,795	0
N. Florida Authority				100	393,697		0		0
Biddleford Maine				100	307,587		1149	26,770	0

Table A.3: Cost Escalation ΔC (%) by Project.

	$\Delta C_{Inst.}$	ΔC_{FM}	Prop. Insts.	Actual Insts.	Cost per Inst.	Prop. Fiber Miles	Fiber Miles	Cost per Fiber Mile	Term. Early
Columbia County GA				99	181,840		205	87,815	0
North Georgia Network				94	445,353		500	83,726	0
University of Wisconsin				92	96,300		74	119,725	0
OpenCape Mass				91	441,334		306	131,246	0
Puerto Rico INTECO				84	194,568		0		0
DeKalb County IL				78	190,131		132	112,350	0
Zito OH and PA				66	116,229		363	21,133	0
Hardy WV				63	74,516		107	43,874	0
Keystone PennREN				59	2,185,729		1612	79,999	0
Navajo AZ				50	918,052		570	80,531	0
State of Pennsylvania				47	765,532		0		0
North Idaho First Step				44	68,001		0		0
Pyramid Lake Tribe NV				25	380,080		44	215,955	0
Indiana Zayo				21	1,346,397		645	43,836	0
Plumas Sierra CA				17	1,012,518		189	91,073	0
Nelson County VA				13	175,639		31	73,655	0
DeltaCom East TN				2	5,865,908		44	266,632	0
Virginia Tech				2	3,462,500		106	65,330	0
Puerto Rico Critical Hub				1	33,125,408		0		0
State of Wisconsin			467	0		203	0		1
State of Mississippi			217	0		0	0		1
Los Angeles Public Safety			204	0		1769	0		0
State of New Jersey			149	0		739	0		1
Southwest VA Bristol		5%	0	0		388	370	97,893	0
Trillion Alabama				0			29	2,974,379	0
Louisiana Board of Regents				0		910	0		1
UCAN Michigan				0			0		0
Motorola SF				0			0		1
Indiana ENA				0			0		1
Level 3 TX				0			0		1
Level 3 CA				0			0		1
Level 3 FL				0			0		1
Level 3 GA				0			0		1
Level 3 TN				0			0		1
Level 3 Kansas				0			0		1

I use backwards induction to measure cost underestimation or overestimation in proposals. I define cost escalation by the difference in proposed unit costs and actual unit costs, divided by proposed unit costs. I generalize a unit cost by dividing the total budget by institutions or fiber miles. I include the cost escalation formula here. For example, the University of Hawaii System proposed to deliver 388 institutions at a cost of 109,448 dollars each, and connected 384 institutions at a cost of 110,589 dollars each. Cost escalation by cost per institution is 1 percent.

$$\Delta C_{Inst.} = \frac{Costper_{Inst.} - Costper_{ProposedInst.}}{Costper_{ProposedInss.}}$$

$$\Delta C_{FM} = \frac{Costper_{FiberMile} - Costper_{ProposedFiberMile}}{Costper_{ProposedFiberMile}}$$

$$Costper_{Inst.} = \frac{TotalBudget}{Insts.}$$

$$Costper_{ProposedInst.} = \frac{TotalBudget}{ProposedInsts.}$$

$$Costper_{FiberMile} = \frac{TotalBudget}{FiberMiles}$$

$$Costper_{ProposedFiberMile} = \frac{TotalBudget}{ProposedFiberMiles}$$

Table A.4: Descriptive Statistics.

Variables	N	Mean	Std Dev	Min	Max
Cost Escalation Dataset					
Proposed Directly Connected Institutions	59	264	468	-	3,138
Directly Connected Institutions	116	221	494	-	3,711
Proposed Indirectly Connected Institutions	57	1,368	2,223	-	8,999
Indirectly Connected Institutions	116	563	967	-	6,293
Terminated Early (1)	116	0.11	0.32	-	1.00
Total Budget	116	39,495,354	39,833,429	1,331,225	217,894,365
Over 10 Institutions Connected (1)	116	0.82	0.39	-	1.00
Per Project Direct Institution Cost	100	962,373	3,602,215	8,470	33,125,408
Per Project Indirect Institution Cost	107	262,532	512,733	4,712	3,462,500
Proposed Fiber Miles	59	589	969	-	5,544
Proposed Backbone Miles	58	471	855	-	4,925
Proposed Lateral Miles	57	195	663	-	4,925
Fiber Miles	116	355	419	-	1,887
Proposed Cost Per Mile	48	63,559	60,911	283	400,873
Middle Mile Average Cost	100	52,929	33,099	3,597	197,274
Middle Mile Average Speed (mbps)	107	16,212	29,901	-	102,400
Middle Mile Max Speed (mbps)	97	1,431	2,692	-	10,240
Total Strands	116	43,136	54,398	-	245,044
Build Actual Strands	116	1,766	10,694	-	107,210
Build Leased Strands	116	153	1,545	-	16,632
Build Dark Strands	116	2,335	10,384	-	81,413
Sq Feet Total NOC	116	1,501	2,618	-	15,000
Proposed Points of Interconnection	54	118	304	1	2,100
Points of Interconnection	116	128	327	-	2,035
Signed Agreements Number	115	7.43	11.51	-	60.00
Providers with New Access	116	3.41	7.11	-	60.00
Providers with Improved Access	116	2.83	7.08	-	37.00
Org Code (1 to 5)	116	3.16	1.32	1.00	6.00
Tech Code (1 to 3)	116	1.34	0.62	1.00	3.00
Firm Age	55	18.33	16.97	-	60.00
Sq Mile Area of Network	68	11,835	22,841	3	121,356
NTIA Amendments	116	3.91	2.56	-	12.00
NTIA Corrective Action	116	0.11	0.32	-	1.00
ASR Analytic Cases	116	0.10	0.31	-	1.00
NTIA Btop In Focus	116	0.29	0.46	-	1.00
NTIA Last Mile Waiver	116	-	-	-	-
NTIA FirstNet Suspension	116	0.04	0.20	-	1.00
ARRA Vendor Sum	115	492	959	-	5,085
ARRA Vendor Count Above 25k	115	42	71	-	483
ARRA Payments Above 25k	115	17,150,842	24,240,574	-	113,421,493
ARRA Vendor Count Under 25k	115	451	937	-	4,984
ARRA Payments Under 25k	115	1,307,135	2,488,375	-	12,758,839
ARRA Award	116	28,907,583	29,834,784	499,386	154,640,000
ARRA Invoiced	116	25,336,406	28,630,518	-	154,640,000
Total Budget	116	42,659,146	45,015,746	1,331,802	245,107,017
Ratio Grant to Budget	116	0.74	0.09	0.37	1.00
Id	116	63	35	1	123
Fund Round (1 or 2)	116	1.65	0.48	1.00	2.00
Number of Applications by Grantee	116	2.22	2.54	1.00	25.00
Price (per mbps per month)	59	68	323	0	2,500
Number of Congressional Districts	115	4.82	5.77	1.00	50.00
EasyGrant Id	116	4,239	2,530	28	7,835
Yearly Revenue of Grantee	68	897,317,383	3,620,000,000	-	22,000,000,000
Employees of Grantee	62	1,235	4,380	-	27,000
Match Percentage	115	0.27	0.09	0.13	0.88
Proposed Schools	87	1,747	14,183	-	132,436
Indirect to Schools	116	188	425	-	2,837
Proposed Libraries	84	251	1,952	-	17,914
Indirect to Libraries	116	31	56	-	306
Proposed Colleges and Univ.	82	38	138	-	1,152
Indirect to Colleges and Univ.	116	20	38	-	313
Proposed Healthcare Offices	84	1,084	6,823	-	58,454
Indirect to Healthcare Offices	116	79	213	-	1,535
Proposed Public Safety	83	180	697	-	6,183
Indirect to Public Safety	116	81	156	-	875
Proposed Other Gov	78	130	335	-	2,388
Indirect to Other Gov	116	103	308	-	2,852
Proposed Non Gov	54	58	131	-	612
Indirect to Non Gov	116	46	121	-	702
Proposed Public Housing	25	100	249	-	1,151
Indirect to Public Housing	116	15	73	-	500
Proposed Project Revenues	43	6,022,009	8,653,596	-	41,794,929
Proposed Net Incomes	42	190,006	2,840,765	-9,859,589	6,543,167
Cost per Directly Connected Institution	100	962,373	3,602,215	8,470	33,125,408
Proposed Cost per Directly Connected Institution	57	350,102	477,328	30,714	2,903,369
Cost per Indirectly Connected Institution	107	262,532	512,733	4,712	3,462,500
Proposed Cost per Indirectly Connected Institution	56	143,381	222,060	3,816	1,282,982
Cost Escalation by Directly Connected Institution	53	2.02	9.03	-0.89	64.33
Cost Escalation by Indirectly Connected Institution	55	4.87	16.16	-0.88	88.07
Cost Escalation (%) by Directly Connected Institution	53	202	903	-89	6,433
Cost Escalation (%) by Indirectly Connected Institution	55	487	1,616	-88	8,807
Cost per Fiber Mile	90	194,534	454,674	8,778	2,974,379

Table A.4: Descriptive Statistics.

Variables	N	Mean	Std Dev	Min	Max
Proposed Cost per Fiber Mile	55	140,7918	274,911	11,722	1,972,524
Cost Escalation by Fiber Mile	49	0.37	1.24	-0.56	5.40
Cost Escalation (%) by Fiber Mile	49	37	124	-56	540
Applicant Pool Dataset					
EasyGrant Id	773	4,276	2,485	21.00	10,074
Budget	773	33,262,393	55,694,139	-	581,031,251
Tech Code (1 to 4)	773	1.82	1.00	1.00	4.00
Org Code (1 to 5)	773	3.17	1.15	1.00	6.00
Awarded	773	0.16	0.36	-	1.00
Fund Round (1 or 2)	773	1.51	0.50	1.00	2.00
Number of Applications by Grantee	773	4.20	7.27	1.00	33.00
Ratio Grant to Budget	773	0.76	0.18	-	1.00
Project Type (1 or 2)	773	0.37	0.62	-	2.00
Firm Years	212	18.08	26.87	-	280.00
Sq Mile Area of Network	195	15,849	69,649	0.09	700,000
Proposed Households	431	330,085	827,535	-	8,666,346
Proposed Businesses	390	42,616	136,281	-	1,589,252
Proposed Directly Connected Institutions	404	1,340	5,522	2.00	66,000
Proposed Fiber Miles	232	602	1,281	1.27	12,960
Proposed Backhaul Speed (mbps)	336	77,878	734,775	3.10	10,000,000
Proposed Last Mile Speed (mbps)	247	614	6,390	0.01	100,000
Proposed Indirectly Connected Institutions	326	1,170	12,298	1.00	216,139
Proposed Schools	236	811	8,660	-	132,436
Proposed Libraries	192	130	1,292	-	17,914
Proposed Colleges and Universities	190	25	93	-	1,152
Proposed Healthcare Offices	210	544	4,358	-	58,454
Proposed Public Safety	231	137	499	-	6,183
Proposed Other Gov	179	125	302	-	2,388
Proposed Non Gov	135	45	97	-	612
Proposed Public Housing	71	1,057	6,161	-	50,000
Subscribers Households	240	489,585	4,811,025	-	66,000,000
Subscribers Businesses	110	3,221	10,676	-	99,000
Subscribers Institutions	174	1,096	7,799	4.00	100,000

Table A.5: Average Prices per Mbps.

Price for Service per Month	Per Mbps
10 G Service	
5000 per month for 10 G, 1500 for 1 G	$0.05
11000 per month for 10 G	$1.10
14300 for 10 G	$1.43
15000 per month for 10 Gig	$1.50
16000 per month for 10 G	$1.60
44.95 for 10 mbps, 30000 for 10000 mpbs	$4.50
20435 per month for 1 to 10 Gig backhaul	$20.44
25435 per month for 1 to 10 G backhaul	$25.44
25000 for 10000 mbps, 2500 for 1000 mbps	$30.00
1 G Service	
500 per month for 20 mbps, 210 for 1000 mbps	$0.21
15000 + 1000 per month per pair, $250 for 1 G	$0.25
650 per month for 1 G to schools	$0.65
1300 per month per Ethernet circuit	$1.30
1500 per month for VLAN 1 G	$1.50
2000 per month for 1000 mbps	
157.16 per pair per month, 121.68 per strand per month	
1000 per month per strand.	$2.00
2100 per Gbps per month for 1 G	
74160 per year for cai, 360 per month subs.	$2.10
Less than 4000 per month per school	$4.00
60 for 5 mbps, 4500 for 1 G, $325 equipment	$4.50
4995 per month for 1 G	$5.00
Federal GSA pricing, 400 per month for 2 mbps	
DCFreeWifi, Layer 1: Dark fiber: 175 per strand per mile	
Wavelength: 4500 per access node 1 G, 6000 for 10 G	
Layer 2: 100 mbps 2200 per access site, 3200 for 1 G	
6000 for 1000 mbps, 100 per month per megabit	$6.00
6059.20 per month for 1000 mbps	$6.06
7000 per month for 1 G, 1500 per month for 100 mbps	$7.00
8610.53 per month for 1000 mbps	$8.61
10625 for 1 G, 20000 for OC-48	
Verizon DS3 Tariff Rates FCC 11	$10.63
18518 for 1 G	$18.52
5000 per month for colleges, 40 per month per Gig	$40.00
100 mbps Service	
150 per mbps per month for 100 to 1000 mbps	
(T1 1.5 mbps currently costs $800-$1100 per month).	$1.50
Dark Fiber: 750 per strand per mile per year	
500 per month for 1 G for public entities	
4-strands free to the county from the private operator	
400 for 100 mbps	
Competitor offers 1293 for 100 mbps.	
Will offer $19.99 for 5 mbps for low income households	$4.00
500 per month for 100 mbps	
972 per month for 100 mbps peak fastE	$5.00
1000 per month for 100 mbps	$10.00
1500 per month for 100 mbps	$15.00
15 per month per mbps (compared to 300 per mbps)	$15.00
600 per month for 400 mbps	
20 per mbps (schools can lower 2k or 8k	
telco bills to 480 or 2k monthly)	$20.00
21 per 1 mbps per month to 2 per 1 mbps	$21.00
2395 per month for 100 mbps	
10 mbps for 50% discount for homes	$23.95
6000*(1-.56) for 100 mbps, 2095 for 100 mbps	$26.40
3500 for 100 mbps, 44.95 for 4 mbps	$33.27

Table A.5: Average Prices per Mbps.

Price for Service per Month	Per Mbps
3327 per month for 100 mbps	$33.27
3950 per month for 100 mbps	$39.50
4000 for 100 mbps	$40.00
6000 per month for 130 mbps, 67.95 per month for 8 mbps	$46.15
50 per mbps per month for 5 mbps, 0 for 100 mbps cais	$50.00
1450 per month per cai for 25 mbps	
2500 per month per cai for 100 mbps	
$12.50 per strand per mile	
and $10 per mbps over 500 mb	$58.00
6800 per month for 100 mbps	
13000 per month for 10 G for 2 years	$68.00
100 per month per mbps	
(228 per month average AT&T to libraries).	$100.00
124475.40 per year for 100 mbps	
Based on AT&T quotes, formal bid.	$103.73
20 to 50 mbps Service	
1500 per month for 50 mbps	$1.50
718 per month for 30 mbps	$23.93
500 per month for 20 mbps	$25.00
1485 per month for T3 (44.736 mbps)	$33.19
5000 per month for 40 mbps	$125.00
1.5 to 10 mbps Service	
60 for 6 mbps	$10.00
75 for 6 mbps, 550 per month for 100 mbps	$12.50
38 per month for 1.5 mbps	
283210 per month for 1000 mbps	$25.33
40 for 1.5 mbps	$26.67
60 per mbps (600 for 10 mbps) + 5k installation	$60.00
$386 per month for 5 mbps	$77.20
1000 per month for 10 mbps	
State of Ohio negotiated $425 per month	
for T1's to schools in 1990s.	$100.00
2500 per month per 1 mbps	$2,500.00

Source: Broadband stimulus application files with unredacted price data (N = 59). Zayo Bandwidth, LLC cites industry averages of 500 to 800 per month for T-1 (1.5 mbps) service, and 35 to 70 dollars per megabit per second per month for 1 gigabit serivce (Zayo Application, p. 23).

