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Abstract

The American Recovery and Reinvestment Act's Broadband Technology Opportunities Program (BTOP) spent $4.7B during 2009-2013 to, int. al, increase broadband adoption in underserved communities. We characterize the BTOP grants and examine the impact of the awards on broadband adoption. Econometric specifications controlling for award endogeneity related to observed and unobserved county-level factors find that spending is apparently associated with increased broadband adoption. Further investigation, however, reveals that the impacts of spending are nonlinear and even nonmonotonic over the range of county-level BTOP spending in the data. Controlling for trends to reduce the potential for spurious correlation between spending and outcomes removes most of the significance of the results. We conclude with three lessons for policymakers derived from the uncertain outcomes of BTOP spending found in our exploration.

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I. Introduction

In 2009, the United States federal government passed The American Recovery and Reinvestment Act (ARRA), a stimulus act that comprised the immediate goals of creating and saving jobs and spurring economic activity while claiming to provide accountability and transparency in spending. Of the over $800 billion in stimulus funds, $7.2 billion was allocated for expanding access to broadband services throughout the nation (NTIA, 2011). There is a great deal of research showing that increases in broadband penetration are associated with increases in GDP, which provides a link between the broadband program and the government's ultimate goals of the stimulus act.[1]

Of the $7.2 billion allocated for broadband generally, Congress appropriated $4.7 billion for the National Telecommunications and Information Administration (NTIA) to administer the Broadband Technology Opportunities Program (BTOP).[2] The availability of BTOP funds was intended to increase broadband access and adoption rates among populations underrepresented with respect to broadband usage, such as minorities and low-income households, along with the larger goals of creating jobs and spurring economic growth.[3] In this paper, we analyze one of the BTOP program outcomes by asking: did BTOP spending result in increased broadband adoption?

By September 30, 2010, two rounds of applications and funding for BTOP were completed, and over $4 billion had been disbursed to 289 recipients proposing projects in four

[1] Gillett et al., (2006) and Katz and Suter, (2009) identified positive links between broadband deployment and economic prosperity. Scott (2012) similarly found that a 10% increase in broadband penetration is correlated with a 1.35% increase in GDP for developing countries, and a 1.19% increase for developed countries. See also Koutroumpis (2009) and Qiang et al. (2009).

[2] NTIA is an executive branch agency under the U.S. Department of Commerce that advises the executive branch of the federal government on the telecommunications industry. The remaining $2.5 billion the ARRA allocated to broadband was to be distributed through the Rural Utilities Service (RUS).

[3] ASR (2012).

categories: supporting communities' efforts to sustain adoption of broadband service ("sustainable adoption," 44 grants; $251 million), the deployment of broadband infrastructure (123 grants; $3,500 million), expanding public computer centers (66 grants; $201 million), and maintaining a nationwide public map of broadband service capacity and availability (56 grants – one per state, five U.S. territories, and Washington D.C.; $293 million) (NTIA 2014).[4]

Applicants for BTOP funds were to describe fully their goals and implementation plans and to satisfy at least one of the statutory purposes,[5] the most relevant of which for this investigation are to provide access to broadband service in unserved and underserved areas and to stimulate demand for broadband.[6] Funds awarded in the sustainable adoption category, to which we pay special attention below, could be used to deploy broadband-related technology, digital literacy programs aimed at broadband usage, broadband-related education and outreach, and programs to provide potential users with greater access to broadband.[7] Each BTOP applicant was expected to specify which of the federal goals and target groups the project would benefit. Using each funded project's application summary and quarterly reports, we created a dataset of all programs funded under both rounds of the program in 2009 and 2010.[8] Details of the data are found in Section 3.

[4] Prior to implementation of the BTOP program, the government broadly determined funding priorities by specifying the total allocation of funds to be granted in each category.

[5] See NARA (2009). For an excellent summary of the funding process see Rosston and Wallsten (2013). Broadband USA also offers documentation explaining the rules and processes of the BTOP program: http://www2.ntia.doc.gov/. Finally, the following NTIA website offers answers to frequently asked questions about BTOP: http://www2.ntia.doc.gov/files/nofa2_faqs_5_28_10.pdf.

[6] From BroadbandUSA Connecting America's Communities, accessed August 17, 2014, at http://www2.ntia.doc.gov/documents/BTOPPolicyReviewPPT.pdf. Unserved areas have less than 10% broadband penetration, and underserved areas have less than 40% penetration. The other purposes of BTOP were to support the missions of schools, libraries, healthcare providers and public safety agencies with broadband access, training, and use.

[7] Eligible Costs for Sustainable Broadband Adoption, 74 *Fed. Reg.*33113 (July 9, 2009).

[8] Applications in Round 1 were accepted from July 14, 2009 to August 14, 2009. Round 2 applications were accepted from February 16, 2010 to March 16, 2010, with the exception of an extension until March 26, 2010 for awards in the category of comprehensive community infrastructure.

To analyze outcomes, we employ econometric models that relate broadband adoption before and after implementation to the amount of BTOP funding in the county. Given the interval censored (i.e., ordinal categorical) nature of the observed dependent variable, fixed broadband lines per household in a county, we develop a novel adaptation of an estimation method for ordinal logit models with fixed effects. Our adaptation, unlike existing methods, allows identification of the marginal effects in the scale of the latent continuous variable. Thus, we are able to estimate the impact of BTOP spending on broadband penetration, even though the latter is only indirectly observed in the data. Simple regression specifications find apparently significant impacts of the BTOP awards on broadband adoption. However, estimations based upon more stringent econometric specifications (i.e., a higher bar for evidence of causality by accounting for trends) reveal that the marginal impacts of spending vary greatly at different spending levels and are far less certain than the simple specifications indicate. In fact, the impact of the stimulus spending on broadband adoption may well be zero, at least across most of the range of spending.

Historically, relatively few analyses have measured actual program outcomes from broadband and other Internet adoption programs (Hauge and Prieger, 2010); most evaluations focus only on program implementation. For example, one might confirm that computers with Internet access were installed at a school, but find no assessment of whether students' access to the Internet, grades, test scores, graduation rates, or future labor market outcomes improved as a result.[9] Our work thus provides a valuable contribution to the literature on program effectiveness in the area of digital diffusion programs. The paper proceeds as follows. In Section II we provide a brief review of relevant literature. Section III explains the data. Section IV explains

[9] See Goolsbee and Guryan (2006) for a rare exception.

the empirical method and Section V provides results. Section 0 offers policy implications and the conclusion.

II. Literature

There are huge literatures—largely separate—on outcomes from government spending and the determinants of broadband deployment and adoption. We constrain our review to those works that seek to determine program outcomes, and highlight research that considers the direct and indirect effects of spending or other factors driving broadband adoption. With broadband infrastructure of some form now reaching nearly all the population, cost might be deemed the next critical barrier to adoption. However, according to the FCC's "Broadband Adoption and Use in America" (Horrigan, 2010), only 36 percent of non-adopters cite cost as the main reason they do not have broadband at home. This means the majority of non-adopters cite other factors for not adopting. For example, 22 percent of non-adopters cited digital illiteracy as a factor and 19 percent cited lack of relevance. If it is important to increase digital literacy and the perceived relevance of broadband and the Internet, then a multi-faceted approach to increasing broadband adoption is appropriate. In prior work (Hauge and Prieger, 2010), we reviewed both supply-side (infrastructure) and demand-side (adoption and use) programs and the few available subsequent analyses of such programs. We noted that "Encouraging broadband adoption is only part of a larger digital literacy effort, and programs work when they make non-users want to connect, make the Internet cheaper and easier to use, and adjust to users' preferences" [page 1]. Turner-Lee and Gant (2010) affirm our assertion and suggest that policy should focus on the perceptions and behaviors of broadband consumers to encourage increased adoption and usage. Their paper offers a survey of the existing evidence regarding the acceptance of broadband given affordability, availability, and accessibility. Turner-Lee and Gant cite the expected performance of broadband and the time, energy, and social aspects of adoption as driving forces behind such adoption. They do not, however, examine the impact of public computing centers or sustainable adoption programs on adoption.

Some research focuses on communities which lag in broadband adoption and examine barriers to use. Gant et al. (2010) use data from the National Minority Broadband Adoption Study conducted in 2009 and 2010, and present evidence on white, black, and Hispanic broadband adoption and usage, concluding that the value of adoption is not seen equally across races and ethnicities. Similarly, Horrigan and Satterwhite (2010) suggest that broadband adoption requires three "pillars": infrastructure, sustained innovation (that results in lower costs and improvements in usability), and a network of social support for potential users. Horrigan and Satterwhite focus on the last of these pillars, and argue that policymakers must understand that the social infrastructure around non-adopters is crucial to drawing them to sustained and meaningful Internet use. The primary method for such encouragement is providing support at a local level that focuses on education of non-adopters so that they become comfortable with technological innovations, and so that a culture of use is promoted. Similarly, Prieger (forthcoming) notes that the differences in usage rates (generally) are statistically significant and reveal large adoption gaps by race and ethnicity that do not appear to be caused by lack of access to broadband. Interestingly, the racial gaps for blacks do not persist when considering mobile broadband.

Finally, Peronard and Flemming (2011) cite the lack of relevant content as reason for non-adoption, and suggests that encouraging more appropriate content may be optimal for increasing adoption.[10] He points out that there is a need for "an enriched theoretical approach aimed at empirically examining the relationship between broadband adoption and the

[10] See also: Firth and Mellor, 2005; Papacharissi and Zaks, 2006; Preston, Cawley, and Metykova, 2007.

interpretation of causes and effects” (page 692). These papers present the state of affairs, and together suggest that the inclusion of public computing center grants and sustainable adoption grants are likely to be effective if they target non-adopting communities, but the research fails to link such programs to increased adoption.

In addition to more general research on broadband adoption, some recent research specifically addresses BTOP as part of the ARRA. Many such papers report negative findings. Gimpel et al. (2013) state that the geographic distribution of funds was poorly mismatched with needs, therefore resulting in the lack of success of the program. Rosston and Wallsten (2013) echo this conclusion calling the program’s allocation of funds inefficient, and later in Wallsten and Rosston (2013) calling the program a “rural boondoggle”. Given their early date, none of these works considered the intended outcomes of the various programs; rather, they analyzed the distribution of funds and its efficiency and apparent equity. In another paper, Jackson and Gordon (2011) studied 27 projects that engaged in BTOP and the Broadband Initiatives Program. They found examples of difficulties and also of successes and from these projects offer lessons for future publicly funded programs.

Jayakar and Park (2012) offer a thorough study of factors likely to lead to the success of Public Computer Center (PCC) grants. They note that the BTOP required PCC projects to specify the degree of accessibility of the planned PCC to the public and to verify the technical feasibility of the project. The authors suggest that the demand characteristics of the community would allow better prediction of the anticipated success of PCCs, and therefore allow for more efficient distribution of funds, but that the BTOP grant process did not incorporate these considerations. In contrast to their earlier, prospective work, the same authors subsequently (Park and Jayakar, 2013), analyze empirically the distribution of BTOP PCC funds and find that money went to areas of pre-existing high broadband availability and demand, contrary to the BTOP's goals. Nevertheless, they conclude that this pattern of funding is cost-efficient.

