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The Impact of Technology, Demography, and Market Structure on Broadband Service Delivery

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Increasing broadband network diffusion to reach all American homes at higher speeds than currently offered has become a national priority. The National Broadband Plan represents a response to the growing sentiment among policy makers that the United States' lag behind other peer OECD countries is a source of embarrassment. With the highest FCC estimates for the Plan reaching close to $350 billion, it is clear that now more than ever policy makers need specific recommendations supported by actionable research. Current academic literature is largely descriptive in exploring areas of under-provision within certain demographic groups, the so-called 'digital divide,' and has not yet provided a satisfactory casual answer to the problem of broadband under-provision. We attempt to fill in this void by answering the question "What roles do technology, demography, and market structure play in levels of broadband service provision?" Employing multivariate statistical analyses, this paper examines census tract-level data recently released as part of the National Broadband Map. Ultimately, these analyses provide recommendations for how the US government can direct its efforts to attempt to increase broadband service provision across the country.

Keywords

technology, broadband service, US, FCC

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Increasing broadband network diffusion to reach all American homes at higher speeds than currently offered has become a national priority. The National Broadband Plan represents a response to the growing sentiment among policy makers that the United States' lag behind other peer OECD countries is a source of embarrassment. With the highest FCC estimates for the Plan reaching close to $350 billion, it is clear that now more than ever policy makers need specific recommendations supported by actionable research. Current academic literature is largely descriptive in exploring areas of under-provision within certain demographic groups, the so-called 'digital divide,' and has not yet provided a satisfactory casual answer to the problem of broadband under-provision. We attempt to fill in this void by answering the question "What roles do technology, demography, and market structure play in levels of broadband service provision?" Employing multivariate statistical analyses, this paper examines census tract-level data recently released as part of the National Broadband Map. Ultimately, these analyses provide recommendations for how the US government can direct its efforts to attempt to increase broadband service provision across the country.

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I. Introduction

The political consensus for greater national service provision of high-speed broadband services has rarely been as high as it is today. The Obama administration's recent push for greater diffusion of broadband service is articulated in its National Broadband Plan, which calls for 100 million households to have access to at least 100mbps download speeds by 2020.[1] The rationale inherent in this proposal as well as others that have been introduced internationally is that various types of 'new media' will require increasingly higher speed levels to allow for user engagement. Though many claim that such high speed levels are unlikely to be achieved given current limitations of coaxial technologies and cost issues, it is clear that identifying factors that have the potential to improve service provision can directly inform public policy proposals to more realistically 'overhaul' broadband. This research paper focuses on the effects of market structure on broadband service delivery – both in terms of diffusion and speed level – in order to give policy makers and academics direction in their proposals and research. This inquiry seeks to determine what affects broadband diffusion and the speeds that providers offer, using census tract-level data acquired from the recently released National Broadband Map. Specifically, the paper will examine whether the two factors of diffusion and offered speed are affected by demography, technology, or market structure. On a practical level, we hope to give direction to policy makers so that they can consider initiatives in whichever of these areas are found to be statistically significant by this study.

The tenor of debate on digital access and literacy in national discourse and academia has often been of a controversial nature with much of the literature focusing on the differences

[1] National Broadband Plan, FCC, Page 9

that exist between racial, ethnic, and other socioeconomically-significant groups. This paper seeks not to identify where under-provision may occur with regard to the aforementioned groups, but instead finds value in understanding if, and how, policy makers can tailor their broadband proposals to encourage different levels of competition in markets across the United States to attempt to rectify situations of under-provision.

II. The Rationale Behind Recent Broadband Proposals

Before analyzing what role market structure plays in broadband service provision, it is first appropriate to more closely examine the rationale that underlies recent proposals to improve high-speed service provision, this being that higher speeds are necessary for user engagement with new forms of online content. The National Broadband Plan is unique in that it primarily advocates higher speed levels, which has been a hallmark of other countries' broadband proposals, such as South Korea, but not in the United States.