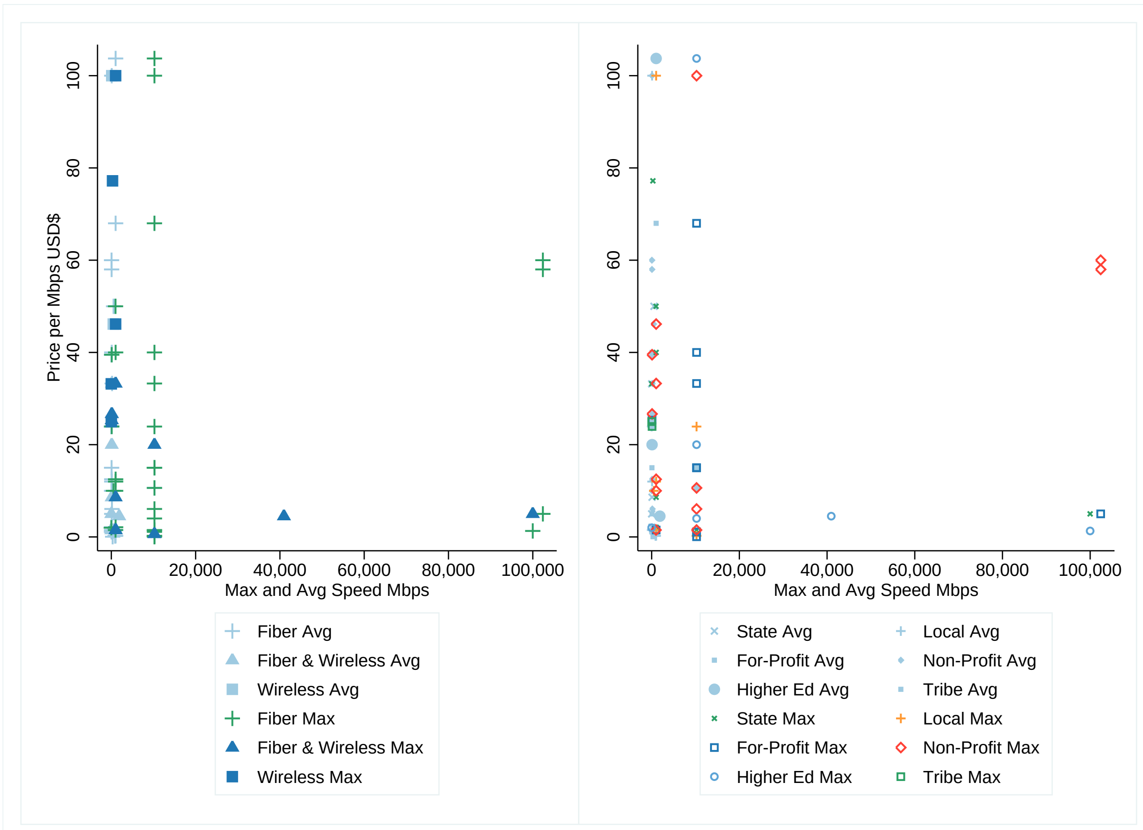

Figure A.1: Price per Mbps and Max and Average Speeds.

Source: Broadband stimulus application files with unredacted price data (N = 59).

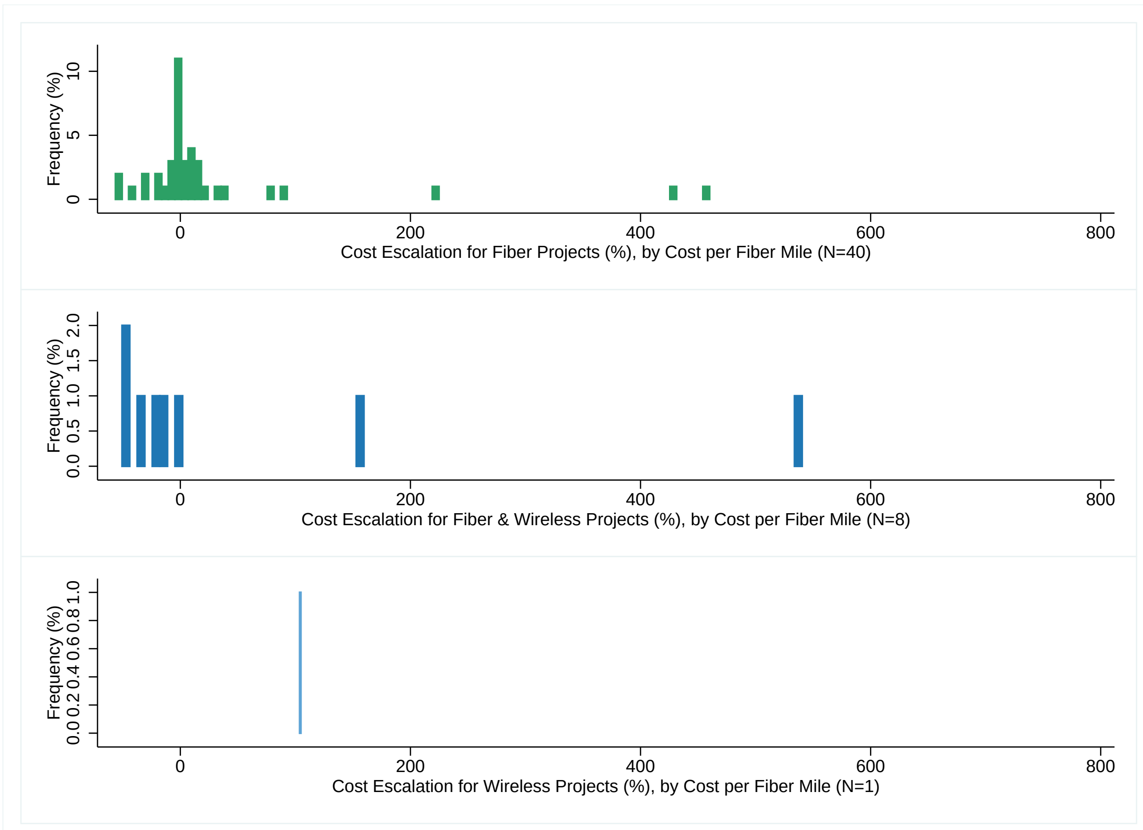

Figure A.2: Frequency of Cost Escalation ΔC_{FM} (%) by Technology.

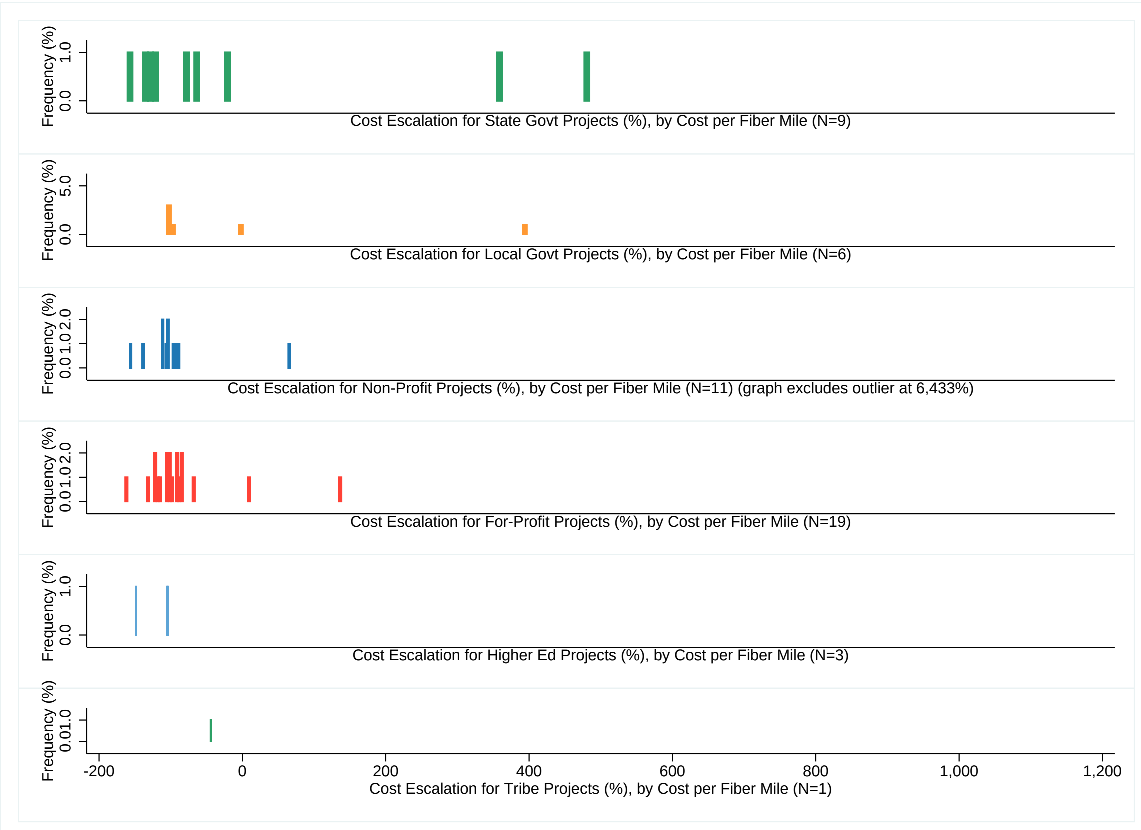

Figure A.3: Frequency of Cost Escalation ΔC_{FM} (%) by Institution.

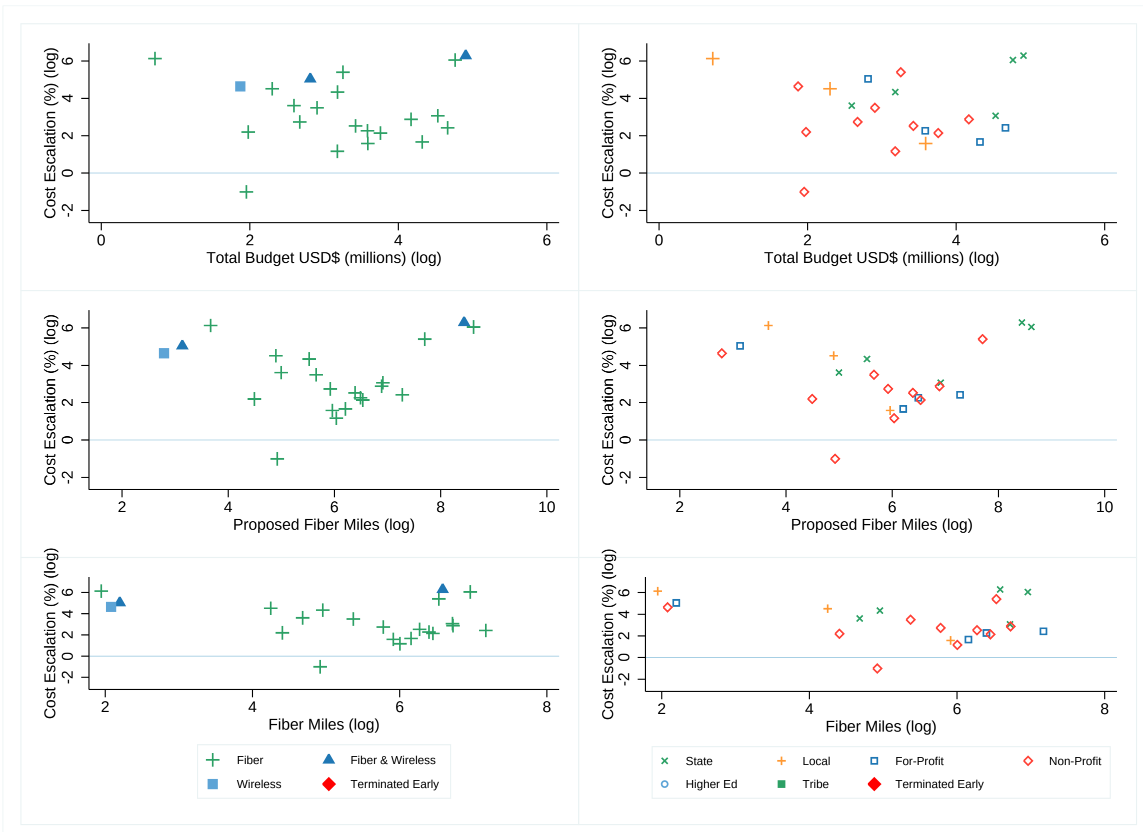

Figure A.4: Cost Escalation ΔC_{FM} (%) and Outputs.

Scatterplot shows data for positive cost escalations. Negative cost escalations are undefined in a natural log transformation.

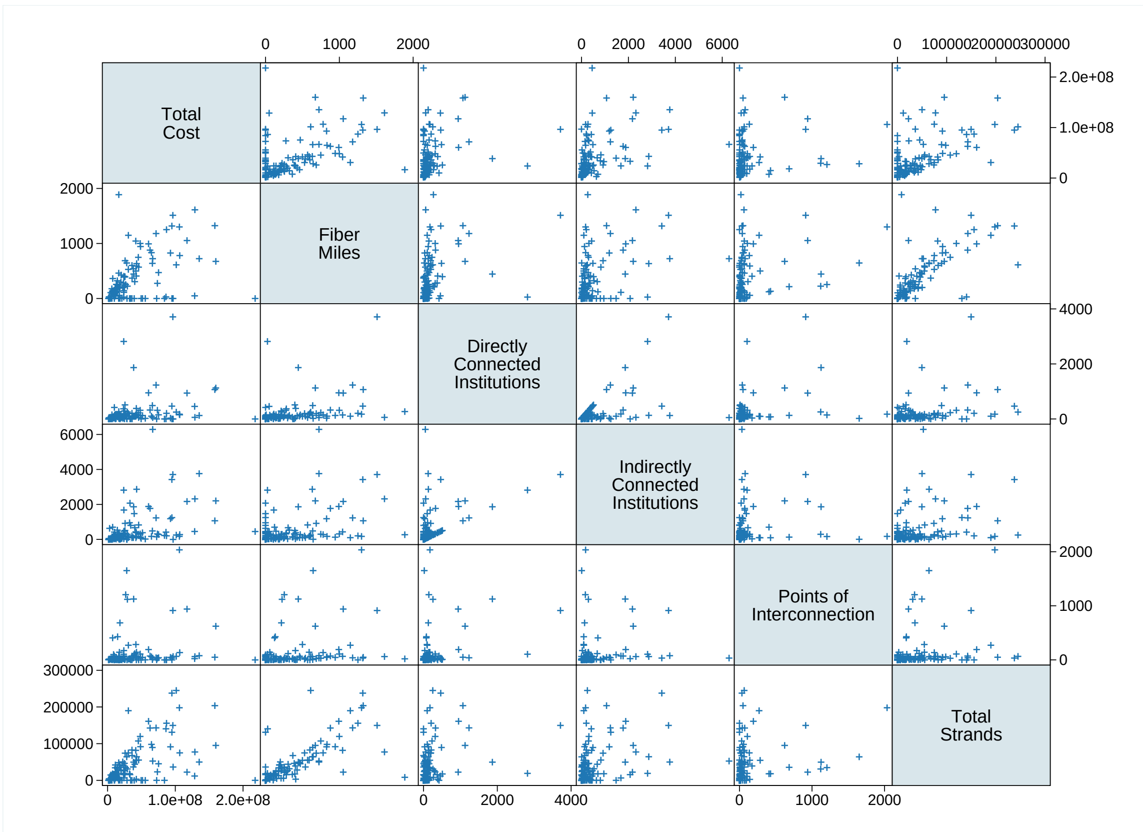

Figure A.5: Network Characteristics Correlation Matrix.

Grantee self-reports for actual results. NTIA, 2015. Correlation between proposed and actual directly connected institutions is 0.796 (N = 59), 0.631 for indirectly connected institutions (N = 57), 0.485 for fiber miles (N = 59), 0.786 for points of interconnection (N = 54).

Table A.6: Average Vendor Payments.