Perhaps closest to our work in this respect is that by LaRose et al. (2014), who provide an excellent overview of the BTOP applicants and funds distributed, and emphasize that the main empirical studies in the U.S. are correlational and as such, offer limited evidence of the causal impacts of broadband investment, and even less the effects of public investment. While they utilize a database similar to that which we have amassed, they did not include an empirical evaluation as BTOP projects were not scheduled to be completed until the end of 2012 (with possible extensions through the end of 2013). This small subset of projects, however, does little to inform the overall analysis is BTOP program outcomes.

While we have not found prior research indicating that public computer centers or sustainable adoption programs have increased broadband adoption, we do find that certain factors have proven to be successful in increasing adoption. For example, Prieger (forthcoming) shows that mobile broadband may be successful in connecting minority communities to the Internet where they live. In a 2006 paper, Glass (2006) found that adoption rates for Digital Subscriber Line (DSL) services in rural areas increase significantly once video is added to the service bundle. Subsequently, Glass and Stefanova (2010) show that policies that lower the cost of providing video may stimulate broadband adoption. Other important drivers of adoption are content on the Internet (Howell, 2002), specifically home entertainment in general (Choudrie and Dwivedi, 2006) and applications such as downloading music and online purchasing (Kolko, 2010) in specific.

The Office of Management and Budget states that an appropriate evaluation of a federal project such as BTOP should assess whether implementing the program resulted in its intended results for its intended beneficiaries (OMB, 2009). Clearly it is easier to determine progress towards project execution than to determine the effects of implemented projects. Regardless, projects should be designed to have real impacts on participants, and potential impacts should be verified empirically using convincing econometric methods to establish causal relationships. Therefore, in this paper we focus on the effects on broadband adoption of projects funded by BTOP. The success of specific demand-side programs designed to encourage broadband adoption remains largely unproven in the literature (Hauge and Prieger, 2010). For this reason, our attempt to discern the outcome of BTOP program funding represents an important contribution to the literature.

III. Research questions and associated data

To determine program outcomes, we started by categorizing projects by the claimed outcomes in the applications. We included all applicants classified by project category; type of applicant (e.g., a city, private company, or university); the location of both the applicant and the proposed project's targeted recipient(s); characteristics of each project's targeted group(s) (e.g., Native American, disabled, or veteran); and the stated goal(s) of the project (e.g. , digital literacy, healthcare, or workforce development).[11] We added the associated county-level socio-demographic data for each project's target area for analysis in this section.

A BTOP grant may cover a single county, several counties, an entire state, areas of multiple states, or (in a few cases) the whole nation. The econometric results in Section IV are based on the geography claimed as the intended recipient of the benefit of the grant. For the key "treatment" variable for the estimations, we construct a county-level BTOP spending variable as

[11] Rosston and Wallsten attempted to obtain data directly from the NTIA but were given an estimated initial fee of $144,715.09 to process their data request; they concluded that "the NTIA does not make such information readily available." (Rosston and Wallsten, 2013, footnote 10).

follows. First, the set of counties claimed to be benefited by each award was determined. This step necessarily involved judgment in some cases, because the NTIA did not require applicants to be specific.[12] Second, out of necessity the total award amount was split among associated counties proportionally to the numbers of households they contained. While this assumption of uniform spending across the area of intended benefit is surely wrong, there are no consistent data in the applications to allow more refined allocations. Thus, there is inescapably some measurement error in the key treatment variable, and we explore this in our robustness tests below. Third, the spending per household was aggregated across all funded projects to arrive at the total BTOP award amount per household for each county in the nation. Funding in aggregate for the county ranges from $0.71 per household (those counties only covered by the three nationwide projects) to $5,049 per household. Average spending is $55 and median spending is $22. The distribution of the log of this variable is shown in Figure 1.[13]

Table 1 provides details on the type of applicants across BTOP categories. Private entities (listed as "Others" in the table), including both non-profit and for-profit organizations compose the majority (52.8 percent) of applicants, receiving just under half of all funds disbursed (48.4 percent). States, tribal applicants, and universities were better able to secure funding than each of the other applicant types: their percentage point difference in total applications funded less total applications were 14.7, 0.5, and 0.01, respectively. Cities (-8.2 percentage point difference between applications and funded projects), Other (-4.3), and Libraries (-2.1) were least successful. While this result indicates tribal lands were recognized as a target group as specified

[12] Examples of judgment include matching statements such as "rural New Mexico" to noncore RUPRI counties and "south central rural North Dakota" to non-CBSA counties in the south central part of the state.

[13] Logging the variable reduces greatly the skewness in the spending levels, but the inherent bimodality remains. While bimodality does not, in principle, render the spending variable unsuitable for use as a regressor, it does lead us to consider carefully in the econometrics whether the variable's impact on outcomes of interest changes as spending increases.

by BTOP goals, it also suggests local applicants were less successful than might be ideal given the BTOP's emphasis on local community driven programs. [14]

In Table 2, we differentiate between applications designed to provide programs within a single county and those covering multiple counties, including state-wide, multi-state, and national programs. We find that multi-county programs (i.e. those of larger geographic scope) were more successful at securing funding than programs designed to serve a single county. This seems counter to BTOP's emphasis on the importance of community support and community anchor institutions, and runs counter to the notion that local level programs are likely to have greater demand-side impact on unserved and underserved communities than non-local programs.

Next, we quantified the frequency with which stated program targets were cited in applications. To do this, we recorded any statement in an application referencing aid to the various groups BTOP was designed to help. The frequencies of citations of these BTOP target groups are shown in Table 3. We note the importance of digital literacy and workforce development as demand-side programs, and the importance of mapping for entities to determine infrastructure needs. Similar analysis for the category of the proposal is in Table 4. Note that while Infrastructure proposals were not the majority category by number of proposals, such proposals were most often funded and received the most money. Public Computer Center and Sustainable Adoption proposals were funded at a lower rate. Since Sustainable Adoption projects were aimed specifically at increasing broadband adoption, we examine this category by itself in the empirical work below. The distribution of spending in the Sustainable Adoption category is shown in Figure 2. About 45% of counties received no specific BTOP funding in this

[14] In the Broadband Technology Opportunities Program Frequently Asked Questions (May 28, 2010, page 10), it is stated that "Proposals that would benefit tribal entities receive extra consideration by the program during review, and the comments of tribes are a selection factor in choosing BTOP awards."

category apart from the single nationwide award (which contributed $0.13 per household to each county). Another 22% of counties each received $0.58 per household, the sum of the nationwide and a single large multistate grant. The average Sustainable Adoption funding per household is $1.82, the median is $0.58, and the maximum is $240.

Did groups most in need, termed "unrepresented and underrepresented" in the BTOP guidelines, apply for and receive funding commensurate with those needs? We cannot determine why some (statistically) needy communities did not apply for funding, but we can compare the size of BTOP target subpopulations in counties with applications and counties covered by no application. Since technically all counties are covered by statewide and(the few nationwide projects, only applications targeting specific counties are included in these statistics. The left side of Table 5 summarizes these data using the proportion of the county population composed by various socio-demographic characteristics. The proportions are first calculated with simple and population-weighted averages. The table shows, for example, that in counties specifically covered by at least one BTOP application, blacks compose an average of 10.2% of the population (see column one), while in other counties blacks make up 4.4% of the population (column three). The population weighted figures, 13.6% vs. 7.2%, show that subpopulation from counties appearing in applications has a higher proportion of blacks than does the subpopulation from counties not covered by an specific application. For a different comparison, column two of Table 5 reports an application-weighted version of the figures, so that a county covered by *n* applications receives *n* times as much weight in the averages. The application-weighted proportion of blacks in applicant counties is even higher than the previous figures from column one, implying that not only were minority-heavy counties targeted by applications, they also received coverage under more applications. The same is true, to different degrees, for Hispanics and Asians, but not for Native Americans, the disabled, veterans, or senior citizens. This suggests that some of the populations most in need (but not all) were more likely to apply for funding, in accordance with BTOP goals.

The last two columns of Table 5 show, for the subset of counties covered by an application, a comparison of demographics when applications were funded versus denied. When there are material differences in the demographics between these groups of counties, as there are for blacks, Hispanics, Asians, and possibly American Indians, they are in the direction of favoring applications covering more minorities. Because these minorities (apart from Asians) are typically underrepresented among broadband users,[15] these results suggest that funding, generally speaking, was allocated according to BTOP goals of serving those populations most underrepresented in terms of broadband.

How should we expect BTOP spending to stimulate broadband adoption? At one end of the black box, money is spent on programs with various BTOP goals. At the other end is the potential for increased broadband adoption (as well as the other BTOP targets not examined here). There are many mechanisms, direct and indirect, by which spending on broadband programs may lead to adoption. Sustainable adoption projects, by definition and goal, should have a direct impact on adoption. Infrastructure projects have indirect effects on demand through the supply side, to the extent that new areas gain access to broadband (or to higher quality or lower price broadband). Finally, spending on any type of project may have indirect effects on broadband adoption through many channels: demand-side externalities through

[15] In July 2011, 71% of non-Hispanic whites and 72% of Asians used the Internet at home, but only 52% of blacks and 49% of Hispanics did. Another way to examine broadband availability for minorities is to compare the number of residential broadband providers available to a representative member of each racial or ethnic group. Sixty-four% of white non-Hispanics have the greatest chance of having four or more fixed broadband providers where they live. Blacks have the lowest similar probability, at 46%, followed by Asians and Pacific Islanders (49%) and Hispanics (53%) (all statistics from Prieger (forthcoming)).

network effects, demand stimulation from being introduced to broadband through a public computer center or digital literacy project, market externalities stemming from increased competition or lowered prices prompted by BTOP activity, or other supply-side externalities (e.g., high participation in a BTOP sustainable adoption project may prompt existing broadband providers to market more attentively and attractively to the target population). We do not seek to disentangle these mechanisms, but instead look for whether the total effect through all channels is large enough to be measureable. Given the special connection between sustainable adoption projects and broadband adoption, however, we do examine sustainable adoption spending by itself in some estimations.

The specific outcome we consider is fixed residential broadband connections per 100 households (RFC/HH). "Broadband" is defined two ways: by the FCC definition of at least 200 kbps in at least one direction; or, by the BTOP definition of at least 768 kbps downstream and greater than 200 kbps upstream. The latent variable y_{it}^* is not observed; instead, categorical variable y_{it} = 0,1,…,5 is observed. The categories are defined as in Table 6. Summary statistics of these outcomes and the BTOP spending variables are shown in Table 7.