The position that higher speed provision will be increasingly necessary as technology advances takes its cues not from projections of what service will require, but rather is founded in speculative conjecture that reflects how much internet content has changed to its current point from its earliest form. The evolving nature of technology means that digital literacy, or a user's ability to engage with internet content, has moved from interaction with a stand-alone terminal to interaction with computer networks, and finally to the internet as a whole. Though recognized in educational methodology literature since the mid 1980's, it has been almost universally accepted in the past ten years that digital literacy is not just a field of interest, but a skill necessary to function as a fully-integrated member of society. Authors B.R. Jones-Kavalier and S.L. Flannigan frame literacy as “a person’s ability to perform tasks effectively in a digital environment, with ‘digital’ meaning information represented in numeric form and primarily for use by a computer. Literacy includes the ability to read and interpret media (text, sound, images), to reproduce data and images through digital manipulation, and to evaluate and apply new knowledge gained from digital environments.” In a recent survey of work done on digital learning in the UK, JISC grouped digital literacy into the broader category of ‘learning literacies,’ acknowledging that “the nature of knowledge is changing…what counts as useful knowledge is increasingly biased towards what can be represented in digital form…” Beyond achieving credibility in the expression of one’s ideas, the paper makes the claim that one must embrace digital media – in addition to traditional forms – in order to become more adept at self-expression and critical analysis. The ETS’ definition is perhaps more succinct and functional, with digital literacy relating to the manipulation of information: “the ability to use digital technology, communication tools and/or networks appropriately to solve information problems in order to function in an information society” (ets.org, quoted in Lankshear, 2006). It is clear that definitions vary somewhat but are in agreement that capacity to actively engage with technology is more important than an ability to passively interpret or appreciate others’ digital experiences.

The rapidly evolving definition of internet media means that what constitutes broadband literacy is changing. Newer forms of internet media are increasingly requiring higher connection speeds. In a paper authored by the Information Technology and Innovation Foundation, it is argued that the four main functionalities that faster broadband will allow are: “1) dramatically faster file transfer speeds for both uploads and downloads; 2) the ability to transmit streaming video, transforming the Internet into a far more visual medium; 3) the means to engage in true real-time collaboration; and 4) the ability to use many applications simultaneously." [2] It further ventures that higher bandwidth uses of current consumer online activities, such as high-definition videoconferencing, television, and video-based security services would be made possible by faster speeds.[3] If one accepts the position of policymakers previously presented that broadband access affects digital literacy, then it is clear that the ability to become literate is constrained by broadband connection speed. According to the FCC, the need for increased broadband connection speeds results from the fact that "…network capabilities, consumer expectations, consumer applications and expectations—have evolved in ways that demand increasing amounts of bandwidth..."[4] In the Federal Communications Commission's Sixth Broadband Deployment Report issued to Congress, the Commission redefined and contextualized the minimum standard for broadband service. This paper's position that access must keep up with the dynamic nature of broadband service interaction is supported by the FCC's view that what constituted a high standard of service, 200 kbps upload and download, in 1999, is now woefully inadequate given that "interconnected VoIP is subscribed to by over 21 million Americans, most web sites feature rich graphics and many embed video, and numerous websites now exist primarily for the purpose of serving video content to broadband users." [5]

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[2] Ezell, Stephen, Robert Atkinson, Daniel Castro and George Ou, "The Need for Speed: The Importance of Next-Generation Broadband Networks." Washington, DC: The Information Technology and Innovation Foundation, 2009. Online. p. 5.

[3] Ibid., p. 5.

[4] *Sixth Broadband Deployment Report*. Rep. Washington, DC: Federal Communications Commission, 2010. Print. p. 9558

[5] Ibid., p. 9559

III. Implications of This Inquiry

Previously-completed studies have mostly focused on identifying whether certain demographic groups experience lower levels of broadband access or service provision. This paper aims to provide policy makers with direction in their mission to rectify situations of where the so-called "digital divide" is present. For example, one demographic that has had public policy attention lavished on it is the rural broadband user. Given that recently completed studies rarely analyze delivery and speed of connection with regard to how urban an area is, as measured through a measure such as population density, it is important to consider these factors to better understand the causes of under-provision (in this case, with regard to speed). For example, if a rural community is underserved due to lower average download and upload speeds of statistical significance, the question naturally becomes whether this is because of a demographic factor(s) such as the average level of income of its citizens, or if the true cause is an uncompetitive market-structure (i.e. number of providers). If, on the other hand, the rural community's income level is lower than average by a statistically significant measure, then the consumer's ability to pay for service may be the causal factor instead of market structure. Summary reports provided by the National Broadband Map detail these factors among many descriptive statistics for broadband internet. These metrics alone do not appropriately direct the policy maker; this paper aims to provide meaningful analysis to recommend solutions within the context of existing telecommunications public policy.