	Number of Vendors > $25k	Average Payment	Number of Vendors < $25k	Average Payment	Grantee Annual Revenues*	Grantee Number of Employees*
By Technology						
Fiber	33	17,636,240	525	1,399,603	170,423,179	1,379
	(49)	*(25,324,432)*	*(1,061)*	*(2,670,662)*	*(421,909,479)*	*(4,992)*
Fiber & Wireless	57	17,758,987	239	934,133	650,516,866	884
	(105)	*(24,280,182)*	*(372)*	*(1,556,769)*	*(2,229,133,934)*	*(2,302)*
Wireless	86	11,133,891	273	1,355,883	7,128,307,657	759
	(118)	*(11,308,515)*	*(499)*	*(2,720,354)*	*(10,381,874,395)*	*(1,494)*
Total	4,773	1,972,346,877	51,821	150,320,555	61,017,582,038	76,567
Total Fiber	2,754	1,481,444,140	44,114	117,566,675	7,839,466,240	62,041
Total Fiber & Wireless	1,243	390,697,720	5,252	20,550,934	10,408,269,857	11,490
Total Wireless	776	100,205,017	2,455	12,202,946	42,769,845,941	3,036
By Institution						
State Govt	78	$30,168,667	592	$2,144,012	579,902,914	205
	(116)	*($33,590,351)*	*(1,190)*	*($3,429,482)*	*(2,168,002,608)*	*(291)*
Local Govt	34	$8,118,746	236	$544,374	2,688,827,140	786
	(81)	*($9,039,808)*	*(501)*	*($959,650)*	*(6,550,604,072)*	*(1,096)*
Non-Profit	36	$22,650,968	460	$1,085,444	155,708,536	1,775
	(43)	*($27,664,780)*	*(1,051)*	*($2,019,831)*	*(493,020,938)*	*(5,094)*
For-Profit	38	$12,733,734	545	$1,587,910	1,321,183,924	78
	(58)	*($19,518,065)*	*(953)*	*($2,798,454)*	*(5,340,334,328)*	*(108)*
Higher Ed	18	$10,978,947	75	$189,255	845,705,796	12,355
	(24)	*($11,280,670)*	*(84)*	*($186,202)*	*(540,782,703)*	*(13,260)*
Tribe	10	$1,638,589	136	$441,194	52,402,008	235
	(12)	*($1,899,531)*	*(181)*	*($461,089)*	*(72,863,665)*	*(319)*
Total	42	$17,150,842	451	$1,307,135	897,317,383	1,235
	(71)	*($24,240,574)*	*(937)*	*($2,488,375)*	*(3,623,500,737)*	*(4,380)*
Total Funds		$1,972,346,877		$150,320,555	61,017,582,038	76,567
Total State Govt		$603,373,331		$42,880,243	9,858,349,542	2,868
Total Local Govt		$105,543,697		$7,076,866	21,510,617,122	6,289
Total Non-Profit		$634,227,092		$30,392,420	2,802,753,655	28,394
Total For-Profit		$534,816,826		$66,692,211	22,460,126,712	1,483
Total Higher Ed		$87,831,574		$1,514,039	4,228,528,982	37,064
Total Tribe		$6,554,357		$1,764,776	157,206,025	469

Project averages for vendor payments are shown by grantee institution (N = 115). The Los Angeles Regional Interoperable Communications System Authority cited annual revenues of 18.8 billion dollars with 17 employees to manage the grant. Standard deviations are in parentheses. *Observations are limited for annual revenues (N = 68) and number of employees (N = 62).

Table A.7: Indirectly Connected Institutions.

	Schools	Libraries	Univ./ Colleges	Health Care	Other Govt	Non. Govt	Public Housing	Public Safety
Proposed Institutions								
State Govt	291	61	51	84	48	48	35	266
	(382)	*(83)*	*(85)*	*(100)*	*(399)*	*(70)*	*(43)*	*(332)*
Local Govt	138	12	4	17	19	19	2	60
	(282)	*(21)*	*(3)*	*(37)*	*(28)*	*(25)*	*(1)*	*(128)*
Non-Profit	7,164	1,039	73	3,038	36	36	4	341
	(30,341)	*(4,212)*	*(254)*	*(13,049)*	*(53)*	*(85)*	*(5)*	*(1,375)*
For-Profit	287	37	27	941	109	109	134	84
	(668)	*(83)*	*(75)*	*(4,218)*	*(467)*	*(203)*	*(188)*	*(153)*
Higher Ed	91	22	19	106	15	15	4	90
	(116)	*(21)*	*(12)*	*(179)*	*(53)*	*(23)*	*(3)*	*(123)*
Tribes	2	2	1	3	8	8	577	9
	(1)	*(2)*	*(1)*	*(0)*	*(7)*	*(8)*	*(812)*	*(5)*
Total	1,747	251	38	1,084	58	58	100	180
	(14,183)	*(1,952)*	*(138)*	*(6,823)*	*(335)*	*(131)*	*(249)*	*(697)*
Actual Institutions								
State Govt	442	63	39	86	170	46	11	213
	(720)	*(81)*	*(78)*	*(135)*	*(303)*	*(87)*	*(26)*	*(261)*
Local Govt	37	7	5	27	39	111	1	63
	(42)	*(8)*	*(7)*	*(72)*	*(64)*	*(244)*	*(1)*	*(119)*
Non-Profit	209	39	23	111	75	31	2	65
	(415)	*(64)*	*(36)*	*(297)*	*(126)*	*(56)*	*(8)*	*(128)*
For-Profit	136	23	15	76	125	37	33	51
	(317)	*(45)*	*(26)*	*(230)*	*(447)*	*(119)*	*(117)*	*(101)*
Higher Ed	90	17	17	77	37	23	3	39
	(98)	*(16)*	*(18)*	*(136)*	*(36)*	*(31)*	*(4)*	*(48)*
Tribes	30	4	6	18	79	80	5	11
	(55)	*(4)*	*(7)*	*(0)*	*(130)*	*(152)*	*(9)*	*(11)*
Total	188	31	20	79	103	46	15	81
	(425)	*(56)*	*(41)*	*(213)*	*(308)*	*(121)*	*(73)*	*(156)*

Project averages for indirect connections are shown. Non-Profit organizations include cooperatives and mutuals. Institutions of higher education are often state government entities. Indirect connections to community anchor institutions are not included here. Standard deviations in parentheses.

Appendix B: Appendix for Chapter 2

Table B.1: Internal Connections Funds by State.

State	Average Discount Rate (1998-2012)	Average Discount Rate (2010)	Internal Connections Funds (1998-2012)	Internal Connections Funds (2010)
AK	78	90	$22,888,128	$876,630
AL	77	79	$164,425,520	$21,920,947
AR	80	83	$65,447,691	$6,053,295
AZ	85	85	$468,320,981	$31,801,601
CA	81	83	$2,664,352,718	$129,564,106
CO	75	80	$97,745,819	$22,293,521
CT	76	78	$131,694,420	$7,867,195
DC	83	88	$74,361,442	$3,293,525
DE	65	76	$764,962	$305,879
FL	81	83	$333,170,852	$18,106,295
GA	82	84	$410,457,151	$27,347,174
HI	72	84	$22,754,628	$1,112,431
IA	67	67	$13,266,649	$1,516,240
ID	77	81	$14,328,103	$2,287,549
IL	78	83	$685,318,657	$28,199,039
IN	75	86	$61,539,883	$6,927,578
KS	70	78	$25,299,042	$1,535,610
KY	77	80	$217,580,302	$26,668,401
LA	82	86	$280,600,151	$16,668,767
MA	67	75	$163,182,413	$7,572,659
MD	73	85	$53,867,500	$12,411,731
ME	73	78	$10,605,255	$2,009,066
MI	71	80	$300,689,656	$14,678,723
MN	73	79	$76,421,373	$10,178,063
MO	76	83	$197,593,990	$6,271,537
MS	84	86	$174,673,997	$5,587,014
MT	72	79	$9,383,766	$255,895
NC	82	84	$223,276,222	$26,785,229
ND	72	83	$8,515,059	$105,708
NE	70	86	$4,506,557	$99,860
NH	63	80	$2,087,611	$291,163
NJ	76	86	$292,701,794	$18,791,689
NM	86	85	$328,707,017	$16,417,583
NV	81	87	$17,455,216	$1,515,093
NY	77	86	$2,309,109,125	$112,664,807
OH	77	84	$329,969,288	$16,513,922
OK	81	85	$275,191,362	$20,774,325
OR	76	82	$29,883,391	$8,008,770
PA	71	83	$412,638,541	$22,641,064
RI	76	85	$33,123,983	$3,714,519
SC	81	84	$299,252,729	$19,743,750
SD	77	82	$23,772,556	$1,141,027
TN	78	82	$168,516,533	$17,887,083
TX	81	83	$1,966,417,575	$248,148,122
UT	75	79	$18,699,687	$4,129,559
VA	74	79	$63,641,471	$15,140,537
VT	69	81	$984,273	$183,761
WA	75	79	$124,539,151	$9,302,754
WI	68	76	$77,028,592	$4,548,497
WV	79	76	$35,931,737	$6,549,460
WY	73	82	$9,942,659	$1,482,029
Total	76	82	$13,796,627,176	$989,890,783

Source: USAC Advanced Search Tool (2013).

Table B.2: Schools and Students by Locale by State from 2011-2012.

	Schools by Locale Type				Students by Locale Type			
State	City	Suburb	Town	Rural	City	Suburb	Town	Rural
AK	94	25	69	303	40,864	4,642	25,613	45,997
AL	411	318	227	760	179,152	145,258	109,376	362,190
AR	295	156	216	633	134,958	54,414	99,328	217,741
AZ	1035	380	268	576	539,729	187,956	108,397	271,847
CA	5098	4274	932	1731	2,887,523	2,533,393	389,387	720,906
CO	683	588	237	620	304,292	288,975	88,516	203,564
CT	385	715	67	266	172,572	316,519	23,255	83,688
DC	280	0	0	0	85,434	0	0	0
DE	78	118	45	70	25,146	60,555	21,755	32,541
FL	1567	2190	386	1094	755,351	1,404,039	148,743	585,648
GA	641	950	308	1071	285,168	673,129	172,923	655,527
HI	120	147	86	65	53,959	89,284	47,691	25,589
IA	309	160	355	843	149,479	60,587	129,826	201,628
ID	188	109	139	322	81,486	47,354	57,532	99,078
IL	1430	1888	755	1470	729,299	972,156	239,757	341,671
IN	714	616	440	1046	331,520	280,854	166,186	368,864
KS	321	232	380	810	130,185	83,816	132,748	173,218
KY	314	259	310	689	157,898	118,038	157,380	301,009
LA	346	358	285	531	172,281	183,504	124,687	231,137
MA	572	1484	92	409	230,796	655,287	23,401	114,291
MD	524	983	140	420	191,342	537,786	51,802	171,273
ME	86	121	84	441	28,809	28,142	32,004	107,001
MI	893	1253	494	1198	392,405	630,424	181,234	376,086
MN	432	467	369	837	197,083	265,242	167,037	256,199
MO	671	801	534	1418	201,474	312,804	188,352	319,646
MS	173	137	279	531	68,535	58,486	144,728	264,289
MT	112	48	138	633	38,478	5,559	50,164	56,740
NC	806	497	366	1380	431,686	244,920	179,764	740,468
ND	67	27	69	350	27,308	10,860	20,103	43,886
NE	239	126	228	634	115,627	49,738	75,136	96,398
NH	108	239	93	312	35,300	70,795	31,735	74,218
NJ	511	2476	123	521	156,485	1,147,578	31,432	153,154
NM	274	129	233	351	118,237	45,803	91,447	94,479
NV	281	201	72	201	178,179	145,744	29,563	101,091
NY	2379	2339	497	1235	1,322,001	1,136,314	205,510	402,405
OH	1042	1453	660	1382	413,195	754,365	257,248	498,837
OK	321	247	375	1003	158,501	138,799	154,206	243,450
OR	502	368	358	420	201,434	141,732	145,797	100,874
PA	1153	2356	490	1395	421,052	905,803	216,667	428,427
RI	123	223	14	72	51,667	85,872	3,990	19,271
SC	320	363	222	624	146,291	191,427	106,634	327,211
SD	72	22	101	528	36,385	4,712	35,281	59,991
TN	694	386	288	842	328,172	185,017	143,034	410,253
TX	3219	1925	1079	2897	2,048,748	1,278,133	496,548	1,319,276
UT	217	429	133	261	105,239	303,988	76,420	116,916
VA	692	829	228	861	330,445	518,370	92,843	409,998
VT	42	75	53	247	9,112	13,372	21,083	48,846
WA	745	882	296	594	331,163	434,546	125,765	180,348
WI	716	622	509	1130	280,160	247,947	179,846	268,763
WV	121	136	136	420	41,727	47,553	59,939	144,150
WY	63	18	98	189	21,319	2,161	37,688	29,671
Total	32,482	35,144	14,356	36,636	15,874,651	18,103,752	5,899,501	12,899,749

Source: NCES (2013a, 2013b).

Table B.3: National School Lunch Program Students by State and Funds.

State	Internal Connections Funds (1998-2012)	Funds per NSLP Student	Funds per Student	NSLP Students	Total Students	City Students
CA	2,664,352,718	816	408	3,263,170	6,531,209	2,887,523
NY	2,309,109,125	1,285	753	1,796,395	3,066,230	1,322,001
TX	1,966,417,575	589	382	3,339,322	5,142,705	2,048,748
IL	685,318,657	596	300	1,149,222	2,282,883	729,299
AZ	468,320,981	710	423	659,146	1,107,929	539,729
PA	412,638,541	365	209	1,131,546	1,971,949	421,052
GA	410,457,151	319	230	1,285,533	1,786,747	285,168
FL	333,170,852	205	115	1,622,139	2,893,781	755,351
OH	329,969,288	296	172	1,113,710	1,923,645	413,195
NM	328,707,017	1,457	939	225,652	349,966	118,237
MI	300,689,656	332	190	904,739	1,580,149	392,405
SC	299,252,729	605	388	494,399	771,563	146,291
NJ	292,701,794	409	197	715,589	1,488,649	156,485
LA	280,600,151	479	394	586,357	711,609	172,281
OK	275,191,362	619	396	444,703	694,956	158,501
NC	223,276,222	237	140	943,032	1,596,838	431,686
KY	217,580,302	394	296	552,631	734,325	157,898
MO	197,593,990	310	193	638,054	1,022,276	201,474
MS	174,673,997	436	326	400,402	536,038	68,535
TN	168,516,533	245	158	686,769	1,066,476	328,172
AL	164,425,520	290	207	566,601	795,976	179,152
MA	163,182,413	304	159	536,588	1,023,775	230,796
CT	131,694,420	443	221	297,027	596,034	172,572
WA	124,539,151	232	116	536,383	1,071,822	331,163
CO	97,745,819	250	110	391,084	885,347	304,292
WI	77,028,592	130	79	592,176	976,716	280,160
MN	76,421,373	123	86	622,637	885,561	197,083
DC	74,361,442	1,576	870	47,176	85,434	85,434
AR	65,447,691	188	129	347,928	506,441	134,958
VA	63,641,471	85	47	746,761	1,351,656	330,445
IN	61,539,883	77	54	797,238	1,147,424	331,520
MD	53,867,500	125	57	431,642	952,203	191,342
WV	35,931,737	176	122	204,277	293,369	41,727
RI	33,123,983	421	206	78,731	160,800	51,667
OR	29,883,391	97	51	307,874	589,837	201,434
KS	25,299,042	71	49	357,824	519,967	130,185
SD	23,772,556	222	174	107,245	136,369	36,385
AK	22,888,128	425	195	53,839	117,116	40,864
HI	22,754,628	202	105	112,816	216,523	53,959
UT	18,699,687	55	31	342,930	602,563	105,239
NV	17,455,216	86	38	203,751	454,577	178,179
ID	14,328,103	85	50	168,252	285,450	81,486
IA	13,266,649	34	24	393,750	541,520	149,479
ME	10,605,255	99	54	107,145	195,956	28,809
WY	9,942,659	177	109	56,145	90,839	21,319
MT	9,383,766	108	62	86,505	150,941	38,478
ND	8,515,059	102	83	83,799	102,157	27,308
NE	4,506,557	18	13	246,846	336,899	115,627
NH	2,087,611	20	10	106,107	212,048	35,300
VT	984,273	18	11	54,134	92,413	9,112
DE	764,962	8	5	93,481	139,997	25,146
All	13,796,627,176	445	261	31,031,200	52,777,653	15,816,379

Source: NCES (2013a, 2013b).

Appendix C: Appendix for Chapter 3

Table C.1: Participation by Designated Market Area.