IV. Empirical methods

The years of data included in the estimations are 2009, before the programs were funded, and 2013, after funding and implementation. Let G_{it} be the BTOP log award size per household in county i and year t, where award dollars have been aggregated to the county level as described in the previous section. Treatment variable G_{it} will be defined variously as total spending, spending allocated to Sustainable Adoption grants, and spending allocated to awards in categories other than Sustainable Adoption. Let y_{it}^* be the outcome of interest, RFC/HH, measured midyear for 2009. For 2013, the FCC version of RFC/HH is measured at year end, while the BTOP version is measured at the beginning of the year (the latest available).[16] For G_{it}, it is assumed (in accord with program start dates) that no money is spent as of Q1 2009 and all money is spent as of the end of 2013, although some projects from round two of the funding had not finished as of that date.[17] Additionally, because some broadband and economic data for 2014 is not yet available, 2013 makes a natural ending date for us in any event. So $G_{it} = 0$ for 2009 and G_{it} for 2013 is the full amount awarded. We present several models for assessing the association between local BTOP spending and outcomes, proceeding from simple to more complex specifications.

Each specification for the latent variable is of the general linear form

$$y_{it}^{*} = \beta' x_i + \gamma G_{it} + \varepsilon_{it} \tag{1}$$

or

$$y_{it}^{*} = \alpha_i + \gamma G_{it} + \varepsilon_{it} \tag{2}$$

where x_i is a vector of variables (including a constant) for the economic and demographic characteristics of the county at the start of our study period, 2009;[18] α_i is a county-specific term incorporating all time-invariant observed and unobserved heterogeneity; and ε_{it} is a mean-zero error term following the logistic distribution with scale parameter σ, possibly correlated across t within the same county. The term α_i subsumes factors related to the endogeneity of G due to selection bias in the awarding of BTOP money. Furthermore, note that the county-specific intercept also includes factors such as the economic growth or change in broadband usage in the county, *expected* as of 2009, which also may be related to the distribution of the BTOP awards.

[16] The RFC/HH data using the BTOP definition are unavailable after December 31, 2012 due to a change in data collection at the FCC.

[17] By December 2013, 192 projects (86% of all) had been completed (according to NTIA's 20th Quarterly Status Report, issued June 26, 2014). The remaining 32 projects in progress had received an unspecified extended award period.

[18] Given our short period under study, how slowly demographics typically evolve, and our inclusion of county fixed effects in the estimations, we will not worry about year-specific demographic covariates.

Terms α_i and β are not separately identifiable, which is why only one of these will appear in any particular regression. We also allow for nonlinearity in the impact of BTOP spending on RFC and control for national trends by examining the following additional specification,

$$y_{it}^* = \alpha_i + f(G_{it}) + \tau_t + \varepsilon_{it} \tag{3}$$

where *f* is a nonlinear function of *G* and τ is a year fixed effect. We estimate *f* with a flexible curve-fitting method, restricted cubic splines.[19] The addition of the trend to the specification implies that identification of the impact of spending comes from increases in spending and broadband adoption that are net of national trends. Controlling for trends may be important in this application because both *G* and *y* trend upward.

Since latent variable y^* is unobserved, we estimate the unknown parameters of the model by maximum likelihood (MLE). The relationship between the latent and observed variables is shown in Figure 3.[20] In equation (1), the parameters (β, γ, σ) are identifiable with MLE.[21] We use the Baetschmann (2012) extension to Baetschmann, Staub, and Winkelmann's (2011) "blow up and cluster" (BUC) method for fixed effects ordered logit to account for the fixed effects α_i in equations (2) and (3). In the BUC method, the dependent variable is converted to a set of dichotomous dependent variables, and conditional logit regression is then used to estimate the slope coefficients. Baetschmann (2012) showed how BUC can be extended to identify the ordered logit cutpoints in addition. Finally, in the appendix we show how these methods,

[19] Restricted cubic splines (Harrell, 2001) result in an estimated continuous and differentiable *f* that is linear before the first knot and after the last knot, and is a piecewise cubic polynomial between adjacent knots.

[20] The figure reveals that we have made a slight simplification in identifying y^* with RFC/HH. Latent y^* takes values on the real line, while actual RFC/HH cannot be negative (although it could, in principle, exceed 100). A more pedantic exposition would define the latent variable y^{**} to take values on the real line, then define y^* = RFC/HH to be a left censored version of y^* a la the Tobit model, and then finally to define *y* as the categorical observed variable. For our purposes, the only thing that matters, however, is that y^* as we have defined it has units on the appropriate scale of RFC/HH.

[21] We estimate the model using constrained ordered logit estimation, as described in the appendix. In ordered logistic regression, the scale parameter σ is not identified separately from the coefficients and the cutpoints, but here σ and the constant in β are identified because the cutpoints are known (see Figure 3).

combined with our knowledge of the location of the actual cutpoints, can be used to identify the scale of the logistic error term. With the variance of the logistic error term estimated, we can then estimate the marginal effects in the natural scale of RFC/HH. In particular, the marginal effects will correspond to changes in residential broadband lines per hundred households. To account for correlation over time among the error terms from the same county, we estimate all standard errors using a cluster-robust estimator.

V. Results

This section contains the estimation results and the implied marginal effects of the BTOP spending. Using data on all funded projects, we begin with a simple linear specification, add county fixed effects to control for selection bias, demonstrate the need to allow for nonlinear impacts of spending, and finally estimate the model accounting for time trends.

A. Linear Specifications

The results for the regression specification based on equation (1) are in Table 8. Each column in the table is for a regression with the dependent variable RFC/HH defined with the definition of broadband as given in the column heading. The first pair of columns is for the impact of total BTOP spending, while the last two columns are for sustainable adoption spending only. Given the log form of the spending variable G_i, the coefficient on spending, γ, is 100 times the marginal effect on RFC/HH (on a 100 point scale) of a 1% increase in the BTOP award per household in the county. Thus the estimated coefficient of spending of 2.6 in column one of Table 8, for the FCC definition of broadband, implies that a 1% increase in total BTOP spending is associated with increased broadband adoption of 0.026 (i.e., an additional 0.026 connections per 100 households). The marginal effects using the BTOP definition of broadband RFC/HH is a bit larger (2.92) and is also statistically significant. In general, across all our regressions the marginal effects are typically (but not always) slightly larger for the BTOP version of the dependent variable but—importantly—do not have higher significance levels (compared to the FCC version of *y*). With that in mind, and given that the FCC-defined data are available for longer than are the BTOP-defined data, we will not discuss explicitly the results for the BTOP definition of RFC/HH below.

While the covariates added to the regressions are included only to control for omitted variable bias in the impacts of BTOP spending, it is interesting to note that many of their coefficients are significant, and in the direction typically found in other studies of broadband penetration, diffusion, and adoption (e.g., Chaudhuri, et al., 2005; Prieger and Hu, 2008). Counties with more people and business establishments, counties with a lower proportion of non-Asian minorities, and higher proportions of Asian minorities, more educated residents, and higher-income households generally have higher predicted RFC/HH (although the impact of income and education are not monotone). The only unexpected result is that counties with more senior citizens have higher broadband penetration.[22]

The coefficients on spending from BTOP awards that target sustainable adoption, in columns three and four of Table 8, are higher than those for total spending. This is as expected, since not all BTOP spending is aimed specifically at increasing home adoption of broadband.

The estimates of the impact of spending from equation (1) may be biased if awards were granted to counties based on their prospects for growth in broadband adoption. We may naturally expect that selection bias would attenuate the estimated impact of spending (or even reverse it) if more money was awarded to counties with dimmer prospects for increased adoption in the absence of the awards. However, other work suggests that money was steered toward

[22] In July 2011, 69.9% of those between the ages of 18 and 64 used broadband Internet at home, while only 39.7% of senior citizens used broadband (computations by the authors using the Computer and Internet Use Supplement to the Current Population Survey).

counties with influential representatives in Congress (Hauge, 2015) and relatively favorable conditions for broadband adoption (Park and Jayakar, 2013). Thus, in principle, the bias may be in either direction. Adding county fixed effects, as in equation (2), and estimating via the BUC method removes selection bias from the estimate of γ.

The results from estimations based on equation (2) are in the first six columns of Table 9. Again we examine total (columns 1 and 2) and sustainable adoption spending (columns 3 and 4) in separate regressions, and also split total spending into sustainable adoption and other spending in the final pair of regressions (columns 5 and 6). Compared to the estimates in Table 8, adding the fixed effects increases the coefficients on total and sustainable adoption spending in the first four columns of Table 9. The increase is largest for the sustainable adoption coefficient, which increases from 3.7 to 4.9 (for the FCC definition of the dependent variable). Thus selection bias appears to have attenuated the marginal effects in the previous regressions. Even so, the marginal effects are not large; a 10% increase in total spending would move the needle for RFC/HH less than a third of a broadband connection. The coefficients fall when both sustainable adoption and other spending are included in the same regression (columns 5 and 6 of Table 9), but all are still significant.

In summary, the results from this section show that the BTOP spending is apparently statistically significantly associated with broadband adoption, assuming that a linear-log regression specification is correct. However, these results are not definitive—and we make no claim regarding causality—because there may be additional nonlinearity in the marginal effect of BTOP spending, and some of the positive association between G and y may come from spurious correlation between trending variables. We investigate these issues in the following sections.

B. Nonlinearity in the effect of BTOP spending

Turn now to equation (3), where spending variable *G* enters the specification for the mean outcome in a nonlinear fashion. We at first set aside the time trends, taking τ to be zero in equation (3). The results of the interval censored logistic estimation via the BUC method, where nonlinear function $f(G)$ is estimated with restricted cubic splines, are in the first two columns each of Table 10 and Table 11. The general significance of the spline variables 2 through 6, which allow for the nonlinearity in *f*, provides evidence that constraining the impact of *G* to be linear is incorrect.

The slope of *f* is the marginal impact of log spending. The nonlinearity and nonmonotonicity between spending and adoption outcomes is clearly seen in Figure 4 (for total spending) and Figure 5 (for sustainable adoption spending). If a linear specification as in regression specifications (1) and (2) were correct, the plotted lines would be horizontal. The estimated marginal effects lead to several conclusions. First, the confidence bands for the marginal effects do not span zero in most places, indicating apparent statistically significant association between spending and RFC/HH remains at most spending levels. Second, the marginal effect is not always positive. At medium and the highest levels of total spending, there is significant *negative* association between spending and adoption. The same is true for medium levels of sustainable adoption spending. Third, the marginal effect is not monotone; there is substantial nonmonotonicity in *f*.

C. Accounting for time trends

We now turn to the full regression specification based on equation (3) including the trend term. Inclusion of the trend along with the fixed effects implies that identification of γ comes from variation in the increase in adoption and spending that is net of the average increases.

This specification removes omitted variable bias potentially caused by spurious correlation between the trending dependent variable and BTOP spending. The former has a positive trend since broadband adoption, however measured, has steadily increased since the FCC first began to measure it in 1999. The latter has a positive trend because BTOP spending is zero in every county in 2009 and positive everywhere in 2013 (since there were a few nationwide projects that contributed at least a little spending to each county). This specification sets the highest bar for convincing evidence that BTOP spending causally affected adoption. The disadvantage of this specification is that controlling for trends necessarily removes some of the variation in the data, not all of which necessarily contributes to spurious correlation between spending and adoption. Thus, while this specification yields regression results that are least likely to be afflicted with spurious correlation, they are not necessarily the "best" estimates.

The estimation results for the flexible, nonlinear parameterization of the spending impacts are in the last two columns each of Table 10 and Table 11, and the marginal effects are plotted in Figure 6 and Figure 7. Comparing the marginal effects of total spending with and without the trend in Figure 4 and Figure 6, it is apparent that the greatest difference is the wider confidence band when the trend is included. For the FCC definition of broadband, spending has a positive, significant impact on broadband adoption only for low levels of spending (up to about 1 log dollar) and in a middle range (roughly between 2 and 3 log dollars). Elsewhere the marginal effects are insignificant or (in a narrow range from roughly 3.4 to 4 log dollars) significantly negative. For the BTOP definition of broadband, spending has a positive, significant impact on broadband adoption only for a middle range, roughly between 2 and 3 log dollars. The impact of spending beyond that level turns negative. For sustainable adoption spending, the marginal effect is statistically indistinguishable from zero for all levels of spending, for both definitions of broadband.

The conclusion that controlling for trends removes most or all of the apparent positive association between BTOP spending and broadband adoption does not depend on the nonlinearity in *G* allowed by equation (3). Adding a trend to any of the previous linear specifications based on equation (2) results in either lack of significance of the spending coefficient or, in the case of the FCC definition of broadband regressed on total spending, a significant *negative* coefficient. As an example, the estimates for sustainable adoption spending with trend are in the last two columns of Table 9.

D. Robustness Checks

To bolster the strength of the findings above, we report the results of several additional estimations in this section. For the first test of the robustness of the results, the spending variable *G* is changed to be BTOP awarded amounts per capita, instead of per household. The estimated spending coefficient γ with the new definition of *G* is very similar to the results above in each Table (almost always to the first or second decimal place). The nonlinear marginal effects are also virtually identical to those in Figure 4 through Figure 7. For the second robustness check, the estimations are weighted by the number of households in the county. The size of the coefficients rises (results not reported), but the significance levels and therefore our conclusions do not change. For the third robustness check, we dropped observations for Alaska, Hawaii, and Washington, D.C., the former two because they may have unique challenges for broadband diffusion and the latter because its governance structure differs from a state. Again, the changes in coefficients, marginal effects, and significance levels were trivial.

In a fourth set of regressions, the regression in the final two columns of Table 9 is estimated with spending in the Infrastructure category replacing spending in categories other than Sustainable Adoption (see Table 12). Since most spending is in the Infrastructure category, the difference between the two definitions is not great. Nevertheless, the size of the coefficients on Sustainable Adoption spending changed markedly, both in regressions with and without the residual "other spending" category. From these results we draw two conclusions. The apparent statistical significance of Sustainable Adoption spending does not depend on how total spending is categorized (although the magnitude of the apparent impact changes). Furthermore, the instability of the spending coefficients with regard to the set of spending variables included provides further evidence for the results being driven by spurious correlation among trending variables. This provides further support for the inclusion of controls for trends in the regressions.

Another way to categorize BTOP awardees is by whether the recipient was a government entity. In the fifth robustness test, we split total spending into amounts awarded to state, local, and county governments and other recipients. The latter category includes private entities, libraries, universities, and the few tribal awards granted. Since there is much evidence that management by government leads to less efficient outcomes than when markets discipline the managers, a dollar spent by a government may accomplish less of BTOP's goals than a dollar spent by other entities.[23] On the other hand, most (roughly two-thirds) of the awardees from the private sector were nonprofits, which also may be largely shielded from market discipline, particularly when spending money that is granted to them.[24] Thus we have no clear a priori expectation of whether there will be a difference in the impact of spending by government versus

[23] Ros (1999) finds that publicly owned telecommunications firms had lower labor productivity than privately owned firms. For other industries, Megginson and Netter's (2001, p.380) survey article concludes that the body of research "supports the proposition that privately owned firms are more efficient" than state owned firms.

[24] There are likely to be deficient incentives for managers of nonprofits, since managers cannot legally share in the surplus their decisions may create (see Weisbrod (1988) and citations therein).

other entities. In linear specifications, whether year fixed effects are included or not, we cannot reject the hypothesis that the coefficients on the spending by the two groups are the same.

For the sixth alternative approach, we remove from the sample any award that required judgment in assigned spending to counties. As explained in Section III, many grant applications were vague concerning the affected geography. This removes 535 county/award observations out of the total of 19,383.[25] The regressions with the linear specifications yield similar results to the main estimations. However, the nonlinear specifications return marginal effects that are statistically insignificant over even larger ranges of spending. Figure 8 shows the marginal effects for total spending from this sample. For almost all spending above de minimis levels, the marginal effect is insignificant. When trends are controlled for, in Figure 9, the marginal effects are insignificant *everywhere* except in a small region in which they are negative. Thus the conclusions from the main set of estimations are strengthened.

In a seventh set of robustness tests, a difference in differences (D-D) approach is adopted as an alternative method to control for trends. Since the treatment in the present context, G, is not binary, we split the counties into binary spending groups various ways. First, counties are assigned a treatment variable $T_1 = 1$ if the county was granted sustainable adoption money from at least one award apart from the single nationwide Sustainable Adoption grant. Out of the 3,137 counties in the sample, 1,711 are "treated" by this definition. Second, $T_2 = 1$ if $T_1 = 1$ and the county received at least \$0.58 per household. This threshold is the amount of spending from the 22-state project that results in the rightmost probability spike in the distribution of Sustainable Adoption spending shown in Figure 2. In this regression, counties with intermediate spending levels are removed from the sample to differentiate more starkly the treated and untreated

[25] These are the observations created by prorating each project to its affected counties, before spending is summed over awards for each county.

groups. With this definition, 1,631 of the 3,057 counties remaining in the sample are treated. Finally, $T_3 = 1$ if $T_1 = 1$ and the county received more than \$0.58 per household. This definition is similar to the previous, except that counties covered only by the 22-state project are excluded from the sample, yielding the most differentiation between treated and control counties among these three D-D regressions. The results are in Table 13, which shows that none of the D-D coefficients are close to statistical significance, particularly for the BTOP definition of broadband. Indeed, two of the six estimated D-D coefficients are negative. Thus, we again conclude that controlling for trends removes the statistical significance of BTOP spending on broadband adoption. Furthermore, the D-D specification shows that this conclusion does not depend on the nonlinearity allowed in equation (3).

VI. Implications and conclusion

The empirical results lead to several implications for investigators attempting to evaluate BTOP and for policymakers. First, the impact of the stimulus spending on broadband adoption is highly uncertain. We did not find clear evidence supporting the position that BTOP led to beneficial outcomes of increased adoption. We addressed endogeneity with fixed-effects modeling and spurious correlation by controlling for trends. However, in the end many of our results fall into the gray area between finding significant impacts of spending, at least in some ranges, when not accounting for trends and complete or greatly reduced lack of significance when accounting for trends. With such a high degree of uncertainty in the results, no sweeping claims can be made for the success of BTOP as regards the goal of sustainable adoption. In fact, in at least some ranges of spending, additional BTOP spending appears to lead to lower levels of adoption.

How do the implied costs per residential fixed connection from our estimates compare with the figures from the NTIA's evaluation of BTOP? The only residential broadband subscription analysis in the NTIA's report is for the Sustainable Adoption grants, where the average cost across all awards is $476 per household subscriber.[26] The marginal costs per RFC from Sustainable Adoption spending derived from our estimations are reported in Table 9, and range from $40 to $116 from the estimations without controlling for trends. Since NTIA's estimate is based on a simple count of households served by grantee projects, without controlling for trends in adoption or any other counterfactual, these estimates based on equation (2) are the most comparable to the NTIA figure. It is natural that our figures are lower than NTIA's average cost per subscriber. Our estimates are *marginal* costs, and if there are some fixed costs in the BTOP projects marginal cost is likely lower than average cost. However, our work above shows that it is important to control for trends in the analysis. Controlling for trends, the point estimation for marginal cost per RFC balloons to $667 for the FCC definition of broadband and $8,611 for the BTOP definition (see the last two columns of Table 9). Furthermore, given that the coefficients on Sustainable Adoption spending are insignificant in this latter regression, arbitrarily large marginal costs per subscriber cannot be ruled out on grounds of statistical insignificance.[27] Thus the true costs of connecting households via BTOP may be greatly higher than NTIA's estimate.

Furthermore, it appears that the marginal impacts of the BTOP spending, at least in the aggregate, are neither linear nor even necessarily monotonic. Thus, a second lesson for policymakers is to be suspicious of any policy evaluation of BTOP or other broadband-centric stimulus or digital inclusion initiative that assumes spending (or log spending) has constant

[26] The figure is apparently derived from the new subscribers each grantee claimed in its progress reports to NTIA.
[27] Put in the inverse way, the 95% confidence interval for the number of households connected with an extra dollar of sustainable adoption spending, which is [-0.0027,0.0029] for the estimation with trend, spans zero.

returns. The parallel lesson for empirical investigators is to avoid overly constraining the econometric specifications to yield (the perhaps "desired") positive results. If the only estimations we performed were those in Table 8 and Table 9, we would have missed important features of the data and been falsely optimistic about both the precision of the estimates and the direction of the impact of spending on broadband adoption. The work here demonstrates that the marginal effects on two measures of broadband adoption can be quite different at different spending levels.

A third lesson for policymakers concerns the design of programs. While it would have been possible to require awardees to submit projects that allowed for convincing evaluation of outcomes (e.g., randomized selection of participants, constructing and monitoring control groups, etc.), the NTIA did not do so. Ignoring best practice in policy design and evaluation in this way violates the spirit, if not the letter, of the ARRA's intent to provide accountability in spending.[28] A full understanding of accountability requires assessing what society gained from the expenditure of public funds. As the results above demonstrate, trying to recover the causal impacts of the spending on broadband and labor market outcomes proved difficult, due to the facts that every part of the country received at least some spending (at least in theory), there was no true control group, and the impacts appear to be impossible to distinguish from state-specific trends.