DMA Rank	DMA	Acr. DMA Zip %	By By %	By Sum Zip %	OTA %	Cab. %	ADS %	Req. By DMA	Req. By Sum Zip	Pop. By Sum Zip
175	LAKE CHARLES, LA	41.4	33.2	31.8	8.5	73.6	28.3	31,524	12,425	39,069
135	WAUSAU, WI	40.7	45.5	35.1	20.3	58.3	42.4	82,130	146,786	417,610
208	ALPENA, MI	38.8	32.4	34.6	11.2	69.9	30.8	5,699	6,115	17,656
70	GREEN BAY, WI	38.8	46.9	34.0	22.5	67.4	33.1	204,057	372,387	1,095,950
137	COLUMBIA, MO	38.6	37.3	30.4	14.2	65.0	36.0	63,514	312,073	1,026,004
107	FT. WAYNE, IN	37.8	49.1	35.1	22.5	57.0	43.9	133,419	240,255	683,694
201	ST. JOSEPH, MO	37.8	33.6	22.1	12.7	73.5	27.7	15,406	25,693	116,029
171	QUINCY, MO, IA	37.0	43.8	29.0	15.1	54.6	46.9	45,434	48,875	168,684
87	HARLINGEN, TX	36.9	70.8	35.8	37.3	64.8	36.1	231,408	373,178	1,041,087
181	JONESBORO, AR	36.5	32.7	22.7	10.3	64.0	37.2	29,229	47,492	209,250
91	SOUTH BEND, IN	35.9	48.1	33.7	23.3	57.2	43.5	160,824	291,339	865,056
72	DES MOINES, IA	35.9	43.4	30.2	20.3	65.7	35.0	181,522	284,658	941,236
176	ELMIRA, NY	35.3	16.0	36.2	6.5	74.6	26.1	15,493	329,876	911,173
104	MYRTLE B., SC	35.3	39.1	26.7	11.3	75.4	25.4	106,441	176,660	662,680
73	TOLEDO, OH	35.2	39.4	29.0	17.2	75.0	25.9	167,662	298,807	1,030,468
153	ROCHSTER, IA	35.1	32.4	23.2	16.6	84.9	15.9	46,412	81,483	350,970
173	JACKSON, TN	34.9	32.1	22.5	6.6	64.4	36.6	30,536	52,617	234,224
68	FLINT SAGINAW, MI	34.5	38.4	28.4	14.0	70.5	30.4	182,198	308,889	1,086,460
88	CEDAR RAPIDS, IA	34.3	35.4	24.6	16.3	71.3	29.5	118,116	211,898	862,100
167	HATTIESBURG, MS	34.0	37.5	25.0	12.0	54.5	47.5	41,862	68,792	274,798
111	SPRINGFIELD, MA	33.2	13.4	27.8	21.8	45.5	55.3	53,865	278,244	1,000,024
79	COLUMBIA, SC	33.0	45.5	28.5	16.7	51.2	49.8	171,909	33,290	116,899
187	GREENWOOD, MS	32.9	31.1	21.9	7.7	72.2	29.5	23,877	39,925	182,143
35	MILWAUKEE, WI	32.7	48.4	34.2	20.6	81.0	19.5	427,765	782,432	2,286,515
65	DAYTON, OH	32.7	39.9	29.9	15.4	80.2	21.0	211,678	342,658	1,145,986
185	MERIDIAN, MS	32.6	37.1	26.8	12.1	48.7	52.6	27,652	47,672	177,760
63	CHARLESTON, WV	32.4	19.7	21.4	12.7	75.5	25.3	93,989	163,038	762,853
117	TRAVERSE CITY, MI	32.4	37.8	27.3	16.8	60.4	40.4	94,063	159,781	585,404
115	LANSING, MI	31.2	37.5	26.0	16.7	69.7	31.3	96,018	162,207	622,796
200	OTTUMWA, IA MO	31.2	33.1	23.2	13.1	54.6	46.2	17,047	18,788	80,943
182	BOWLING GR., KY	31.1	33.8	22.7	11.0	74.3	27.0	25,994	46,442	205,040
34	COLUMBUS, OH	31.0	30.4	25.0	11.6	45.7	55.3	272,962	120,036	480,131
41	GRAND RAPIDS, MI	30.7	36.8	25.2	18.1	67.2	33.4	270,396	467,509	1,857,606
33	CINCINNATI, OH	30.7	39.6	28.0	18.0	74.4	26.0	351,439	642,631	2,298,723
99	DAVENPORT, IA IL	30.7	34.6	25.2	14.7	70.5	30.4	106,693	191,191	758,009
118	MONTGOMERY, AL	30.6	28.7	19.5	8.9	76.3	24.8	69,208	117,060	599,774
139	DULUTH, MN	30.4	41.7	31.4	24.9	54.4	46.4	71,577	125,795	400,686
132	WILMINGTON, NC	30.3	29.7	20.9	8.4	75.6	25.4	51,792	93,976	449,271
114	AUGUSTA, GA	29.9	33.8	22.2	12.5	73.1	27.6	83,604	150,175	677,345
103	GREENVILLE, NC	29.9	37.1	23.6	13.4	68.9	32.3	100,221	181,326	769,714
161	SHERMAN A., TX OK	29.6	37.4	25.4	12.2	54.0	47.3	46,475	51,533	202,494
194	PARKERSBURG, WV	29.5	23.7	18.4	6.2	81.3	20.0	15,154	27,706	150,518
10	HOUSTON, TX	28.7	48.2	29.2	22.6	67.5	33.1	955,054	1,764,520	6,043,469
133	COLUMBUS, MS	28.6	35.4	18.4	8.1	81.4	19.6	66,191	96,878	526,968
152	TERRE HAUTE, IN	28.4	33.5	22.5	13.7	57.8	43.1	48,516	76,704	340,533
11	DETROIT, MI	28.4	37.0	28.4	10.3	75.3	26.2	717,811	1,165,821	4,099,350
144	SALISBURY, MD	28.4	32.9	22.1	6.6	80.9	20.2	49,620	84,609	382,434
205	PRESQUE ISLE, ME	28.3	33.6	25.3	10.7	62.8	39.1	10,485	17,560	69,490
21	ST. LOUIS, MO	28.2	37.6	28.4	19.1	61.3	39.8	462,673	707,475	2,488,040
151	PANAMA CITY, FL	28.1	29.9	20.9	9.4	71.7	29.4	42,090	73,462	351,943
49	LOUISVILLE, KY	28.0	31.7	21.9	13.7	70.1	30.7	205,402	371,869	1,694,504
90	JACKSON, MS	28.0	30.7	21.2	10.5	53.6	47.4	105,534	180,937	854,812
85	MADISON, WI	27.9	37.2	25.5	19.6	70.4	30.3	137,247	229,690	899,469
147	JOPLIN, MO KS	27.6	37.1	26.0	20.7	53.9	46.9	57,350	103,231	396,690
15	MINNEAPOLIS, MN	27.5	40.6	27.8	23.3	71.6	29.1	681,133	1,232,727	4,439,052
199	MANKATO, MN	27.5	23.4	17.0	13.5	76.3	24.6	11,969	19,859	116,837
25	INDIANAPOLIS, IN	27.5	35.3	24.7	15.7	69.1	31.6	374,208	674,493	2,735,062
102	EVANSVILLE, IN	27.5	29.6	20.9	14.2	62.7	38.0	85,653	144,329	689,079
58	RICHMOND, VA	27.2	35.0	23.4	10.9	67.3	33.7	181,208	324,255	1,384,684
26	RALEIGH, NC	27.1	36.0	23.1	12.6	69.1	31.8	361,786	605,715	2,617,744
188	LAREDO, TX	27.0	64.2	30.7	24.5	86.9	14.9	42,266	80,749	262,656
55	FRESNO, CA	27.0	48.3	26.1	23.9	58.6	42.8	269,280	478,365	1,833,049
76	OMAHA, NE	26.9	31.3	20.5	11.1	82.9	17.7	126,213	180,016	876,286
110	YOUNGSTOWN, OH	26.7	32.9	24.8	13.1	79.7	20.9	91,091	95,430	385,533
134	ROCKFORD, IL	26.7	29.4	20.6	15.4	71.0	30.1	54,201	99,479	483,437
159	WHEELING, WV	26.6	30.6	22.5	7.9	80.2	20.9	43,199	66,200	294,749
5	DALLAS, TX	26.5	42.4	27.4	20.3	56.1	45.3	1,007,763	1,831,659	6,685,085
177	WATERTOWN, NY	26.4	28.3	19.0	8.1	73.9	27.4	26,647	46,604	244,702
179	ALEXANDRIA, LA	26.2	28.5	18.1	7.9	71.7	30.3	25,527	40,669	225,262
127	LA CROSSE, WI	26.1	34.6	23.2	18.0	67.6	33.2	72,600	125,230	538,705
50	MEMPHIS, TN	26.1	37.8	25.9	15.5	62.7	38.3	251,403	448,990	1,735,085
46	GREENSBORO, NC	25.9	31.1	21.4	11.5	72.4	28.4	205,265	357,669	1,669,521
164	YUMA, CA	25.9	48.8	26.2	24.9	59.6	41.8	52,422	86,599	330,449
172	DOTHAN, AL	25.8	24.6	17.0	7.6	76.4	24.6	24,504	40,817	239,503
204	VICTORIA, TX	25.8	33.6	21.0	11.2	76.7	24.5	10,232	17,468	83,305
146	ERIE, PA	25.6	36.0	25.7	15.9	75.0	26.2	56,879	101,606	395,439
60	MOBILE, AL, FL	25.5	28.5	20.6	10.6	71.7	29.4	149,556	276,615	1,340,428
180	MARQUETTE, MI	25.5	25.6	18.2	8.3	76.9	24.1	22,942	37,203	204,089
61	TULSA, OK	25.3	34.7	23.8	15.2	61.1	41.1	177,979	315,198	1,322,054
112	BOISE, ID	25.1	45.7	28.0	30.3	52.3	48.4	109,322	188,156	672,916
154	BANGOR, ME	25.0	32.9	24.4	20.2	60.6	40.6	47,031	83,576	342,050

Table C.1: Participation by Designated Market Area.

DMA Rank	DMA	Acr. DMA Zip %	By By %	By Sum Zip %	OTA %	Cab. %	ADS %	Req. By DMA	Req. By Sum Zip	Pop. By Sum Zip
148	SIOUX CITY, IA	24.8	30.5	18.9	16.6	69.2	31.6	47,680	26,713	141,004
3	CHICAGO, IL	24.8	41.0	28.0	17.9	76.4	24.5	1,417,976	2,559,975	9,155,467
78	PADUCAH, KY MO IL	24.6	27.7	19.6	13.7	53.3	47.4	106,682	168,173	856,938
191	LAFAYETTE, IN	24.4	23.6	16.0	11.7	78.0	23.0	15,241	16,315	102,068
32	K. CITY, KS MO	24.3	35.3	24.4	15.0	73.8	26.6	322,772	583,632	2,393,495
80	ROCHESTER, NY	24.3	36.5	24.3	14.8	80.6	20.2	143,416	88,132	363,095
128	COLUMBUS, GA	24.3	28.5	21.7	13.0	79.6	20.9	58,962	451,316	2,080,339
158	MINOT, ND	24.0	27.7	18.9	12.3	71.0	30.1	37,510	60,870	322,174
143	LUBBOCK, TX	23.8	37.3	23.6	20.4	59.2	41.6	56,489	103,137	436,136
82	SHREVEPORT, LA	23.5	29.7	21.1	12.6	49.8	51.7	113,115	200,850	951,823
37	SAN ANTONIO, TX	23.4	39.2	23.2	15.1	73.5	27.4	303,617	565,659	2,440,138
183	CVILLE, VA	23.4	25.6	15.2	10.7	60.9	40.1	21,479	27,278	178,992
86	CHATTANOOGA, TN	23.2	29.7	20.5	10.5	71.8	29.4	103,222	189,060	923,136
116	PEORIA, IL	23.2	27.0	17.6	12.3	74.2	26.7	65,598	122,890	696,701
24	CHARLOTTE, NC	23.1	29.7	19.1	10.6	70.6	30.3	310,817	554,159	2,901,201
138	MONROE, LA, AR	23.0	26.2	17.9	13.2	63.2	38.4	46,684	82,721	463,388
67	ROANOKE, VA	23.0	29.2	20.3	11.2	57.6	43.1	130,211	228,457	1,125,109
209	N. PLATTE, NE	22.9	25.5	18.3	11.4	73.7	28.1	3,942	6,689	36,589
43	NORFOLK, VA	22.8	27.0	18.9	9.1	81.3	19.7	192,776	345,716	1,832,188
123	LAFAYETTE, LA	22.6	28.8	16.4	8.2	73.7	27.1	65,018	14,739	89,632
36	GRNVLLE, NC SC	22.6	31.4	21.4	12.9	58.3	43.0	259,321	458,522	2,143,946
81	HUNTSVILLE, AL	22.4	25.8	17.8	8.1	69.9	30.6	96,832	167,175	941,782
56	LITTLE ROCK, AR	22.4	27.0	18.5	13.8	55.3	46.0	145,529	253,935	1,372,491
89	WACO, TX	21.7	28.1	16.5	11.1	65.8	35.1	87,654	161,290	979,501
45	OKLAHOMA CITY, OK	21.4	35.7	24.2	15.8	71.3	29.3	236,250	284,203	1,173,825
53	BUFFALO, NY	21.4	29.3	21.5	9.5	76.3	24.9	187,434	243,805	1,133,780
48	AUSTIN, TX	21.3	32.3	19.1	12.2	78.7	22.2	194,339	343,188	1,794,958
84	CHAMPAIGN, IL	21.3	21.4	15.6	11.2	71.8	29.0	81,094	128,757	822,850
186	LIMA, OH	21.3	31.0	18.8	9.4	79.1	22.2	16,498	26,283	140,042
141	BEAUMONT, TX	21.1	29.0	19.1	12.4	74.5	26.7	48,518	86,471	453,498
121	FARGO, ND	21.0	23.5	16.6	14.6	67.2	33.4	55,343	97,402	586,619
100	FT. SMITH, AR	20.9	26.1	16.5	11.5	60.9	39.8	73,253	130,843	794,311
18	CLEVELAND, OH	20.7	28.8	22.1	14.7	81.1	19.5	443,233	731,314	3,311,372
83	SYRACUSE, NY	20.7	24.1	18.0	12.3	84.4	16.2	93,178	179,336	997,650
105	LINCOLN, NE	20.6	25.1	17.3	12.6	67.9	33.1	69,205	121,930	704,143
113	SIOUX FALLS, SD	20.6	25.6	16.8	11.6	71.2	29.4	63,308	106,579	635,247
51	NEW ORLEANS, LA	20.4	33.0	20.7	14.5	91.1	11.1	187,357	333,431	1,608,652
136	TOPEKA, KS	20.3	23.9	15.9	12.8	73.2	27.7	40,867	72,045	452,541
27	BALTIMORE, MD	20.3	30.3	21.1	13.6	83.7	16.9	332,270	600,947	2,842,934
163	BILOXI, MS	20.0	29.7	17.9	8.9	74.2	26.7	39,923	58,114	325,546
57	ALBANY, NY	19.7	21.2	14.7	10.3	67.4	33.6	117,690	50,873	345,477
2	LA, CA	19.6	36.4	22.0	19.7	68.2	32.9	2,044,002	3,782,746	17,200,000
129	C. CHRISTI, TX	19.6	27.0	16.3	10.7	81.0	19.9	52,341	92,361	566,979
4	PHILADELPHIA, PA	19.6	26.2	17.8	7.8	84.6	16.8	771,256	1,399,539	7,852,164
29	NASHVILLE, TN	19.4	25.1	16.4	11.7	63.2	37.7	236,702	421,778	2,572,775
40	BIRMINGHAM, AL	19.0	23.1	16.2	8.9	63.3	37.5	166,755	298,087	1,837,101
47	JVILLE, FL GA	18.7	29.1	19.9	10.8	73.8	27.7	185,843	335,215	1,681,078
206	HELENA, MT	18.6	28.8	20.6	19.4	69.8	31.2	7,487	13,851	67,244
122	MACON, GA	18.5	26.6	17.1	8.6	66.4	34.8	61,292	113,050	661,147
189	BEND, OR	18.4	32.5	18.8	16.5	72.1	29.6	18,785	9,896	52,691
109	TYLER, TX	18.4	26.2	16.0	12.5	52.3	49.0	67,884	105,204	658,406
59	KNOXVILLE, TN	18.4	27.2	19.5	8.3	67.8	33.3	142,085	247,730	1,273,348
17	MIAMI, FL	18.3	31.2	20.0	8.7	73.9	28.2	480,810	725,087	3,625,098
19	ORLANDO, FL	18.1	24.4	16.9	7.2	76.3	24.6	340,389	607,955	3,599,880
170	UTICA, NY	18.1	27.8	13.7	7.9	82.2	19.2	29,491	35,322	257,775
66	TUCSON, AZ	18.1	30.3	21.4	16.6	70.7	30.1	131,226	225,224	1,053,302
160	GAINESVILLE, FL	18.0	25.2	15.6	10.1	72.3	29.0	30,088	47,786	306,719
95	BATON ROUGE, LA	18.0	24.1	16.1	9.2	81.5	19.4	77,759	138,707	863,049
14	TAMPA, FL	18.0	24.2	17.6	9.7	81.4	19.4	425,542	696,373	3,953,159
198	SAN ANGELO, TX	17.7	15.1	9.7	7.7	65.9	36.4	8,010	13,691	141,332
125	BAKERSFIELD, CA	17.7	36.7	18.4	17.9	69.0	31.5	77,418	133,420	725,949
77	PORTLAND, ME	17.6	21.2	20.7	21.2	67.3	33.4	86,875	618,865	2,996,251
157	BINGHAMTON, NY	17.5	23.8	17.0	8.0	80.6	20.7	32,861	56,016	328,696
22	PORTLAND, OR	17.4	32.3	15.2	12.0	80.7	20.0	361,625	148,428	979,672
12	PHOENIX, AZ	17.4	30.9	20.6	15.4	71.1	30.1	532,792	830,750	4,040,419
165	ABILENE, TX	17.3	24.4	16.8	13.2	52.2	49.3	27,837	48,895	291,565
106	TALLAHASSEE, FL	17.3	21.1	12.5	9.4	67.7	33.5	56,254	70,415	561,544
20	SACRAMENTO, CA	17.3	26.7	16.9	14.7	60.9	39.9	365,856	650,917	3,861,105
162	IDAHO FALLS, ID	17.3	31.1	17.3	20.1	41.7	58.9	36,290	63,419	365,812
145	ALBANY, GA	17.2	23.7	15.2	9.3	86.2	14.5	36,240	208,264	1,373,759
149	WICHITA F., TX OK	17.1	23.2	16.3	11.4	59.9	41.5	35,343	38,774	237,191
92	COL. SPRS., CO	17.1	29.8	19.1	19.2	60.6	40.3	94,328	162,640	852,713
178	HARRISONBG, VA	17.0	21.7	13.2	9.7	66.8	34.3	19,047	31,148	236,182
23	PITTSBURGH, PA	17.0	22.9	16.9	7.9	81.1	19.4	266,911	467,837	2,769,008
64	FT. MYERS, FL	17.0	22.5	16.4	6.1	79.1	23.2	107,964	175,116	1,069,665
126	YAKIMA, WA	16.8	30.2	17.1	17.6	56.3	44.5	64,543	111,221	651,109
156	BLUEFIELD, WV	16.7	17.7	13.7	4.7	76.2	25.6	25,735	41,912	306,408
44	ALBUQUERQUE, NM	16.6	30.1	20.4	18.4	54.2	47.5	199,295	323,179	1,586,682
130	CHICO, CA	16.5	25.7	17.0	18.2	46.9	54.3	49,671	84,609	496,584
166	MISSOULA, MT	16.4	26.4	17.0	20.3	45.1	55.4	28,089	47,909	282,247
69	WICHITA, KS	16.3	22.9	15.4	13.8	74.7	26.1	102,231	183,264	1,190,559
8	ATLANTA, GA	16.2	25.0	16.2	8.0	66.9	33.7	551,904	1,009,797	6,225,112