The results suggest that there may be substantial heterogeneity in the outcomes of the specific programs. A fruitful avenue for further investigation would be to evaluate individual

[28] The BTOP program took the narrowest approach to accountability, seeking to ensure only that money was spent as intended. Grant recipients' quarterly progress reports were made public in July 2014 (available at http://www2.ntia.doc.gov/awards) and show little detail with respect to project implementation other than funds spent. Recipients were not held accountable for successful project outcomes. For overall project evaluation NTIA paid ASR Analytics $5 million to study project success. As cited by Wallsten (2015), "ASR Analytics itself wrote that 'The selection of grants [to be evaluated] was purposeful and not meant to yield a statistical sample.' Yet, they used those very grants as the basis for the counties they studied statistically."

BTOP-funded projects, provided that an unbiased method for choosing projects to evaluate is used. Another extension would be to return to the evaluation once additional years of broadband adoption data are available, both to account for the few projects that had not been completed in 2013 and to check for longer term effects of the BTOP spending. Unless such future exploration of additional data yields strikingly different results, however, the case for the efficacy of BTOP for stimulating broadband adoption must remain weak.

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Appendix

Here we describe how we adapt existing methods for ordered logit estimation, with and without fixed effects, for our interval censored logistic regression problem.

A. Interval censored logistic regression

Examine first the case in which the latent data y_{it}^* are generated from equation (1), where ε_{it} is distributed logistic with scale parameter σ, and the observation rule for categories j = 0,…,5 is

$$y_{it} = j \quad \text{if} \; (\tau_j < y_{it}^* \le \tau_{j+1}) \Leftrightarrow (\tau_j < \alpha + \beta' x_i + \varepsilon_{it} \le \tau_{j+1}) \tag{4}$$

(refer to Figure 3). In the notation, γ from equation (1) is subsumed into β and the intercept α is written explicitly in equation (4). It is understood that $\tau_0 = -\infty$ and $\tau_6 = \infty$. The likelihood of observing $y_{it} = j$ is then

$$\Pr(y_{it} = j) = \Lambda\left(\frac{\tau_{j+1} - \alpha - \beta' x_i}{\sigma}\right) - \Lambda\left(\frac{\tau_j - \alpha - \beta' x_i}{\sigma}\right) \tag{5}$$

The cutpoints τ are known (0, 20, 40, 60, and 80). In the usual ordered logit case with unknown cutpoints, only $\delta = \beta/\sigma$ and $\kappa_j = (\tau_j - \alpha)/\sigma$, $j = 1, \ldots, 5$, are identified (as can be seen from examination of equation (5)). Given that the τ are equidistant, so are the κ. We thus first perform ordered logit estimation (using Stata 13.1) with the three linear constraints $\kappa_2 - \kappa_1 = \kappa_3 - \kappa_2 = \kappa_4 - \kappa_3 = \kappa_5 - \kappa_4$ to find estimates $(\hat{\delta}, \hat{\kappa})$. Then the parameters of interest are recovered from the following rightmost equations:[29]

$$\kappa_2 - \kappa_1 = \frac{\tau_2 - \tau_1}{\sigma} = \frac{20}{\sigma} \;\Rightarrow\; \hat{\sigma} = \frac{20}{\hat{\kappa}_2 - \hat{\kappa}_1}$$

$$\kappa_1 = \frac{\tau_1 - \alpha}{\sigma} = \frac{-\alpha}{\sigma} \;\Rightarrow\; \hat{\alpha} = -\hat{\sigma}\hat{\kappa}_1$$

[29] The `nlcom` command in Stata 13.1 returns the estimates $(\hat{\alpha}, \hat{\beta}, \hat{\sigma})$ and the associated asymptotic variance matrix.

$$\hat{\beta} = \hat{\sigma}\hat{\delta}$$

B. Interval censored fixed effects logistic regression

Baetschmann's (2012) extension to Baetschmann, Staub, and Winkelmann's (2011) "blow up and cluster" (BUC) method for fixed effects ordered logit allows estimation when α in equation (4) is replaced with a unit-specific fixed effect α_i. The method estimates $\delta = \beta/\sigma$ and $\lambda_j = (\tau_{j+1} - \tau_j)/\sigma, j = 1, \ldots, 4$. As above, constraints are imposed in our estimation to enforce equidistant cutpoints: $\lambda_{j+1} = \lambda_j, j = 1, \ldots, 3$. From the estimates of $(\hat{\delta}, \hat{\lambda})$, the parameters of interest are recovered from $\hat{\sigma} = 20/\hat{\lambda}_1$ and $\hat{\beta} = \hat{\sigma}\hat{\delta}$.

Figures and Tables

Figure 1: The distribution of total BTOP spending per household at the county level

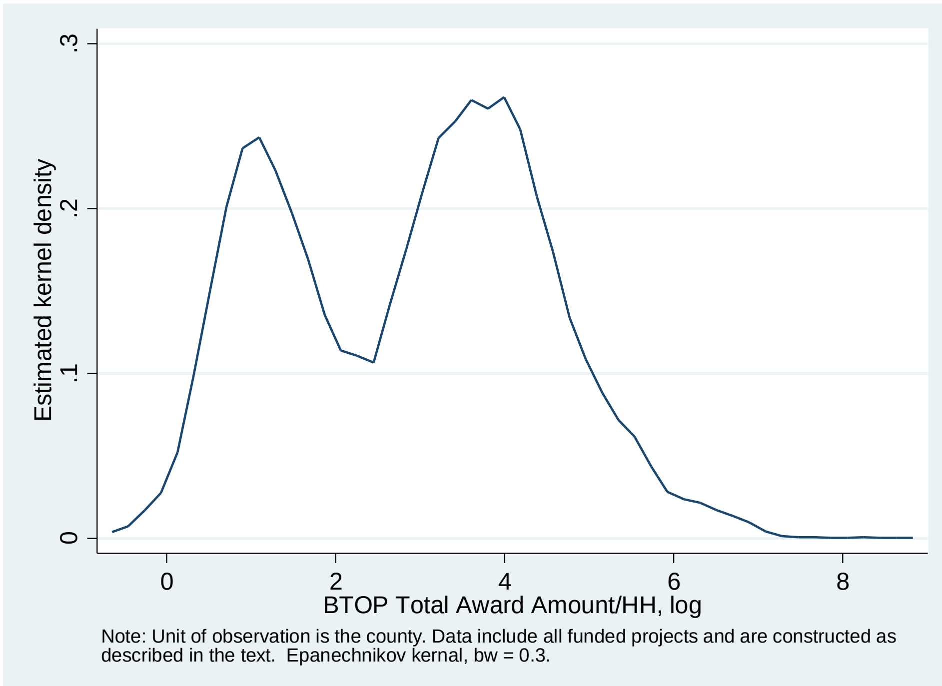


Figure 2: The distribution of Sustainable Adoption BTOP spending per household at the county level

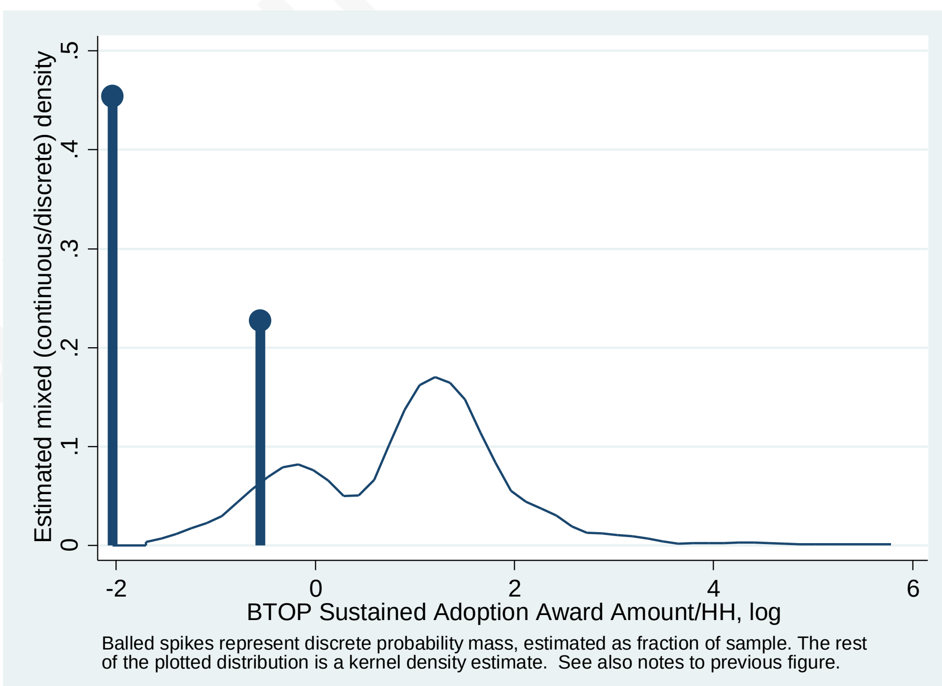


Figure 3: Latent continuous RFC/HH and the observed categorical dependent variable

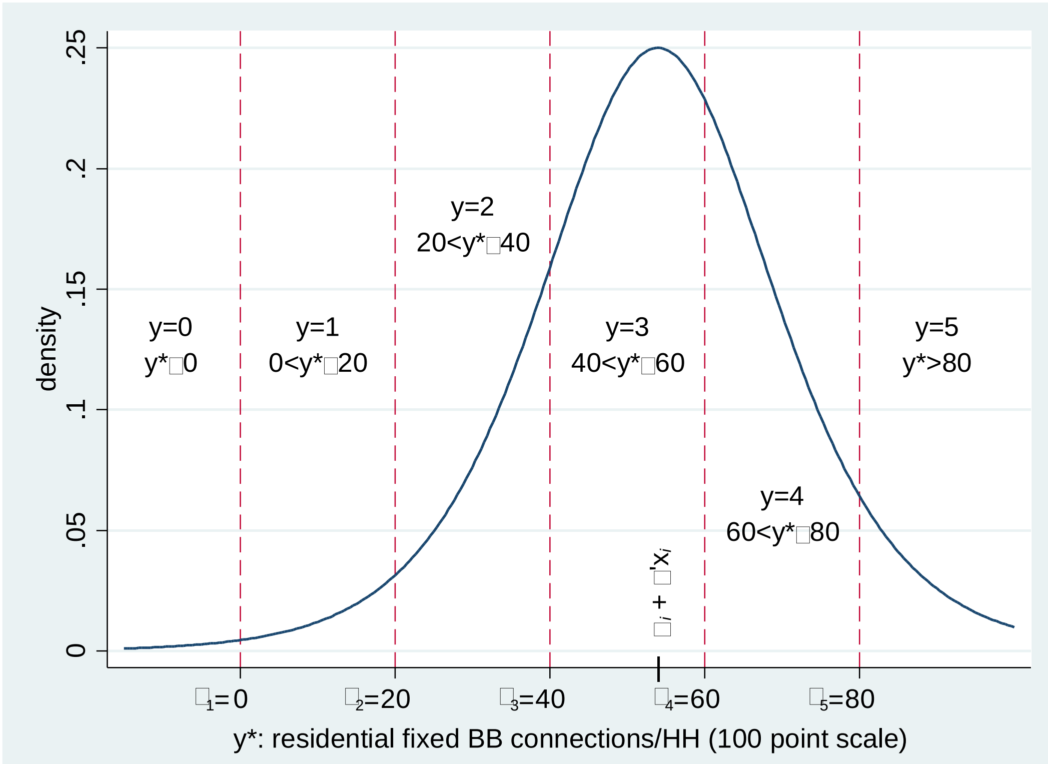
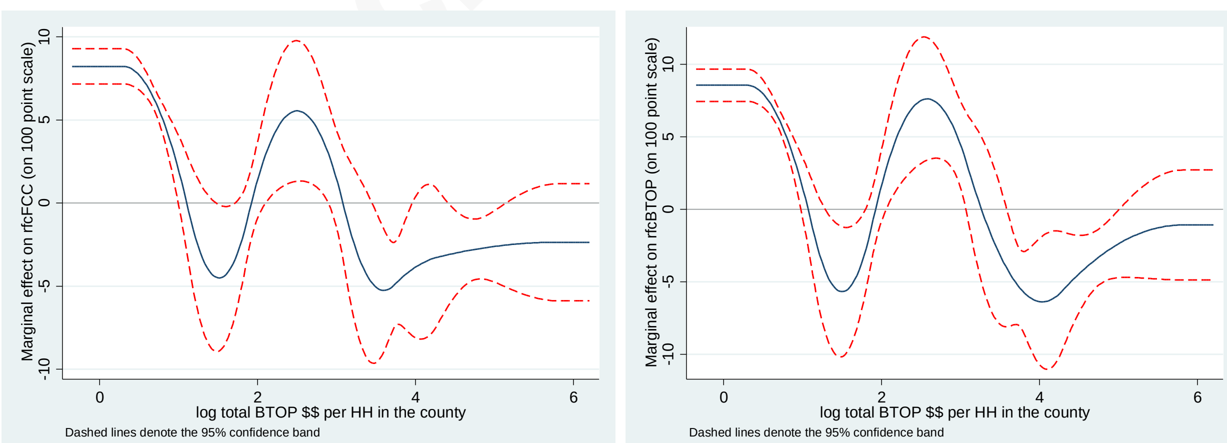


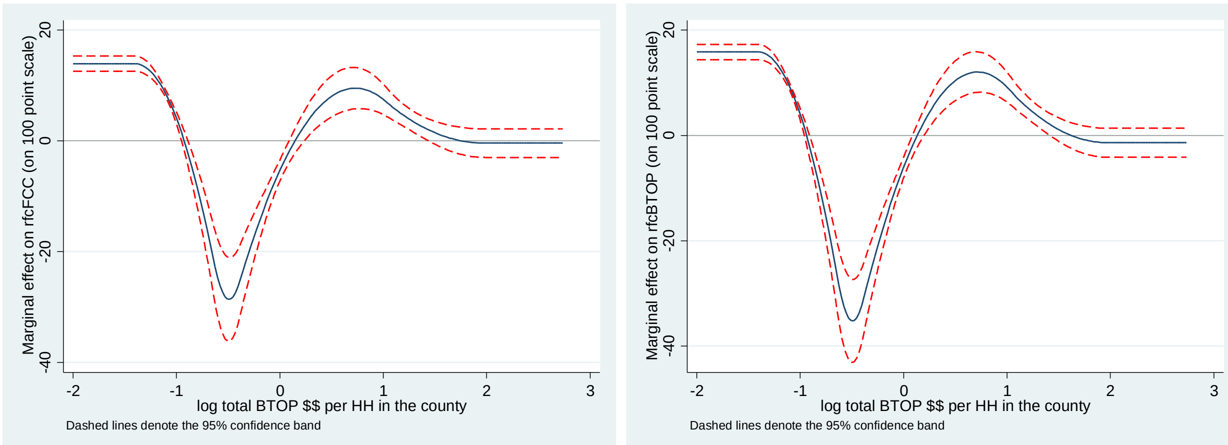
Figure 4: Marginal effects of total BTOP spending on RFC/HH from restricted cubic spline regression



Panel A: FCC definition of broadband

Panel B: BTOP definition of broadband

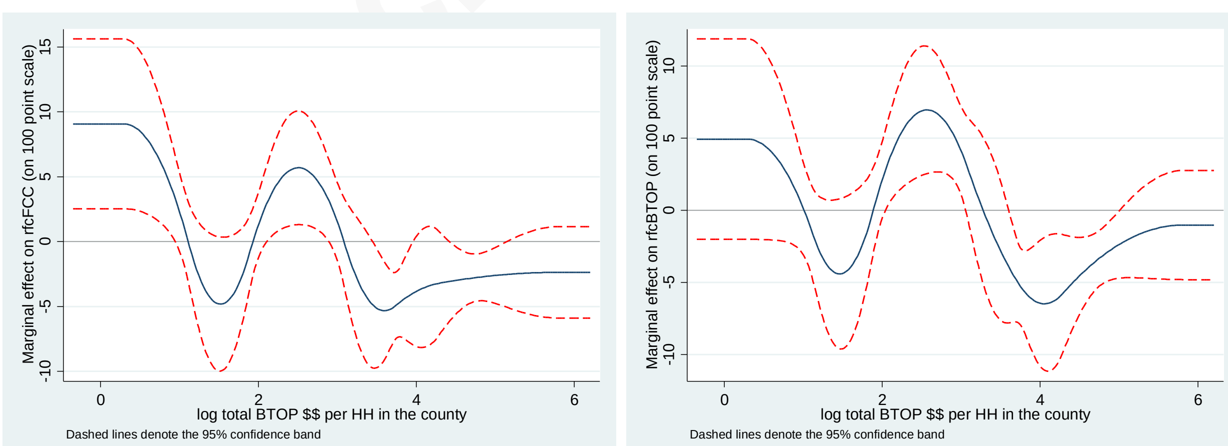
Figure 5: Marginal effects of Sustainable Adoption BTOP spending on RFC/HH from restricted cubic spline regression



Panel A: FCC definition of broadband

Panel B: BTOP definition of broadband

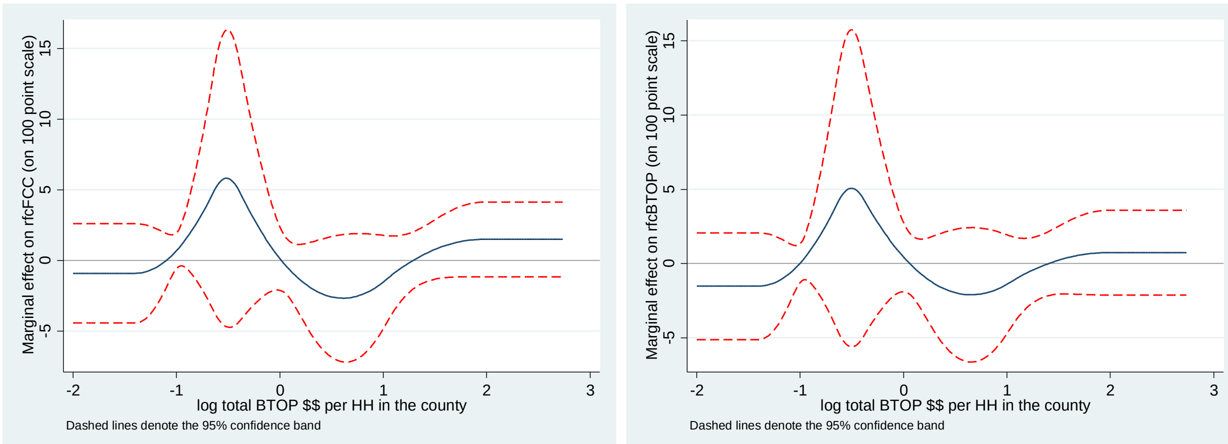
Figure 6: Marginal effects of total BTOP spending on RFC/HH from restricted cubic spline regression with trend



Panel A: FCC definition of broadband

Panel B: BTOP definition of broadband

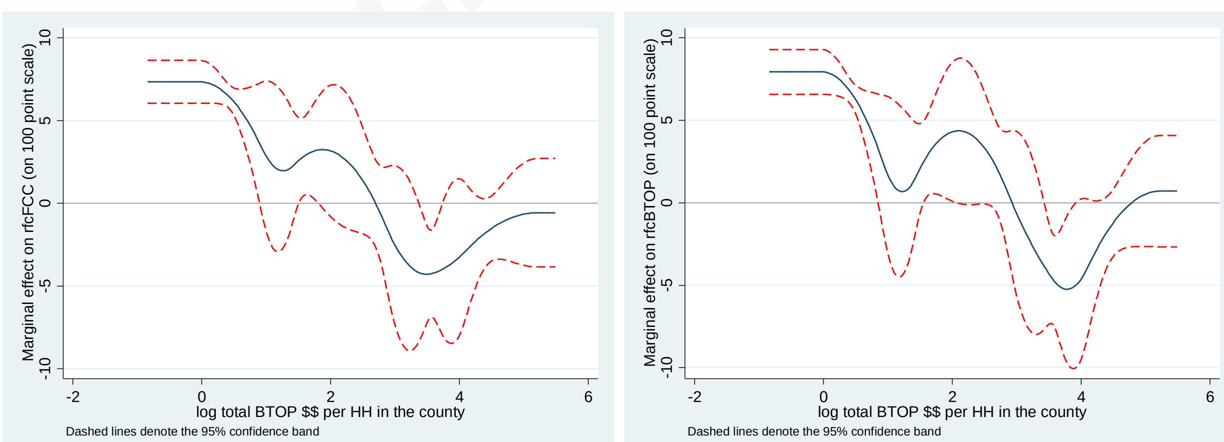
Figure 7: Marginal effects of Sustainable Adoption BTOP spending on RFC/HH from restricted cubic spline regression with trend



Panel A: FCC definition of broadband

Panel B: BTOP definition of broadband

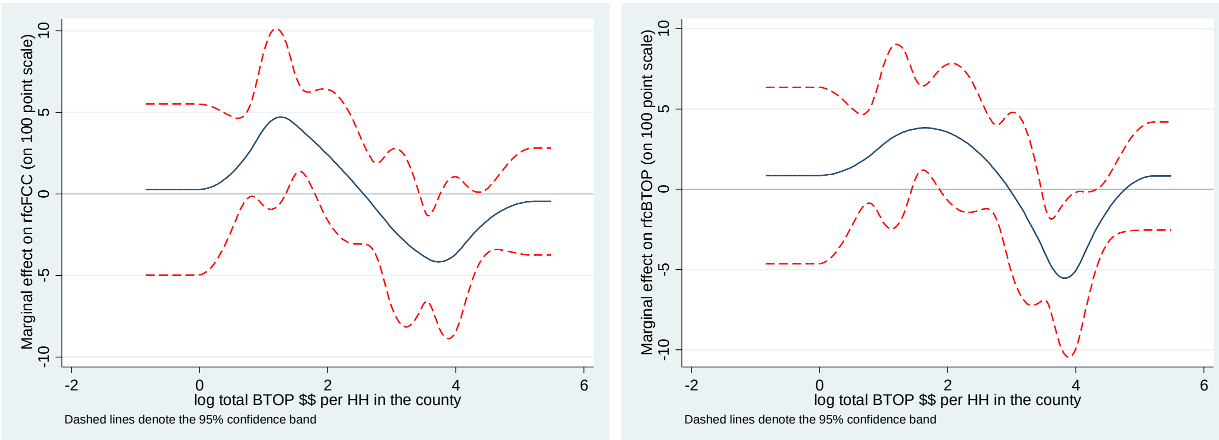
Figure 8: Marginal effects of total BTOP spending on RFC/HH from restricted cubic spline regression, alternative sample



Panel A: FCC definition of broadband

Panel B: BTOP definition of broadband

Figure 9: Marginal effects of total BTOP spending on RFC/HH from restricted cubic spline regression with trend, alternative sample



Panel A: FCC definition of broadband

Panel B: BTOP definition of broadband

Table 1: Applicants by type.