Table C.1: Participation by Designated Market Area.

DMA Rank	DMA	Acr. DMA Zip %	By By %	By Sum Zip %	OTA %	Cab. %	ADS %	Req. By DMA	Req. By Sum Zip	Pop. By Sum Zip
193	TWIN FALLS, ID	16.2	27.1	16.3	15.3	49.8	50.9	16,603	29,920	183,009
96	SAVANNAH, GA	15.7	19.5	11.8	8.5	68.8	32.6	58,051	99,982	847,745
192	GREAT FALLS, MT	15.7	22.2	14.9	14.5	59.6	41.2	14,114	24,273	162,679
184	GRAND JUNCT., CO	15.5	21.4	15.9	18.4	62.1	38.5	14,888	25,370	159,275
168	CLARKSBURG, WV	15.3	18.5	13.4	4.7	63.4	37.5	20,141	28,545	212,697
174	RAPID CITY, SD	15.2	22.2	14.4	12.3	72.9	27.7	20,808	34,904	242,336
52	PROVIDENCE, RI, MA	14.8	22.3	15.8	9.4	90.7	10.1	141,329	250,993	1,592,837
119	EUGENE, OR	14.6	25.9	18.2	17.5	65.4	35.4	59,935	103,092	566,871
31	SALT LAKE C., UT	14.2	31.2	17.0	24.0	53.4	47.1	261,823	462,896	2,720,940
42	LAS VEGAS, NV	14.2	24.8	16.3	11.1	78.7	22.1	166,864	278,219	1,704,392
62	LEXINGTON, KY	13.9	23.0	16.0	10.1	62.6	38.3	111,276	198,920	1,243,516
74	SPRINGFLD, MO	13.8	61.0	14.0	7.6	91.1	9.9	161,463	94,640	677,673
190	BUTTE, MT	13.8	26.0	15.6	21.3	62.0	38.8	15,774	25,313	161,805
9	WASHINGTON, DC	13.8	24.1	14.3	10.0	71.6	29.2	546,822	799,682	5,584,660
93	TRI CITIES, VA, TN	13.5	22.3	16.6	8.1	71.1	29.9	72,709	130,768	787,071
16	DENVER, CO	13.5	26.7	17.6	14.0	66.2	35.1	381,799	658,016	3,728,473
169	BILLINGS, MT	13.5	26.1	18.2	15.9	61.6	39.0	27,077	47,119	259,176
94	BURLINGTON, VT NY	13.3	17.8	12.0	11.8	60.5	40.5	58,425	97,101	809,165
97	CHARLESTON, SC	13.3	31.3	14.5	6.9	66.9	34.4	90,685	156,421	1,080,759
140	MEDFORD, OR	13.0	20.2	13.8	12.2	60.7	40.3	33,239	57,922	420,943
38	W. PALM BEACH, FL	12.9	17.4	12.7	4.0	76.7	24.8	134,186	240,488	1,897,994
75	SPOKANE, WA	12.8	22.6	14.2	16.4	56.6	44.2	89,410	156,564	1,099,597
197	CHEYENNE, WY NE	12.5	19.9	11.1	10.1	67.2	33.6	10,741	15,471	139,085
54	WILKES BARRE, PA	12.5	18.5	13.0	6.9	78.5	22.1	109,007	189,825	1,461,918
131	AMARILLO, TX	12.2	23.6	13.0	12.3	58.1	43.7	44,966	124,906	959,760
6	SF, CA	12.0	22.1	13.7	11.2	78.9	22.9	527,722	930,652	6,794,397
196	CASPER, WY	11.9	17.8	11.3	10.5	67.0	34.0	9,320	15,792	140,069
39	HARRISBG, PA	11.9	21.0	12.2	9.2	82.9	17.8	149,831	148,338	1,218,620
124	MONTEREY, CA	11.8	25.4	13.7	12.8	69.7	31.8	55,566	98,287	719,624
108	RENO, NV	11.7	25.7	14.0	10.4	62.8	38.7	67,171	88,365	632,968
202	FAIRBANKS, AK	11.7	30.7	13.8	26.1	63.3	36.9	10,208	14,493	104,756
7	BOSTON, MA, NH	11.5	18.4	12.4	5.4	89.2	12.0	436,711	681,708	5,498,752
142	PALM SPRINGS, CA	11.0	19.9	10.0	4.7	86.0	15.8	29,898	40,533	405,551
101	JOHNSTOWN, PA	10.9	14.3	9.5	6.4	72.9	27.7	41,944	68,643	719,453
1	NEW YORK, NY	10.7	22.4	14.1	6.1	85.5	16.3	1,647,885	2,795,311	19,800,000
28	SAN DIEGO, CA	10.5	17.9	10.9	8.7	89.9	10.7	184,007	323,228	2,952,491
13	SEATTLE, WA	10.5	17.0	10.8	13.3	80.9	19.6	293,257	488,951	4,523,333
155	ODESSA, TX	10.2	18.0	9.8	9.1	82.0	19.5	24,400	39,017	396,789
30	HARTFORD, CT	9.5	15.3	10.4	5.5	87.0	13.7	155,390	271,208	2,606,328
98	EL PASO, TX	9.5	65.5	7.9	31.9	72.9	28.3	192,303	3,044	38,475
195	EUREKA, CA	9.5	16.7	10.2	14.9	81.2	19.7	9,925	16,000	157,225
210	GLENDIVE, MT	8.6	13.6	9.0	6.5	81.5	19.1	542	882	9,833
120	S. BARBARA, CA	7.9	13.7	7.7	8.0	73.2	27.8	31,253	52,909	683,656
71	HONOLULU, HI	4.6	8.8	4.8	5.5	95.3	5.2	36,866	62,311	1,311,619
207	JUNEAU, AK	3.3	5.3	2.9	7.9	76.3	25.3	1,261	1,624	56,265

ZANESVILLE, OH (DMA 567) with 7,086 requests, and ANCHORAGE, AK (DMA 743) with 28,268 requests are missing from the dataset. Before publication this will be resolved.

ZCTA	DMA	Partic. Rate	Redem. Rate	Pred. Adopt.	Impl. Avail.	OTA %	Cable %	ADS %	Med. Age	LAI	Income Per Cap.	Dep. Per Cap.	Pop. Dens.	Pop.	Red. Coup.	Req. Coup.	Holding Cos.
6357	Hartford, CT	0.00%	0%	0.319	0.760	6%	87%	14%	44.6	0.48	$68,939	0.19	5E-04	12,552	0	0	7
75207	Dallas, TX	0.23%	36%	0.422	1.000	20%	56%	45%	32.3	0.48	$63,945	0.02	1E-03	9,648	8	22	21
25650	Charleston, WV	0.37%	0%	0.248	0.590	7%	67%	34%	42.3	0.64	$34,345	0.19	9E-06	547	0	2	4
41616	Charleston, WV	0.38%	0%	0.290	0.690	7%	67%	34%	38.6	0.72	$38,381	0.22	2E-05	794	0	3	6
78236	San Antonio, TX	0.49%	37%	0.319	0.760	15%	74%	27%	21.8	0.52	$32,524	0.11	4E-04	10,392	19	51	7
16802	Johnstown, PA	0.63%	46%	0.319	0.760	6%	73%	28%	19.7	0.53	$20,979	0.01	6E-03	12,764	37	81	7
96754	Honolulu, HI	0.64%	8%	0.280	0.670	6%	95%	5%	40.7	0.48	$53,069	0.21	4E-05	4,084	2	26	5
28547	Greenville, NC	0.69%	33%	0.319	0.760	13%	69%	32%	21.3	0.56	$39,384	0.13	3E-04	21,884	49	150	7
95064	Monterey, CA	0.79%	41%	0.248	0.590	13%	70%	32%	19.7	0.48	$50,139	0.03	2E-03	7,331	24	58	4
32508	Mobile, AL, FL	0.80%	32%	0.365	0.870	11%	72%	29%	20.6	0.55	$24,207	0.07	3E-04	5,852	15	47	9
80487	Denver, CO	0.82%	30%	0.397	0.940	14%	66%	35%	38.8	0.47	$78,133	0.10	9E-06	16,745	41	138	13
...																	
28629	Charlotte, NC	100%	59%	0.422	1.000	11%	71%	30%	43.8	0.65	$51,930	0.71	1E-05	75	44	75	-
24168	Roanoke, VA	102%	60%	0.280	0.670	11%	58%	43%	51.5	0.66	$30,636	1.73	7E-05	187	114	191	5
70654	Lake Charles, LA	112%	54%	0.248	0.590	9%	74%	28%	38.6	0.62	$38,365	0.91	3E-06	155	93	173	4
72528	Little Rock, AR	117%	59%	0.248	0.590	14%	55%	46%	47.8	0.70	$21,867	1.00	6E-06	65	45	76	4
19736	Philadelphia, PA	122%	46%	0.290	0.690	8%	85%	17%	46.5	0.51	$162,296	2.47	9E-05	32	18	39	6
88024	Elmira, NY	125%	53%	0.422	1.000	7%	75%	26%	24	0.58	$22,066	1.19	1E-04	236	157	295	-
72181	Little Rock, AR	131%	63%	0.422	1.000	14%	55%	46%	35	0.54	$47,212	1.90	2E-05	62	51	81	-
41052	Cincinnati, OH	156%	64%	0.280	0.670	18%	74%	26%	41.9	0.53	$44,573	0.87	2E-05	107	107	167	5
45773	Parkersburg, WV	161%	66%	0.319	0.760	6%	81%	20%	39.6	0.59	$35,574	1.94	7E-06	83	88	134	7
76061	Dallas, TX	178%	68%	0.422	1.000	20%	56%	45%	45	0.52	$49,969	1.22	4E-05	152	184	271	-
76937	San Angelo, TX	189%	81%	0.280	0.670	8%	66%	36%	39.5	0.54	$36,797	2.30	1E-06	37	57	70	5
45418	Dayton, OH	206%	58%	0.378	0.900	15%	80%	21%	35.1	0.54	$41,044	0.32	2E-04	1,351	1599	2777	10
18936	Philadelphia, PA	1850%	47%	0.422	1.000	8%	85%	17%	73	0.53	$64,761	17.75	2E-06	4	35	74	16

Table C.2: Low and High Participation Rates by Zip Code

Nielsen (2009). Rank of Designated Market Areas. Nielsen (2007). Over-the-air household. Also show for comparison only, Wired Cable Subscriptions (WiredCableSubHH) and Alternative Distribution System Subscriptions (ADSSubHH). LAI denotes Location Affordability Index by the share of costs from household and transportation by median income.

Table C.3: Drivers of Participation with State Fixed Effects.

	Participation Rate (log)				
Variables (log)	(1)	(2)	(3)	(4)	(5)
Coupon Redemption Rate	2.102***	2.168***	2.132***	2.053***	1.876***
	[0.647]	[0.667]	[0.657]	[0.633]	[0.578]
Predicted Broadband Adoption		5.116***	4.057***	4.227***	2.671***
		[1.339]	[1.062]	[1.107]	[0.699]
Implied Broadband Availability		-4.693***	-4.159***	-4.141***	-2.679***
		[-1.216]	[-1.078]	[-1.074]	[-0.695]
Population Density			0.059***	0.093***	0.080***
			[0.207]	[0.323]	[0.278]
Over-the-Air TV Households			0.226***	0.241***	0.232***
			[0.139]	[0.148]	[0.143]
Median Age				0.775***	0.798***
				[0.188]	[0.193]
Dependents per Capita				0.293***	0.256***
				[0.123]	[0.107]
Location Affordability Index				0.158***	-0.683***
				[0.025]	[-0.108]
Income per Capita				-0.456***	-0.436***
				[-0.269]	[-0.257]
Alaska					-0.604***
					[-0.040]
Arizona					-0.510***
					[-0.075]
Arkansas					-0.178***
					[-0.037]
California					-0.603***
					[-0.212]
Colorado					-0.652***
					[-0.119]
Connecticut					-0.604***
					[-0.091]
Delaware					-0.361***
					[-0.025]
Florida					-0.286***
					[-0.078]
Georgia					-0.226***
					[-0.053]
Hawaii					-0.980***
					[-0.071]
Idaho					-0.537***
					[-0.074]
Illinois					-0.324***
					[-0.096]
Indiana					-0.166***
					[-0.039]
Iowa					-0.171***
					[-0.038]
Kansas					-0.538***
					[-0.123]
Kentucky					-0.414***
					[-0.099]
Louisiana					0.091***
					[0.017]
Maine					-0.262***
					[-0.047]
Maryland					-0.467***
					[-0.088]
Massachusetts					-0.462***
					[-0.088]
Michigan					-0.114***
					[-0.030]
Minnesota					-0.332***
					[-0.087]
Mississippi					0.183***
					[0.032]
Missouri					-0.278***
					[-0.070]
Montana					-0.564***
					[-0.080]
Nebraska					-0.416***
					[-0.087]
Nevada					-0.592***
					[-0.058]
New Hampshire					-0.662***
					[-0.093]
New Jersey					-0.435***
					[-0.093]
New Mexico					-0.508***
					[-0.069]
New York					-0.366***
					[-0.124]
North Carolina					-0.155***
					[-0.038]

Table C.3: Drivers of Participation with State Fixed Effects.

	Participation Rate (log)				
Variables (log)	(1)	(2)	(3)	(4)	(5)
North Dakota					-0.242***
					[-0.039]
Ohio					-0.210***
					[-0.056]
Oklahoma					-0.229***
					[-0.046]
Oregon					-0.450***
					[-0.079]
Pennsylvania					-0.564***
					[-0.188]
Rhode Island					-0.511***
					[-0.040]
South Carolina					0.114***
					[0.020]
South Dakota					-0.415***
					[-0.067]
Tennessee					-0.118***
					[-0.027]
Texas					-0.353***
					[-0.129]
Utah					-0.739***
					[-0.095]
Vermont					-0.758***
					[-0.109]
Virginia					-0.323***
					[-0.084]
Washington					-0.631***
					[-0.130]
West Virginia					-0.464***
					[-0.098]
Wisconsin					-0.229***
					[-0.056]
Wyoming					-0.947***
					[-0.091]
State Fixed Effects	No	No	No	No	Yes
Constant	-0.435***	4.130***	4.139***	7.176***	5.056***
	[.]	[.]	[.]	[.]	[.]
Observations	25,473	25,473	25,473	25,466	25,466
R-squared	0.419	0.434	0.466	0.542	0.617

Robust normalized beta coefficients in brackets. *** p<0.01, ** p<0.05, * p<0.1.

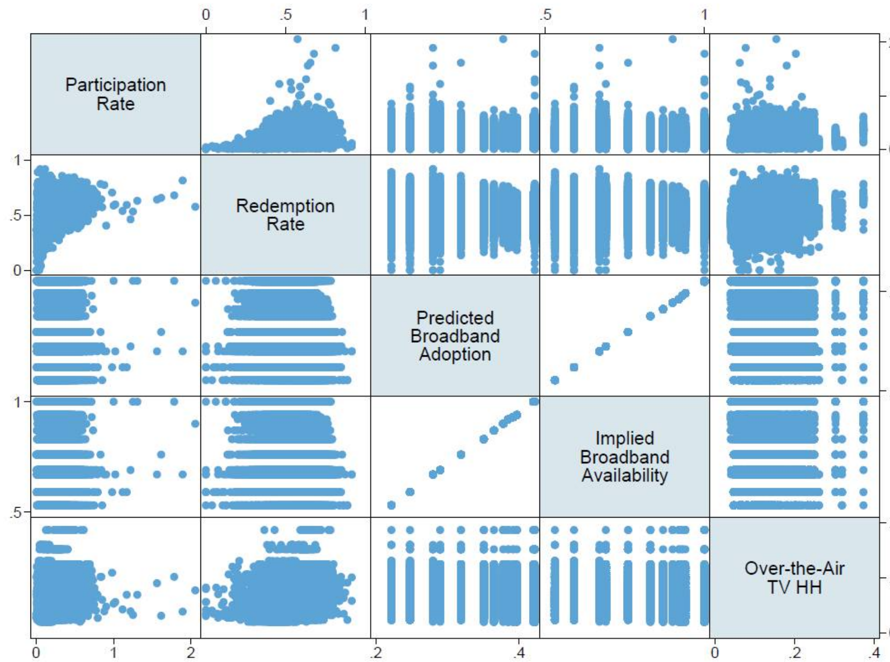

Figure C.1: Matrix for Independent Variables.

Source: Independent variables are shown without a natural logarithm transformation.

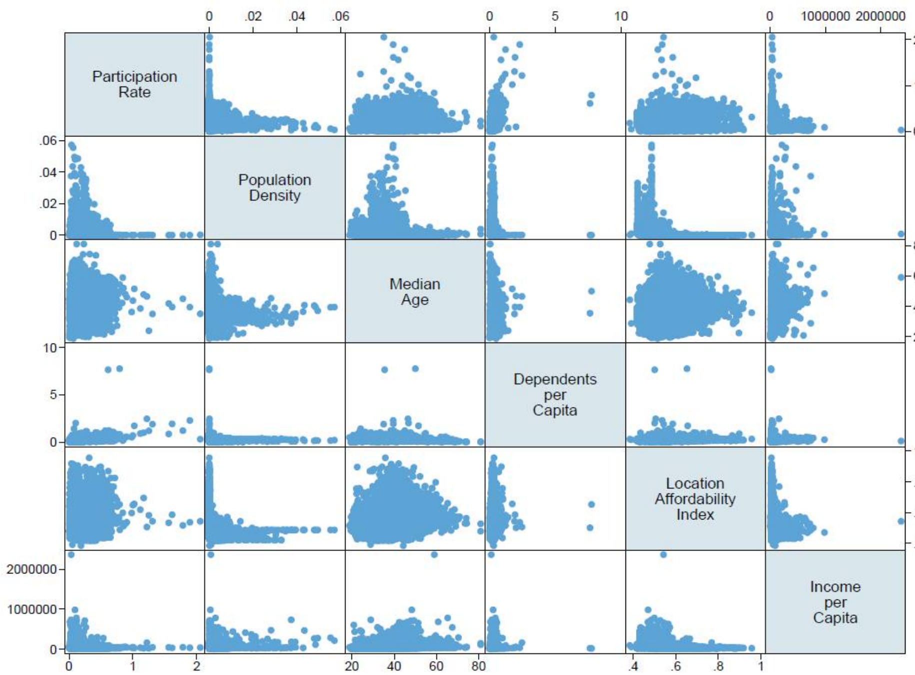

Figure C.2: Matrix for Independent Variables.

Source: Independent variables are shown without a natural logarithm transformation.

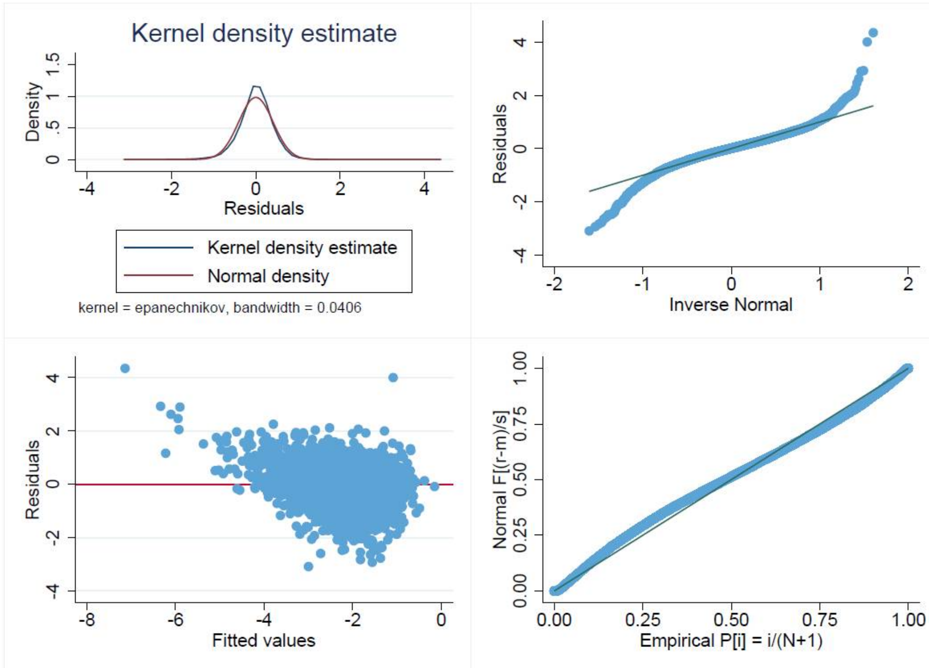

Figure C.3: Regression Diagnostics.

The residual plot on fitted values does not appear to be as randomly distributed as ideal. The residuals plot on inverse normal has tails away from the trend line which also raises a concern about the appropriateness of ordinary least squares linear regression. However, the kernel density estimate and the pnorm curve appears to support the use of linear regression.

Table C.4: Correlation Coefficients for Independent Variables.

	Participation Rate	Pop. Density	Median Age	Dep. Per Capita	Location Aff. Index	Income Per Capita
Participation Rate	1					
Population Density	-0.0038	1				
Median Age	0.02	-0.2073	1			
Dependents Per Capita	0.5846	-0.0199	-0.1679	1		
Location Affordability Index	0.0469	-0.2804	0.2182	-0.0583	1	
Income Per Capita	-0.1402	0.1326	0.1053	0.009	-0.2783	1

	Participation Rate	Redemption Rate	Broadband Avail.	Broadband Adoption	OTA %	Cable %	ADS %
Participation Rate	1						
Redemption Rate	0.4323	1					
Broadband Adoption	-0.0398	-0.2217	1				
Broadband Availability	-0.0402	-0.2218	0.9998	1			
OTA %	0.223	0.3461	0.0098	0.0099	1		
Cable %	-0.1354	-0.2306	0.1651	0.165	-0.512	1	
ADS %	0.1323	0.221	-0.1612	-0.1611	0.5013	-0.9993	1

Independent variables are shown without a natural logarithm transformation. ADS denotes Alternative Distribution System such as satellite television.

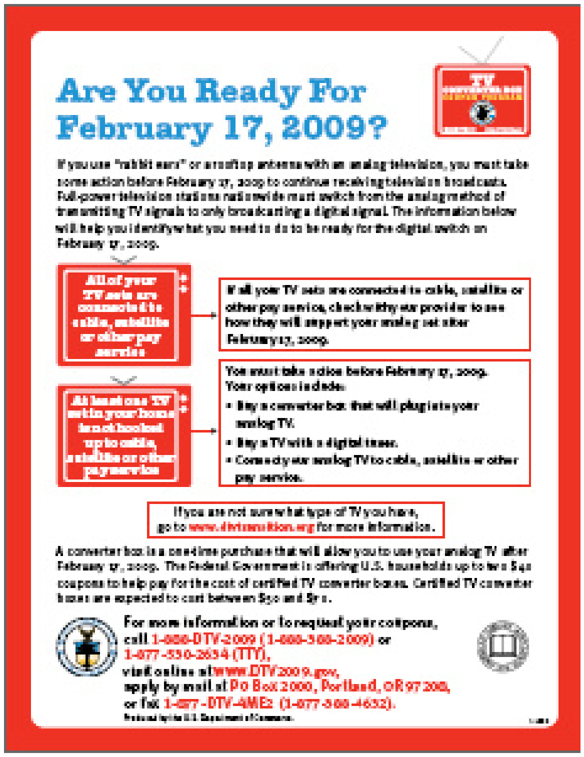

Figure C.4: Flyer for Coupon Program.

Source: Roberts, Jacob. "NTIA Launches DTV Converter Box Coupon Program," Jan. 4, 2008, `http://www.districtdispatch.org/2008/01/ntia-launches-dtv-converter-box-coupon-program/` (last accessed March 15, 2017).

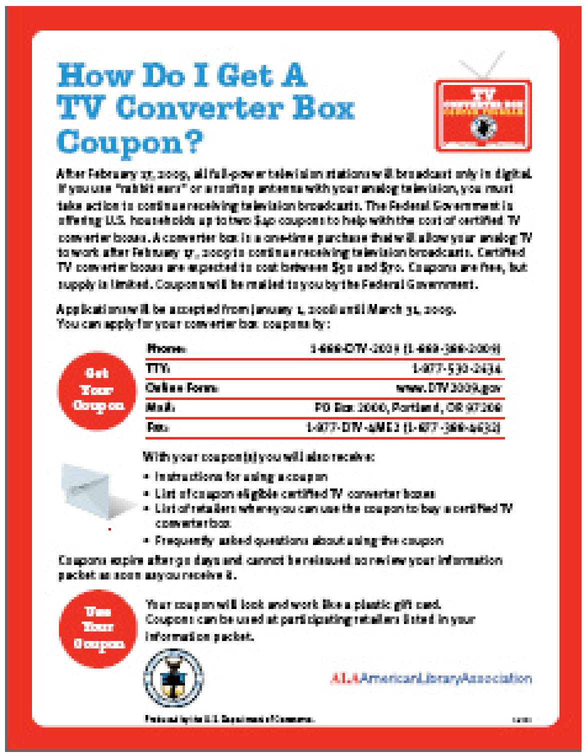

Figure C.5: Flyer for Coupon Program.

Source: Roberts, Jacob. "NTIA Launches DTV Converter Box Coupon Program," Jan. 4, 2008, `http://www.districtdispatch.org/2008/01/ntia-launches-dtv-converter-box-coupon-program/` (last accessed March 15, 2017).

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OMB No. 0660-0024

TV CONVERTER BOX
COUPON PROGRAM

Do you have a TV in your home that works with the help of "rabbit ears" or a rooftop antenna?

If so, you should be aware of an important change in broadcasting coming in ***February 2009***.

If you receive free TV using an antenna and your TV is not digital, you need to take action sometime before ***February 17, 2009*** so you can continue to receive programs after that date.

What's this about? The **Digital Television Transition and Public Safety Act of 2005** requires TV stations to stop broadcasting in analog and to broadcast only in digital after ***February 17, 2009***. The digital transition will provide a better viewing experience for consumers and help emergency responders protect your community.

The Act created the TV Converter Box Coupon Program for households wishing to use their analog TVs after the transition. The Federal government is offering US households up to two $40 coupons to help pa for the cost of a certified converter box. TVs connected to cable, satellite, or other pay services do not need a converter box to receive programs after February 17, 2009.

What do I need to do? For each analog TV you own, you need to decide *before* ***February 17, 2009*** how you would like to get programming after the change to digital.

What are my options?

1. Buy a converter box that will plug into your current TV,
2. Buy a TV with a digital tuner,
3. Connect the analog TV to cable, satellite or other pay service.

More information can be found online at www.DTV2009.gov.

How do I get a coupon? Apply online or by phone. You may also mail in or fax a Coupon Application. You may request one coupon now and one later, but no more than two coupons per household are allowed. Coupon supplies are limited. Coupons expire 90 days after they are mailed. Requests must be received by March 31, 2009. Contact information is listed below.

ONLINE
www.DTV2009.gov

BY PHONE
1-888-DTV-2009 (1-888-388-2009)
TTY: 1-877-530-2634 (English)
1-866-495-1161 (Spanish)

BY MAIL
PO Box 2000
Portland, OR 97208

BY FAX
1-877-DTV-4ME2

A converter box is a new product available beginning in 2008 that makes analog-only TVs work after February 17, 2009. A certified converter box is expected to cost between $50 and $70.

Notwithstanding any other provision of the law, no person is required to respond to, nor shall any person be subject to a penalty for failure to comply with, a collection of information subject to the requirements of the Paperwork Reduction Act (PRA), unless that collection displays a currently valid Office of Management and Budget (OMB) control number. Information collected using this form will not be sold.

Form Approved
OMB No. 0660-0024

TV CONVERTER BOX
COUPON PROGRAM
PO Box 2000, Portland, OR 97208-2000

Apply online:
www.DTV2009.gov

Apply by phone:
1-888-DTV-2009 (1-888-388-2009)

Fax applications to:
1-877-DTV-4ME2

Mail applications to:
PO Box 2000, Portland, OR 97208

TTY: **1-877-530-2634** (English)
1-866-495-1161 (Spanish)

ALL APPLICATIONS MUST BE SUBMITTED BY MARCH 31, 2009.

Expect to receive coupon(s) within 2 - 3 weeks of when you submit this Application.

COUPON APPLICATION All information must be filled out. Please type or print clearly.
This Application is to apply for a $40 Coupon which can be used towards the purchase of a TV converter box.

1. Your Name and Address.

NAME
First Middle Last

HOME ADDRESS
Street Address Apt #
City State Zip

If the US Post Office does not deliver mail to your Home Address, provide as much information as you can above regarding your Home Address and provide your Mailing Address below.

MAILING ADDRESS
If different than above
Street Address - or - P.O. Box # Apt #
City State Zip

2. TV Service: Check the statement below that best describes your household.

☐ All or some of the TVs in my house are connected to one or more pay services, such as cable or satellite.