Applicant Type	Number of Applications	Percent of Total Applications	Number of Applications Funded	Percent of Total Applications Funded
City	257	15.14	20	6.92
County	128	7.54	20	6.92
State	132	7.77	65	22.49
Library	82	4.83	8	2.77
University	176	10.37	30	10.38
Tribal	27	1.59	6	2.08
Others	896	52.77	140	48.44
Total	1,698	100	289	100

Table 2: Applicants by scope of recipients served.

Application to serve:	Number of Applications	Percentage of Applications	Number of Applications Funded	Percent of Total Applications Funded
Multi-county	779	45.88	209	72.31
Single-county	919	54.12	80	27.68
Total	1,698	100	289	100

Table 3: Target groups by frequency of citations.

BTOP Target Group	Number of Times Cited	Percentage of Total Citations
Workforce Development	963	19.19
Mapping	916	18.26
Digital Literacy	887	17.68
Youth	347	6.92
Rural	299	5.96
Public Safety	288	5.74
Medical	245	4.88
Partner with College	201	4.01
Native American	198	3.95
Minorities	130	2.59
Small Businesses	119	2.37
Public Housing	91	1.81
Senior Citizens	85	1.69
Disabled	59	1.18
ESL	54	1.08
Hispanic	40	0.80
African American	21	0.42
Asian	20	0.40
Legal Services	14	0.28
Agriculture	14	0.28
Veterans Military	14	0.28
Homeless	12	0.24
Total	5,017	100

Table 4: Applications funded by category.

Program Category	Number of Applications	Percentage of Applications	Number of Applications Funded	Percentage of Applications Funded	Proscribed Funds ($M)	Amount Disbursed ($M)	Percent of Funds Disbursed
Infrastructure	397	23.38	123	42.56	3,729	3,484.4	93.44
Public Computer Centers	638	37.57	65	22.49	200	200.5	100.25
Sustainable Adoption	584	34.39	45	15.57	250	251.2	100.48
State Data and Development	79	4.65	56	19.38	350	292.8	83.66
Total	1698	100	289	100	4,529	4,228.9	93.37

Table 5: Applicant populations by socio-demographic characteristics.

	All Counties			Counties Covered by an Application	
	Applied		Did Not Apply	Funded,	Denied,
	1 obs./County	1 obs./Application	1 obs./County	1 obs./County	1 obs./County
	p [p_w]	p [p_w]	p [p_w]	p [p_w]	p [p_w]
Black	0.102	0.123	0.044	0.106	0.083
	[0.136]	[0.160]	[0.072]	[0.140]	[0.109]
Hispanic	0.077	0.089	0.076	0.076	0.078
	[0.168]	[0.271]	[0.072]	[0.173]	[0.129]
Asian	0.012	0.017	0.010	0.012	0.010
	[0.051]	[0.076]	[0.019]	[0.054]	[0.032]
American Indian	0.020	0.018	0.018	0.018	0.028
	[0.009]	[0.008]	[0.008]	[0.009]	[0.011]
Disabled	0.156	0.155	0.144	0.157	0.153
	[0.119]	[0.108]	[0.130]	[0.119]	[0.123]
Veteran	0.112	0.107	0.115	0.111	0.114
	[0.094]	[0.074]	[0.111]	[0.092]	[0.112]
Seniors	0.157	0.154	0.159	0.156	0.162
	[0.133]	[0.125]	[0.141]	[0.132]	[0.140]

Statistics are p, the simple average across counties of the proportion of the population in the group given in the header column, and [p_w], the population-weighted average. In columns headed "1 obs./County," the statistics are based on the county as the unit of observation, so each county appears once in the calculations. In columns headed "1 obs./Application," the statistics are based on the application as the unit of observation, so each county appears once per BTOP grant application in the calculations.

Table 6: Categories for the dependent variable, residential fixed broadband connections per hundred households (RFC/HH)

Category Indicator, *y*	**Range of the Latent Variable, *y******
0	0
1	(0,20]
2	(20,40]
3	(40,60]
4	(60,80]
5	(80,∞)

Table 7: Summary statistics of the data used in the regressions

	Mean	S.D.	Min	Max
Outcomes, 2009				
Residential fixed BB (RFC/HH) category, FCC definition (midyear)	2.859	0.842	1.000	5.000
Residential fixed BB (RFC/HH) category, BTOP definition (midyear)	2.439	0.913	0.000	5.000
Outcomes, 2013				
Residential fixed BB (RFC/HH) category, FCC definition (end of year)	3.555	0.787	1.000	5.000
Residential fixed BB (RFC/HH) category, BTOP def'n (beginning of yr)	3.211	0.836	1.000	5.000
Total BTOP Award Amount/HH, log	2.878	1.554	-.345	8.526
Sustainable Adoption BTOP Award Amount/HH, log	-0.761	1.403	-2.036	5.482
Control Variables				
Population, log	10.260	1.464	4.078	16.111
Population change, 2000-09	4.168	14.159	-96.308	120.838
Projected population change, 2009-14	2.191	7.133	-100.000	28.169
Age less than 20	0.254	0.034	0.132	0.454
Age 65+	0.157	0.039	0.028	0.361
Disabled	13.264	4.813	0.000	34.400
Veterans	11.239	2.835	0.000	27.788
Black	0.090	0.145	0.000	0.859
Native American	0.019	0.076	0.000	0.920
Asian	0.012	0.027	0.000	0.528
Multiracial	0.012	0.012	0.000	0.258
Hispanic	0.077	0.130	0.000	0.975
HH Income in $(25,50)K	0.318	0.037	0.148	0.471
HH Income in $ (50,75)K	0.177	0.040	0.057	0.311
HH Income in $ (75,100)K	0.073	0.032	0.002	0.237
HH Income in $ (100,150)K	0.042	0.029	0.000	0.252
HH Income > $150K	0.021	0.019	0.000	0.185
High School degree	0.346	0.067	0.107	0.532
College: Some or 2yr	0.262	0.057	0.088	0.450
College: 4 year+	0.166	0.080	0.045	0.642
Establishment count per capita, log	-3.815	0.371	-5.740	-1.376
CBSA: metropolitan	0.347	0.476	0.000	1.000
CBSA: micropolitan	0.220	0.414	0.000	1.000
Midwest region	0.336	0.473	0.000	1.000
South region	0.454	0.498	0.000	1.000
West region	0.141	0.348	0.000	1.000

Note: All data for covariates are for 2009 unless otherwise mentioned. The statistics for the BTOP spending do not include 2009 values, when all are zero.

Table 8: Interval Censored Logistic Regressions, Linear Impact of BTOP Awards

	Y = 100 × Residential Fixed BB Connections/HH, varying definition			
	FCC	BTOP	FCC	BTOP
Total BTOP Award Amount/HH, log	2.600	2.921		
	(0.093)***	(0.098)***		
Sustainable Adoption BTOP Award Amount/HH, log			3.732	3.920
			(0.136)***	(0.149)***
Constant	48.533	50.351	61.423	66.189
	(8.344)***	(9.501)***	(8.364)***	(9.645)***
Population, log	1.028	1.518	0.999	1.472
	(0.235)***	(0.256)***	(0.234)***	(0.258)***
Population change, 2000-09	-0.028	0.001	-0.022	0.005
	(0.029)	(0.031)	(0.029)	(0.031)
Projected population change, 2009-14	0.020	0.054	0.015	0.054
	(0.046)	(0.049)	(0.047)	(0.051)
Age less than 20	3.644	-9.417	1.386	-13.212
	(10.572)	(11.908)	(10.450)	(11.835)
Age 65+	25.016	19.384	13.931	4.418
	(9.969)**	(11.333)*	(9.950)	(11.546)
Disabled	-0.334	-0.369	-0.326	-0.354
	(0.069)***	(0.075)***	(0.068)***	(0.074)***
Veterans	0.171	0.098	0.241	0.174
	(0.107)	(0.115)	(0.104)**	(0.114)
Black	-8.518	-7.001	-10.981	-9.789
	(2.033)***	(2.168)***	(1.938)***	(2.061)***
Native American	-1.752	-9.141	-6.617	-13.469
	(3.487)	(4.746)*	(3.791)*	(5.315)**
Asian	31.259	29.928	10.905	9.150
	(11.663)***	(16.112)*	(12.070)	(15.232)
Multiracial	-70.428	-70.035	-63.654	-62.807
	(22.012)***	(25.451)***	(22.658)***	(27.300)**
Hispanic	-0.572	-2.550	-2.551	-4.773
	(2.109)	(2.201)	(2.105)	(2.160)**
HH Income ∈ (25,50)K	3.942	-9.017	3.340	-11.416
	(9.162)	(10.351)	(9.157)	(10.382)
HH Income ∈ (50,75)K	4.771	14.118	-3.790	2.952
	(10.188)	(11.230)	(10.225)	(11.345)
HH Income ∈ (75,100)K	41.091	5.882	30.690	-5.457
	(20.054)**	(22.583)	(19.921)	(22.938)