☐ None of the TVs in my house are connected to one or more pay services, such as cable or satellite.

3. Coupons Requested: How many coupons do you want? ☐ ONE - OR - ☐ TWO

4. Signature: By signing below, you declare that the above is true and correct.

Signature Date

Notwithstanding any other provision of the law, no person is required to respond to, nor shall any person be subject to a penalty for failure to comply with, a collection of information subject to the requirements of the Paperwork Reduction Act (PRA), unless that collection displays a currently valid Office of Management and Budget (OMB) control number. Information collected using this form will not be sold.

Figure C.6: Paper Form for the Coupon Program.

Source: NTIA, https://www.ntia.doc.gov/legacy/dtvcoupon/DTV_sample_application_121107b.pdf (last accessed March 20, 2017).

Bibliography

References for Chapter 1

Altshuler, Alan, and David Luberoff. 2003. *Mega-Projects: The Changing Politics of Urban Public Investment.* Washington, D.C.: Brookings Institution Press.

Bailey, Elizabeth. 1973. *Economic Theory of Regulatory Constraint.* Lexington Books.

Besanko, David, and Daniel Spulber. 1992. "Sequential-Equilibrium Investment by Regulated Firms." *The RAND Journal of Economics,* 23(2): 153-170.

Besley, Timothy, and Maitreesh Ghatak. 2001. "Government Versus Private Ownership of Public Goods." *Quarterly Journal of Economics,* 116(4): 1343-1372.

Bickers, Kenneth, and Robert Stein. 2004. "Interlocal Cooperation and the Distribution of Federal Grant Awards." *Journal of Politics,* 66(3): 800-822.

Boone, Christopher, Arindraijit Dube, and Ethan Kaplan. 2014. "The Political Economy of Discretionary Spending: Evidence from the American Recovery and Reinvestment Act." *Brookings Papers on Economic Activity,* 375-441.

Buchanan, James M., Robert D. Tollison, and Gordon Tullock, eds. 1980. *Toward a Theory of the Rent-Seeking Society.* College Station: Texas A&M University Press.

Cambini, Carlo, and Laura Rondi. 2010. "Incentive Regulation and Investment: Evidence from European Energy Utilities." *Journal of Regulatory Economics,* 38: 1-26.

Cantarelli, Chantal C., Bent Flyvbjerg, Eric Molin, and Bert van Wee. 2010. "Cost Overruns in Large-Scale Transportation Infrastructure Projects: Explanations and Their Theoretical Embeddedness." *European Journal of Transport and Infrastructure Research,* 10(1): 5-18.

Congressional Budget Office. 2012. "Estimated Impact of the American Recovery and Reinvestment Act on Employment and Economic Output from October 2011 Through December 2011."

Comments of 71 Concerned Economists. 2009. "Using Procurement Auctions to Allocate Broadband Stimulus Grants," http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1377523.[1]

Conley, Timothy, and Bill Dupor. 2013. "The American Recovery and Reinvestment Act: Solely a Government Jobs Program?" *Journal of Monetary Economics,* 60: 535–549.

Crew, Michael, and Paul Kleindorfer. 1986. *The Economics of Public Utility Regulation.* MIT Press.

Duggan, Mark. 2002. "Does Contracting Out Increase the Efficiency of Government Programs? Evidence from Medicaid HMOs." *NBER Working Paper No. 9091.*

Edwards, Geoff, and Leonard Waverman. 2006. "The Effects of Public Ownership and Regulatory Independence on Regulatory Outcomes: A Study of Interconnect Rates in EU Telecommunications." *Journal of Regulatory Economics,* 29(1): 23-67.

Feyrer, James, and Bruce Sacerdote. "Did the Stimulus Stimulate? Real Time Estimates of the Effects of the American Recovery and Reinvestment Act." *NBER Working Paper No. 16759.*

Flyvbjerg, Bent, Allison Stewart, and Alexander Budzier. 2016. "The Oxford Olympics Study 2016: Cost and Cost Overrun at the Games." *Said Business School Working Paper 2016-20.*

Flyvbjerg, Bent, Mette K. Skamris Holm, and Soren L. Buhl. 2004. "What Causes Cost Overrun in Transport Infrastructure Projects?" *Transport Reviews,* 24(1): 3–18.

Flyvbjerg, Bent, Mette K. Skamris Holm, and Soren L. Buhl. 2003. "How Common and How Large Are Cost Overruns in Transport Infrastructure Projects?" *Transport Reviews,* 23(1): 71-88.

[1] Signers of the letter include, Daniel A. Ackerberg, James Alleman, Kenneth J. Arrow, Susan Athey, Jonathan B. Baker, William J. Baumol, Coleman Bazelon, Tim Brennan, Timothy Bresnahan, Jeremy Bulow, Yeon-Koo Che, Peter Cramton, Gregory S. Crawford, Peter M. DeMarzo, Gerald R. Faulhaber, Jeremy T. Fox, Ian L. Gale, Jacob Goeree, Brent D. Goldfarb, Shane M. Greenstein, Robert W. Hahn, Robert E. Hall, Ward Hanson, Barry Harris, Robert G. Harris, Janice Alane Hauge, Jerry A. Hausman, John Hayes, Thomas W. Hazlett, Kenneth Hendricks, Heather Hudson, Mark A Jamison, John H. Kagel, Alfred E. Kahn, Ilan Kremer, Vijay Krishna, William Lehr, Thomas M. Lenard, Jonathan Levin, Yuanchuan Lien, John W. Mayo, David McAdams, Paul R. Milgrom, Roger G. Noll, Bruce M. Owen, Charles R. Plott, Robert H. Porter, Philip Reny, Michael H. Riordan, Gregory L. Rosston, David Salant, Scott Savage, William F. Samuelson, Richard Schmalensee, Marius Schwartz, Andrzej Skrzypacz, Vernon L. Smith, Daniel R. Vincent, Joel Waldfogel, Scott Wallsten, Robert J. Weber, Bradley S. Wimmer, Glenn A. Woroch, Lixin Ye.

Flyvbjerg, Bent, Mette K. Skamris Holm, and Soren L. Buhl. 2002. “Cost Underestimation in Public Works Projects: Error or Lie?” *Journal of the American Planning Association,* 68: 279-295.

Gimpel, James, Frances Lee, and Rebecca Thorpe. 2012. “Geographic Distribution of the Federal Stimulus of 2009.” *Political Science Quarterly,* 127(4): 567-595.

Greenstein, Shane, Susan McMaster, and Pablo T. Spiller. 1995. “The Effect of Incentive regulation on Infrastructure Modernization: Local Exchange Companies’ Deployment of Digital Technology.” *Journal of Economics & Management Strategy,* 4(2): 187–236.

Guasch, J. Luis, Jean-Jacques Laffont, and Stephane Straub. 2008. “Renegotiation of Concession Contracts in Latin America: Evidence from the Water and Transport Sectors.” *International Journal of Industrial Organization,* 26: 421-442.

Guthrie, Graeme. 2006. “Regulating Infrastructure: The Impact on Risk and Investment.” *Journal of Economic Literature,* 44(4): 925-972.

Hart, Oliver. 2003. “Incomplete Contracts and Public Ownership: Remarks, and an Application to Public-Private Partnerships.” *The Economic Journal,* 113(486): C69-C76.

Hausman, Jerry. 1997. “Valuing the Effect of Regulation on New Services in Telecommunications.” *Brookings Papers: Microeconomics.*

Hayek, Friedrich A. 1978. “Competition As A Discovery Procedure,” in *New Studies in Philosophy, Politics, Economics, and the History of Ideas.*

Hufschmidt, Maynard M., and Jacques Gerin. 1970. “Systematic Errors in Cost Estimates for Public Investment Projects,” in *The Analysis of Public Output, NBER.*

Hobbs, Nathaniel. 2005. “Corruption in World Bank Projects: Why Bribery is a Tolerated Anathema.” *LSE DESTIN Working Paper 05-65.*

Kahn, Alfred. 1971. *Economics of Regulation.* John Wiley & Sons, Inc.

Kahneman, Daniel, and Dan Lovallo. 1993. “Timid Choices and Bold Forecasts: A Cognitive Perspective on Risk Taking.” *Management Science,* 39(1): 17-31.

Laffont, Jean-Jacques, and Jean Tirole. 1993. *A Theory of Incentives in Procurement and*

Regulation. MIT Press.

Laffont, Jean-Jacques, and David Martimort. 2002. *The Theory of Incentives: The Principal-Agent Model.* Princeton University Press.

Laffont, Jean-Jacques, and Jean Tirole. 1986. "Using Cost Observation to Regulate Firms." *Journal of Political Economy,* 94: 614-41.

Leduc, Sylvain, and Daniel Wilson. 2015. "Are State Governments Roadblocks to Federal Stimulus? Evidence on the Flypaper Effect of Highway Grants in the 2009 Recovery Act." *Federal Reserve Bank of San Francisco Working Paper 2013-16.*

Mackie, Peter, and John Preston. 1998. "Twenty-One Sources of Error and Bias in Transport Project Appraisal." *Transport Policy,* 5(1): 1–7.

Manna, Paul, and Laura Ryan. 2011. "Competitive Grants and Educational Federalism: President Obama's Race to the Top Program in Theory and Practice." *Publius: The Journal of Federalism,* 41(3): 522-546.

Martimort, David, and Jerome Pouyet. 2008. "To Build or Not to Build: Normative and Positive Theories of Public-Private Partnerships." *International Journal of Industrial Organization,* 26: 393-411.

Maskin, Eric, and Jean Tirole. 2008. "Public-Private Partnerships and Government Spending Limits." *International Journal of Industrial Organization,* 26: 412-420.

Merewitz, Leonard. 1973. "How Do Urban Rapid Transit Projects Compare in Cost Estimate Experience?" *Reprint No. 104, University of California Berkeley, Institute of Urban and Regional Development.*

Merrow, Edward W. 1988. "Understanding the Outcomes of Megaprojects: A Quantitative Analysis of Very Large Civilian Projects." *RAND Corp. Working Paper R-3560-PSSP.*

Olken, Benjamin. 2006. "Corruption Perceptions vs. Corruption Reality." *NBER Working Paper No. 12428.*

Rosston, Gregory L., and Scott J. Wallsten. 2014. "The Broadband Stimulus: A Rural Boondoggle and a Missed Opportunity." *I/S: A Journal of Law and Policy for the*

Information Society, 9(3): 453-470.

Spiegel, Youssef. 1994. "The Capital Structure and Investment of Regulated Firms Under Alternative Regulatory Regimes." *Journal of Regulatory Economics,* 6: 297-319.

Spiegel, Youssef, and Daniel Spulber. 1994. "The Capital Structure of a Regulated Firm." *The RAND Journal of Economics,* 25(3): 424-440.

Spulber, Daniel. 1989. *Regulation and Markets.* MIT Press.

Taggart, Jr., Robert. 1981. "Rate-of-Return Regulation and Utility Capital Structure Decision." *Journal of Finance,* 36(2): 383-393.

Taggart, Jr., Robert. 1985. "Effects of Regulation on Utility Financing: Theory and Evidence." *Journal of Industrial Economics,* 33(3): 257-276.

Tanzi, Vito, and Hamid Davoodi. 1998. "Roads to Nowhere: How Corruption in Public Investment Hurts Growth." *IMF Economic Issues No. 12.*

Wallsten, Scott. 2013. "Two Cheers for the FCC's Mobility Fund Reverse Auction." *Journal on Telecommunications and High Technology Law,* 11: 369-388.

Zajac, Edward. 1972. "Note on 'Goldplating' or 'Rate Base Padding.'" *Bell Journal of Economics,* 3: 311-315.

Data Sources for Chapter 1

(1) Data Supplement, CCI Data Dictionary with Data.xlsx, http://www2.ntia.doc.gov/files/CCI_Data_Dictionary_with_Data_Open_Data.xlsx. Data comes from sheets called (a) CCI Key Indicators, and (b) CCI Key Indicators Actual. Rows with the latest year available are used. (Data from 2013 released in October 2015).

(2) Key Metrics Dashboard, Comprehensive Community Infrastructure, Submission to NTIA - Broadband Technology Opportunities Program, BroadbandUSA.

(3) Application Part 1 (Incorporated into the award by reference), NTIA Grantee, NTIA Award Documents, Project Application, BroadbandUSA, Broadband Infrastructure Application, Submission to NTIA - Broadband Technology Opportunities Program.

(4) Recovery.gov, Advanced Recipient Data Search, http://www.recovery.gov/arra/espsearch/Pages/advanced.aspx (last accessed, March 2015). Data download available, https://www.fpds.gov/downloads/top_requests/CumulativeNationalSummary_Feb17_2009_Dec31_2013_withDUNS.zip.

(5) Executive Summaries, Legacy Broadband Grant Files by EasyGrant number, http://www.ntia.doc.gov/legacy/broadbandgrants/applications/summaries/#.pdf.

(6) Recovery.gov Recipient Summary, http://www2.ntia.doc.gov/grantee/.

(7) Infrastructure Recipients, BroadbandUSA, Connecting America's Communities, http://www2.ntia.doc.gov/all-recipients?tid[0]=8.

(8) Proposed Service Offerings, Attachment-A, NTIA Grantee, NTIA Award Documents, Project Application, Submission to NTIA - Broadband Technology Opportunities Program, BroadbandUSA, Broadband Infrastructure Application.

(9) Annual Performance Progress Report for Broadband Infrastructure Projects, OMB Control No: 0660-0037. Quarterly Performance Progress Report for Broadband Infrastructure Projects, OMB Control No: 0660-0037.

(11) NTIA, Broadband Technology Opportunities Program (BTOP) Application

Database, http://ssl.ntia.doc.gov/broadbandgrants/applications/results.cfm?org=&keywords=&grantround=&id=&projtype=Comprehensive+Community+Infrastructure&state=&status= (last accessed March 12, 2015).

(12) NTIA, Broadband Grant Application Database, https://www.ntia.doc.gov/legacy/broadbandgrants/applications/search.cfm (last accessed October 25, 2016).

References for Chapter 2

Comments of 71 Concerned Economists (2009). "Using Procurement Auctions to Allocate Broadband Stimulus Grants," http://ssrn.com/abstract=1377523.

U.S. Department of Education Office of Inspector General (2004). "New York City Department of Education's Use of Computer Equipment to Support the E-Rate Program," ED-OIG/A02-D0016, http://www2.ed.gov/about/offices/list/oig/auditreports/a02d0016.pdf.

FCC (2010). "2010 E-Rate Program and Broadband Usage Survey: Report," DA 10-2414, http://transition.fcc.gov/010511_Eratereport.pdf.

FCC (2011). "In the Matter of Schools and Libraries Universal Service Support Mechanism," CC Docket No. 02-6, http://hraunfoss.fcc.gov/edocs_public/attachmatch/DA-11-1354A1.pdf.

FCC (2013). "In the Matter of Modernizing the E-Rate Program for Schools and Libraries, Notice of Proposed Rulemaking," WC Docket No. 13-184, FCC 13-100, http://apps.fcc.gov/ecfs/document/view?id=7520932914.

FCC (2014). "Closing the Wi-Fi Gap in America'sSchools and Libraries," Official FCC blog. (2014, June 6). http://www.fcc.gov/blog/closing-wi-fi-gap-america-s-schools-and-libraries.

Funds for Learning (2003). "In the Matter of Modernizing the E–Rate Program for Schools and Libraries," Comments, WC Docket No. 13184, http://apps.fcc.gov/ecfs/document/view?id=7520944155.

Goolsbee, A. & Guryan, J. (2006). "The Impact of Internet Subsidies in Public Schools," *Review of Economics and Statistics,* 88(2), 336-347.

Hudson, H. (2004). "Universal Access: What Have We Learned from the E-Rate?" *Telecommunications Policy,* 28(3-4), 309-321.

Jayakar, K., & Park, E. (2009). "Impact of School District Demographics and Financial Status on E-rate Funding: Analysis of Pennsylvania Data for 1999 and 2004."

Telecommunications Policy, 33(1-2), 54-67.

Los Angeles Unified School District (2006). "E-rate Status, ABT Committee Report," http://notebook.lausd.net/pls/ptl/docs/page/ca_lausd/fldr_organizations/committee_main/abt_home/abt_agenda/item5-erateoverviewabtupda.pdf.

"Mixed Reaction to iPad Rollout from L.A. Teachers and Administrators." (2013, December 1). *Los Angeles Times.* http://www.latimes.com/local/la-me-ipads-survey-20131202,0,2314290.story?page=1.

NCES (2010). "Table B.1.e.-1 Number and Percentage Distribution of Public Elementary and Secondary Enrollment by Percentage of Students in School Eligible for Free or Reduced-Price Lunch by School Locale and Race/Ethnicity: Fall 2010." Retrieved from http://nces.ed.gov/surveys/ruraled/tables/archive/xls/b.1.e.-1_2010.xls.

NCES (2013a). "Table 4: Number Of City, Suburban, Town, And Rural Regular Public Elementary And Secondary Schools With Membership And Percentage Distribution Of Students In Membership, By State Or Jurisdiction: School Year 2011–12." In "Statistics Selected Statistics from the Common Core of Data: School Year 2011-12," Report No. 2013-441, October 2013. Retrieved from http://nces.ed.gov/pubs2013/2013441.pdf.

NCES (2013b). "Table 4. Number And Percentage Distribution Of Private Schools, By Urbanicity Type And Selected School Characteristics: United States, 2011–12, And Table 15: Number Of Private Schools, Students, Full-time Equivalent (FTE) Teachers, And 2010-11 High School Graduates, By State: United States, 2011–12." In "Characteristics of Private Schools in the United States: Results From the 2011-12, Private School Universe Survey, First Look," Report No. 2013-316, July 2013. Retrieved from http://nces.ed.gov/pubs2013/2013316.pdf.

New America Foundation (2013). "In The Matter Of Modernizing The E-Rate Program For Schools And Libraries," http://newamerica.net/sites/newamerica.net/files/profiles/attachments/NAF_E-Rate_Comments.pdf.

Panagopoulos, C. (2005). "Follow The Money: Assessing The Allocation Of E-Rate Funds." *Social Science Computer Review,* 23(4), 502-506.

"Problems With The E-Rate Program: GAO Review Of FCC Management And Oversight: Hearing Before The Subcommittee On Oversight And Investigations, Committee On Energy And Commerce." 109th Cong. (2005), http://www.gpo.gov/fdsys/pkg/CHRG-109hhrg99904/html/CHRG-109hhrg99904.htm.

Rosston, G. & Wallsten, S. (2013). "The Broadband Stimulus: A Rural Boondoggle And Missed Opportunity," Technology Policy Institute.

State E-rate Coordinators Alliance (2013). "In The Matter Of Modernizing The E-rate Program For Schools And Libraries, Initial Comment," WC Docket No. 13-183, http://apps.fcc.gov/ecfs/document/view?id=7520944060.

USAC (2003). Rural Areas By State, http://www.usac.org/sl/applicants/step04/urban-rural.aspx.

USAC (2013a). Discount Matrix, http://www.usac.org/_res/documents/sl/pdf/samples/Discount-Matrix.pdf, And http://www.sl.universalservice.org/reference/dmatrix.asp.

USAC (2013b). Calculating Your Discount, http://www.sl.universalservice.org/reference/discount.asp.

USAC (2013c). "Schools And Libraries Universal Service Support Mechanism Eligible Services List," CC Docket No. 02-6, GN Docket No. 09-51, http://www.usac.org/res/documents/sl/pdf/ESL_archive/EligibleServicesList-2013.pdf.

USAC Advanced Search Tool (2013). Search Commitments Applicant Report: Year And State [Data Files] Retrieved November 19, 2013, from http://www.universalservice.org/sl/tools/commitments-search/Default.aspx.

USDA Food And Nutrition Service (2014). "Child Nutrition Tables, State Level Tables FY 2009-2013, National School Lunch Participation," data as of June 6, 2014, From http://www.fns.usda.gov/sites/default/files/pd/01slfypart.pdf.

West Virginia Department Of Education (2013). “In The Matter Of Modernizing The E-rate Program For Schools And Libraries,” WC Docket No. 13-183, http://apps.fcc.gov/ecfs/document/view?id=7520943995.

References for Chapter 3

Atkinson, Robert C., Ivy E. Schultz, Travis Korte, Timothy Krompinger, Broadband in America, Second Edition, Where It Is and Where It Is Going, An Update of the 2009 Report Originally Prepared for the Staff of the FCC's Omnibus Broadband Initiative, p. 74, fig. 27, citing Morgan Stanley Research, U.S. Cable, Satellite, Telecom 3Q09 Outlook, Oct. 21, 2009, Cisco Visual Networking Index (North American consumer internet traffic per month by petabit, from 2008 to 2013). Retrieved from http://www8.gsb.columbia.edu/rtfiles/citi/Broadband%20In%20America%20V2.pdf.

Census Bureau (2015d). Download Urban Area Relationship Files [Data file]. https://www.census.gov/geo/maps-data/data/ua_rel_download.html.

Census Bureau (2015e). Explanation of the 2010 Urban Area to ZIP Code Tabulation Area (ZCTA) Relationship File. Retrieved from http://www2.census.gov/geo/pdfs/maps-data/data/rel/explanation_ua_zcta_rel_10.pdf.

Census Bureau (2015f). Urban Area Relationship File Layouts and Contents. Retrieved from https://www.census.gov/geo/maps-data/data/ua_rel_layout.html.

Economist (2012). The Schumpeter Column: Flat-Panel Displays, Cracking Up, Economist Magazine, Jan. 17, 2012, http://www.economist.com/blogs/schumpeter/2012/01/flat-panel-displays-0.

EPA (2011a). Electronics Waste Management in the United States Through 2009, U.S. Environmental Protection Agency.

EPA (2011b). Office of Resource Conservation and Recovery, Report EPA 530-R-11-002, May 2011. Retrieved from http://www.epa.gov/osw/conserve/materials/ecycling/docs/fullbaselinereport2011.pdf.

FCC (2009a). Number of Holding Companies Reporting High-Speed Subscribers by Zip Code as of June 30, 2008, FCC Form 477 and TANA Inc./GDT Inc. Dynamap/ZIP Code Boundary and Inventory Files v16.1, April 2008 (released on February 19, 2009).

Retrieved from
https://transition.fcc.gov/Bureaus/Common_Carrier/Reports/FCC-State_Link/IAD/hzip0608.pdf.

FCC (2009b). National Broadband Plan, OBI Technical Paper No. 1, Chapter 2: Broadband Availability,
http://download.broadband.gov/plan/the-broadband-availability-gap-obi-technical-paper-no-1-chapter-2-broadband-availability.pdf.

FCC (2009c). In the Matter of Annual Assessment of the Status of Competition in the Market for the Delivery of Video Programming, Thirteenth Report, MB Docket No. 06-189, FCC 07-206, January 16, 2009,
https://apps.fcc.gov/edocs_public/attachmatch/FCC-07-206A1.pdf (Video Competition Report).

FCC (2012). In the Matter of Annual Assessment of the Status of Competition in the Market for the Delivery of Video Programming, Fourteenth Report, MB Docket No. 07-269, FCC 12-81, July 20, 2012,
https://apps.fcc.gov/edocs_public/attachmatch/FCC-12-81A1.pdf (Video Competition Report).

FCC (2013). Industry Analysis and Technology Division, Wireline Competition Bureau, February 2013, report on Internet Access Services: Status as of December 31, 2011. Retrieved from
https://apps.fcc.gov/edocs_public/attachmatch/DOC-318810A1.pdf.

FCC (2015). In the Matter of Annual Assessment of the Status of Competition in the Market for the Delivery of Video Programming, Sixteenth Report, MB Docket No. 14-16, FCC 15-41, April 2, 2015,
https://apps.fcc.gov/edocs_public/attachmatch/FCC-15-41A1.pdf (Video Competition Report).

Flint, Joe and Ben Fritz (2015). Netflix Viewership Finally Gets a Yardstick, Wall St. J., Aug. 26, 2015. Retrieved from http://www.wsj.com/articles/netflix-viewership-finally-gets-a-yardstick-1440630513.

GAO (2006). Broadband Deployment is Extensive Throughout the United States, But It Is Difficult to Assess the Extent of Deployment Gaps in Rural Areas, GAO-06-426, May 2006, http://www.gao.gov/new.items/d06426.pdf.

GAO (2008). Increased Federal Planning and Risk Management Could Further Facilitate the DTV Transition, GAO-08-43, November 2007, http://www.gao.gov/assets/270/269612.pdf.

Hanafizadeh, Mohammad Reza, Payam Hanafizadeh, and Erik Bohlin. International Journal of E-Adoption, 5(3): 30-75.

Hart, Jeffrey (2009). The Transition to Digital Television in the United States: The Endgame, International Journal of Digital Television, 1: 7-29.

Howell, Bronwyn (2015). The rural-urban divide on broadband adoption and pricing: Fact or fiction?, May 19, 2015, ttp://www.techpolicydaily.com/internet/rural-urban-divide/?utm_source=newsletter&utm_medium=paramount&utm_campaign=cict.

IBM (2009). Digital-to-Analog Converter Box Coupon Program, Consumer Education Plan Addendum, In Response to U.S. Department of Commerce, National Telecommunications and Information Administration (NTIA), Contract Number: DG-1335-07-CQ-0054, April 23, 2009, Retrieved from http://www.ntia.doc.gov/legacy/dtvcoupon/IBM_NTIA_DTVConsumerEd_Addendum_090423.pdf.

IRS (2010). SOI Tax Stats - Individual Income Tax Statistics - ZIP Code Data (SOI) [Data file 10zpnoagi], accessed February, 2015, Retrieved from http://www.irs.gov/uac/SOI-Tax-Stats-Individual-Income-Tax-Statistics-ZIP-Code-Data-(SOI) and http://www.irs.gov/file_source/pub/irs-soi/2010zipcode.zip.

Katz, Raul L. and Taylor Berry (2014). Driving Demand for Broadband Networks and Services (Springer International Publishing Switzerland).

Kolko, Jed (2010). A New Measure of US Residential Broadband Availability.

Telecommunications Policy 34 (2010): 132–143.

Kruger, Lennard G. and Angele A. Gilroy (2012). Broadband Internet Access and the Digital Divide: Federal Assistance Programs, Sept. 7, 2012, Congressional Research Service, http://www.fas.org/sgp/crs/misc/RL30719.pdf.

Kruger, Lennard G. (2009). The Transition to Digital Television: Is America Ready?, January 21, 2009, RL34165, Congressional Research Service, http://www.mit.edu/afs.new/sipb/contrib/wikileaks-crs/wikileaks-crs-reports/RL34165.pdf.

Location Affordability Index (2017). Data and Methodology: Location Affordability Index Version 2.0, http://www.locationaffordability.info/LAPMethodsV2.pdf.

Location Affordability Index (2017). Data Dictionary, http://lai.locationaffordability.info//lai_data_dictionary.pdf.

Location Affordability Index (2017). About, http://www.locationaffordability.info/About_Data.aspx.

Location Affordability Index (2017). Data http://lai.locationaffordability.info//download_csv.php?state=us&geography=county (last accessed March 1, 2017).

Nielsen (2008). The February 2009 Digital Television Transition: The State of Digital Readiness in the U.S., October 2008. Retrieved from http://www.nielsen.com/content/dam/corporate/us/en/newswire/uploads/2008/10/dtv_update_2_final_edit2.pdf.

Nielsen (2009). Three Screen Report, Television, Internet and Mobile Usage in the U.S., Volume 7, 4th Quarter 2009. Retrieved from http://www.nielsen.com/content/dam/corporate/us/en/newswire/uploads/2010/03/3Screens_4Q09_US_rpt.pdf.

NTIA (2009a). Final Phase Plan for Distributing TV Converter Box Coupons, U.S. Department of Commerce, National Telecommunications and Information Administration (NTIA), November 6, 2008, Retrieved from http://www.ntia.doc.gov/legacy/dtvcoupon/DTV_FinalPhase_081106.pdf.

NTIA (2009b). Outside the Box: The Digital TV Converter Box Coupon Program, U.S. Department of Commerce, National Telecommunications and Information Administration (NTIA), December 2009, Retrieved from http://www.ntia.doc.gov/files/ntia/publications/dtvreport_outsidethebox.pdf.

NTIA (2010). Final Household Participation by DMA, "Ratio of authorized household participation to total households by Coupon Dashboard Market Area (cDMA)."

NTIA (2010a). TV Converter Box Coupon Program: Background and Statistics, U.S. Department of Commerce, National Telecommunications and Information Administration (NTIA), Digital Television Transition and Public Safety. Retrieved from http://www.ntia.doc.gov/legacy/ntiahome/press/press_dtv_background.html.

NTIA (2010b). TV Converted Box Coupon Program, Historical Record of Coupons Requested by ZIP5, Data file zip5Orders_HistoricalRecord.xls. Retrieved February 12, 2015 from http://www.ntia.doc.gov/legacy/dtvcoupon/zip5Orders_HistoricalRecord.xlsx.

NTIA (2010c). TV Converted Box Coupon Program, Historical Record of Coupons Redeemed by ZIP5, Data file Redemptions_by_Zip5_ Historical.xls. Retrieved February 12, 2015 from http://www.ntia.doc.gov/legacy/dtvcoupon/Redemptionsby_Zip5_Historical.xlsx.

NTIA (2010d). Data files from doc.gov (Data files). Retrieved from http://lmgtdfy.usopendata.org/doc.gov/.

NTIA/ESA (2013). Broadband Availability Beyond the Rural/Urban Divide, Broadband Brief No. 2, May 2013, by David Beede and Anne Neville. Retrieved from http://www.ntia.doc.gov/files/ntia/publications/broadband_availability_rural_urban_june_2011_final.pdf.

Park, Sora and Gwangjae Kim (2015). Same Access, Different Uses, and the Persistent Digital Divide between Urban and Rural Internet Users, TPRC 2015. Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2582046.

Pew Research Center (2012a). The Rise of the "Connected Viewer", Pew Research Center's Internet & American Life Project, Aaron Smith & Jan Lauren Boyles, July 17, 2012, http://www.pewinternet.org/files/old-media//Files/Reports/2012/PIP_Connected_Viewers.pdf.

Pew Research Center (2012b). A Bipartisan Nation of Beneficiaries, Pew Research Center's Social & Demographic Trends, Paul Taylor, et al., December 18, 2012, http://www.pewsocialtrends.org/files/2012/12/Benefits_FINAL_12-20.pdf.

Prieger, James (2013). "The Broadband Digital Divide and the Economic Benefits of Mobile Broadband for Rural Areas," Telecommunications Policy, Vol. 37, No. 6-7 (July-August 2013), 483- 502.

Prieger, James, and Wei-Min Hu (2008). The Broadband Digital Divide and the Nexus of Race, Competition, and Quality, Journal of Economic Inequality, http://digitalcommons.pepperdine.edu/cgi/viewcontent.cgi?article=1011&context=sppworkingpapers (applying a maximum likelihood estimation method to broadband adoption factors).

Sandvine (2014). Global Internet Phenomenon Report: 2H 2014, Retrieved from https://www.sandvine.com/downloads/general/global-internet-phenomena/2014/2h-2014-global-internet-phenomena-report.pdf.

Schultz, Ivy, and Bob Atkinson (2013). Will the US Broadband Infrastructure Be Capable of Supporting "Cloud TV"?, September, 26, 2013, p. 8. Retrieved from http://www.citicolumbia.org/media/Presentations/sot2013/Scholtz.pdf.

Yahoo YQL Web Service, Yahoo! GeoPlanet, Data files. Retrieved February 23, 2017 from https://developer.yahoo.com/geo/geoplanet/.

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Effects of the Discount Matrix on E-rate Funds from 1998-2012, *Telecommunications Policy*, 38(11): 1069-1084 (2014)

Exactitude in Defining Rights: Radio Spectrum and the "Harmful Interference" Conundrum (with T. Hazlett), *Berkeley Technology Law Journal*, 28(1): 227-340 (2013)

The Overly Active Corpse of *Red Lion* (with T. Hazlett and D. Clark), *Northwestern Journal of Technology and Intellectual Property*, 9: 51-95 (2010)

On Moral Hazard and Radio Spectrum (2016)

Natural Experiments in Anti-Bundling Legislation: The Empirical Effect of 3G Regulation in Belgium and Finland (with T. Hazlett and B. Skorup) (2014)

Transition in Analog Video: Who Adopted DTV Converter Boxes? (2016)

Estimates for Reasonable Data Breach Prevention (2015)

Spectrum Holdout and Overlay Licenses: An Agent-Based Modeling Simulation (2015)

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