Table continued next page

	Y = 100 × Residential Fixed BB Connections/HH, varying definition			
	FCC	BTOP	FCC	BTOP
HH Income ∈ (100,150)K	8.839	9.963	18.614	23.553
	(24.928)	(27.162)	(24.951)	(27.837)
HH Income > 150K	67.366	70.114	55.171	54.312
	(24.589)***	(26.147)***	(25.163)**	(26.827)**
High School degree	3.149	-12.886	6.373	-7.628
	(6.826)	(7.132)*	(6.663)	(6.938)
College: Some or 2yr	32.610	37.276	28.500	33.707
	(6.869)***	(7.057)***	(6.569)***	(6.869)***
College: 4 year+	3.631	-3.123	10.013	3.344
	(6.222)	(7.053)	(6.137)	(7.056)
Establishment count per capita, log	4.209	3.922	4.036	3.984
	(0.827)***	(1.005)***	(0.833)***	(1.020)***
CBSA: metropolitan	1.055	1.735	0.736	1.322
	(0.652)	(0.687)**	(0.658)	(0.698)*
CBSA: micropolitan	0.581	0.953	0.248	0.529
	(0.536)	(0.591)	(0.524)	(0.590)
Midwest region	-10.350	-10.607	-11.377	-11.762
	(0.838)***	(0.818)***	(0.832)***	(0.840)***
South region	-10.762	-10.840	-12.079	-12.268
	(0.916)***	(0.891)***	(0.915)***	(0.914)***
West region	-10.345	-12.378	-9.957	-11.884
	(1.049)***	(1.103)***	(1.052)***	(1.115)***
σ (logistic scale parameter)	7.902	8.558	8.040	8.806
	(0.096)***	(0.097)***	(0.097)***	(0.099)***
χ^2 statistic	1,958.6	2,075.5	1,976.6	1,957.4
χ^2 degrees of freedom	27	27	27	27
χ^2 *p*-value	0.000	0.000	0.000	0.000
log likelihood	-7,042.4	-7,562.8	-7,128.1	-7,712.1
N (observations)	6,272	6,272	6,272	6,272
N (clusters = counties)	3,136	3,136	3,136	3,136

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Notes: Regression specification is based on equation (1) in the text. No fixed effects are included in these regressions. Estimates are scaled so that coefficients are the marginal effects on the dependent variable (given in the column headings), where the latter is on a 100-point scale. Estimation method is as described in section A of the appendix. Figures in parentheses are estimated standard errors, which are robust to heteroskedasticity and account for clustering on counties. χ^2 statistic is for the null hypothesis that all coefficients are zero.

Table 9: Interval Censored Logistic Regressions, Linear Impact of BTOP Awards (Fixed Effects)

	Y = 100 × Residential Fixed Broadband Connections/Household, varying definition							
	FCC	BTOP	FCC	BTOP	FCC	BTOP	FCC	BTOP
Total BTOP Award Amount/HH, log	2.995 (0.103)***	3.356 (0.104)***						
Sustainable Adoption BTOP Award Amount/HH, log			4.903 (0.182)***	5.224 (0.188)***	2.155 (0.268)***	1.801 (0.271)***	0.313 (0.289)	0.024 (0.297)
Non-Sustainable Adoption BTOP Award Amount/HH, log					2.000 (0.152)***	2.508 (0.155)***		
Year 2013							13.272 (0.713)***	15.226 (0.745)***
σ (logistic scale parameter)	8.167 (0.142)***	8.479 (0.135)***	8.377 (0.138)***	8.868 (0.140)***	8.086 (0.137)***	8.429 (0.134)***	7.839 (0.135)***	8.203 (0.140)***
Marginal cost per RFC from Sustainable Adoption $$			$42.53	$39.91	$96.76	$115.75	$667.03	$8,610.85
χ^2 statistic	668.6	798.9	634.7	645.2	747.3	842.1	825.8	845.0
χ^2 degrees of freedom	1	1	1	1	2	2	2	2
χ^2 *p*-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
log likelihood	-4,030.7	-4,652.4	-4,249.3	-5,078.5	-3,959.0	-4,600.9	-3,718.8	-4,332.7
N (original observations)	6,234	6,268	6,234	6,268	6,234	6,268	6,234	6,268
N (blown up observations)	49,816	77,280	49,816	77,280	49,816	77,280	49,816	77,280
N (clusters = counties)	3,117	3,134	3,117	3,134	3,117	3,134	3,117	3,134

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Notes: Regression specification is based on equation (2) in the text. Marginal cost per residential fixed connection (RFC) is calculated from the coefficients for Sustainable Adoption spending, and is a household-weighted average across counties. County fixed effects are included in these regressions. Estimation method is as described in section B of the appendix. See notes to previous table regarding scaling of coefficients and s.e.'s.

Table 10: Interval Censored Logistic Regressions, Flexible Impact of Total BTOP Awards

	Y = 100 × Residential Fixed BB Connections/HH, varying definition			
	FCC	BTOP	FCC	BTOP
X_{total} = Total BTOP Award Amount/HH, log	8.230	8.552	9.068	4.919
	(0.542)***	(0.569)***	(3.336)***	(3.544)
X_{total}, Spline variable 2	-127.812	-144.498	-138.566	-97.925
	(29.062)***	(29.540)***	(52.785)***	(54.663)*
X_{total}, Spline variable 3	404.143	468.051	433.017	343.019
	(110.146)***	(111.747)***	(162.483)***	(166.680)**
X_{total}, Spline variable 4	-444.089	-504.365	-468.504	-398.632
	(144.488)***	(147.304)***	(176.817)***	(180.438)**
X_{total}, Spline variable 5	365.986	271.211	379.366	213.136
	(211.446)*	(219.331)	(218.570)*	(226.071)
X_{total}, Spline variable 6	-232.064	28.889	-242.552	74.638
	(282.869)	(293.484)	(286.037)	(296.388)
Year 2013			-1.499	6.496
			(5.741)	(6.124)
σ (logistic scale parameter)	7.786	8.159	7.786	8.156
	(0.135)***	(0.142)***	(0.135)***	(0.141)***
χ^2 statistic	887.6	896.1	888.3	904.6
χ^2 degrees of freedom	6	6	7	7
χ^2 *p*-value	0.000	0.000	0.000	0.000
log likelihood	-3,670.8	-4,278.5	-3,670.7	-4,276.7
N (original observations)	6,234	6,268	6,234	6,268
N (blown up observations)	49,816	77,280	49,816	77,280
N (clusters = counties)	3,117	3,134	3,117	3,134

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Notes: Regression specification is based on equation (3) in the text, where *f* is estimated with restricted cubic splines. County fixed effects are included in these regressions. Seven spline knots were used. Estimation method is as described in section B of the appendix. See also notes to Table 8.

Table 11: Interval Censored Logistic Regressions, Flexible Impact of Sustainable Adoption BTOP Awards

	Y = 100 × Residential Fixed BB Connections/HH, varying definition			
	FCC	BTOP	FCC	BTOP
X_{SA} = Sustainable Adoption BTOP Award Amount/HH, log	13.939 (0.704)***	15.843 (0.737)***	-0.905 (1.794)	-1.521 (1.834)
X_{SA}, Spline variable 2	-233.862 (25.202)***	-281.421 (26.260)***	37.999 (39.029)	36.824 (39.611)
X_{SA}, Spline variable 3	1,404.713 (171.774)***	1,713.498 (178.447)***	-265.225 (250.170)	-240.313 (253.244)
X_{SA}, Spline variable 4	-1,276.846 (164.122)***	-1,566.675 (170.289)***	255.865 (233.783)	226.036 (236.430)
Year 2013			14.039 (1.541)***	16.359 (1.592)***
σ (logistic scale parameter)	7.979 (0.138)***	8.386 (0.142)***	7.834 (0.135)***	8.200 (0.140)***
χ^2 statistic	754.6	782.2	838.5	851.9
χ^2 degrees of freedom	4	4	5	5
χ^2 *p*-value	0.000	0.000	0.000	0.000
log likelihood	-3,851.3	-4,524.3	-3,716.0	-4,331.0
N (observations)	6,234	6,268	6,234	6,268
N (observations)	49,816	77,280	49,816	77,280
N (clusters = counties)	3,117	3,134	3,117	3,134

Notes: Regression specification is based on equation (3) in the text, where *f* is estimated with restricted cubic splines. County fixed effects are included in these regressions. Five spline knots were used. Estimation method is as described in section B of the appendix. See also notes to Table 8.

Table 12: Interval Censored Logistic Regressions, Linear Impact of BTOP Awards (Fixed Effects) – Alternative Spending Categories

	Y = 100 × Residential Fixed Broadband Connections/Household, varying definition			
	FCC	BTOP	FCC	BTOP
Sustainable Adoption BTOP Award Amount/HH, log	3.420	3.278	1.069	0.859
	(0.237)***	(0.241)***	(0.273)***	(0.280)***
Infrastructure BTOP Award Amount/HH, log	1.363	1.805	-0.175	0.229
	(0.144)***	(0.148)***	(0.179)	(0.190)
Other BTOP Award Amount/HH, log			2.334	2.416
			(0.162)***	(0.173)***
σ (logistic scale parameter)	8.234	8.618	7.914	8.314
	(0.138)***	(0.136)***	(0.135)***	(0.139)***
χ^2 statistic	698.9	782.0	805.9	869.5
χ^2 degrees of freedom	2	2	3	3
χ^2 *p*-value	0.000	0.000	0.000	0.000
log likelihood	-4,102.2	-4,809.1	-3,805.1	-4,460.7
N (original observations)	6,234	6,268	6,234	6,268
N (blown up observations)	49,816	77,280	49,816	77,280
N (clusters = counties)	3,117	3,134	3,117	3,134

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Notes: Regression specification is based on equation (2) in the text. County fixed effects are included in these regressions.

Estimation method is as described in section B of the appendix. See notes to Table 8 regarding scaling of coefficients and s.e.'s.

Table 13: Interval Censored Logistic Regressions, Difference in Differences Specifications

	Y = 100 × Residential Fixed Broadband Connections/Household, varying definition					
	Treatment Variable T_1		Treatment Variable T_2		Treatment Variable T_3	
	FCC	BTOP	FCC	BTOP	FCC	BTOP
Difference-in-differences coefficient (T×*Year2013*)	0.915	-0.017	0.888	-0.034	1.153	0.264
	(0.836)	(0.868)	(0.841)	(0.873)	(0.975)	(0.999)
Year 2013	13.385	15.282	13.377	15.278	13.376	15.280
	(0.618)***	(0.649)***	(0.618)***	(0.649)***	(0.617)***	(0.649)***
σ (logistic scale parameter)	7.838	8.203	7.796	8.170	7.787	8.187
	(0.135)***	(0.140)***	(0.134)***	(0.141)***	(0.151)***	(0.159)***
χ^2 statistic	819.3	840.4	821.7	831.9	622.6	653.1
χ^2 degrees of freedom	2	2	2	2	2	2
χ^2 p-value	0.000	0.000	0.000	0.000	0.000	0.000
log likelihood	-3,718.7	-4,332.7	-3,602.6	-4,203.9	-2,753.3	-3,243.4
N (original observations)	6,234	6,268	6,078	6,108	4,664	4,684
N (blown up observations)	49,816	77,280	48,644	75,450	37,284	57,818
N (clusters = counties)	3,117	3,134	3,039	3,054	2,332	2,342

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Notes: Regression specification is difference in differences, with treatment group indicated in the column heading (which are described in the text). County fixed effects are included in these regressions. Estimation method is as described in section B of the appendix. See notes to Table 8 regarding scaling of coefficients and s.e.'s.