Being able to identify whether technology use, demography, or market structure is most closely linked to service quality and provision is vital to properly inform governmental initiatives, such as the National Broadband Plan. If the problem lies in demography, then one solution may be for the government to focus on extending subsidies *directly* to low-income households to allow them to access broadband speeds that are necessary to engage at a minimum level to allow, for example, for the content-rich, streaming uses that currently mark the average American's broadband usage. A model which the FCC has considered extending to broadband users is the Universal Service Fund model, which mandates that telecommunications providers contribute to the fund, which seeks to provide federal universal service. FCC Chairman Julius Genachowski commented that the proposed extension was necessary, because "broadband serves the same role in the 21st Century that telephone service served in the 20th Century." The Universal Service Fund model, however, has recently come under attack as "ineffective, inefficient, and inequitable."[6] Aside from the fact that funds are disproportionately directed to rural residents as compared to their low-income, urban counterparts who experience similar underprovision (65% vs. 35% for residential service), Wallsten's research reveals that "each dollar in high-cost subsidies given to an incumbent local exchange carrier (ILEC) is associated with an increase in general and administrative expenses of about $0.59."[7] It seems that direct appropriation of subsidies to ILECs appears even more problematic considering Ellig's analysis that the 2002 tax contributions to the Universal Service Fund from wireless services and interstate long-distance reduced economic welfare by nearly $2 billion.[8] Faulhaber's application of his customer-centric framework to his analysis of the Wireless Communications Market warns that "unless interventions are based on rigorous analysis of market failure and the efficacy of

[6] Wallsten, Scott (2011), "The Universal Service Fund: What Do High-Cost Subsidies Subsidize?" Technology Policy Institute. p. 2.
[7] Ibid., p. 3.
[8] Ellig, Jerry. 2005. "Costs and Consequences of Federal Telecommunications Regulations" *Federal Communications Law Journal*. Vol. 58, No. 1, pp. 37-102.

the remedy, the most likely outcome is increased cost, reduced customer choice, reduced incentives to invest, and reduced incentives to innovate."[9] If there is a case of underprovision related to an 'unfavorable' market structure, but the interventionist policy options are unpalatable, then governmental support of certain technologies subsidies could address such a finding.

Besides potentially playing a role in an alternative plan to increased regulation, technology itself may be shown to be a potential causal factor. If DSL or cable internet is shown to be directly linked with higher quality of service provision, then subsidization could be directed accordingly. For example, policy makers could encourage non-wireline technologies by modifying the National Broadband Plan to redirect funds to wireless technology subsidies, something that might be particularly effective in rural communities where the cost of 'passing' homes with wireline broadband service might be cost prohibitive. If a community lacks at least a duopoly, something that the vast majority of all communities have according to Faulhaber and Farber's analysis (2010), then a lack of competitive impetus for higher service provision may be to blame.[10] Recently released FCC figures show that while 82% of American households are served by at least two providers (78% by two providers and 4% by three providers), 13% of households find themselves in a monopoly market structure.[11] Encouraging the expansion of currently existing wireless broadband networks would directly increase competition.

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[9] Faulhaber, Gerald R. 2009a. "A National Broadband Plan for Our Future: A Customer-Centric Framework" *International Journal of Communication 3*. p. 2.
[10] Faulhaber, Gerald R. and David J. Farber (2010), "The Open Internet: A Customer-Centric Framework Framework" Exhibit 1, Comments of AT&T, FCC GN Dkt. 09-191; WC Dkt. 07-52.
[11] National Broadband Plan, Exhibit 4-A, p. 37

IV. Data Sourcing

The Obama Administration's recent passage of the American Recovery and Reinvestment Act of 2009 includes $7.2 billion earmarked for the Department of Rural Utilities Service and the Department of Commerce's National Telecommunications Information Administration (NTIA). RUS-allocated funds will help further broadband infrastructure projects in rural areas through the Broadband Initiatives Program. NTIA-allocated funds will provide grants to fund comprehensive broadband infrastructure projects, public computer centers, and sustainable broadband adoption projects via the Broadband Technology Opportunities Program. Most integral to this analysis is the NTIA's State Broadband Initiative's completion of a publicly-accessible National Broadband Map, a collaboration of all 50 states, 5 territories, and the District of Columbia to develop an integrated view of all broadband-related metrics available.

The National Broadband Map provides the following data categories for analysis:

- Geography (divided into: state, county, Metropolitan Statistical Area (MSA), congressional district, state legislative district, census place, and USF Study Area)
- Speed (including: speed combination, maximum advertised download speed, and maximum advertised upload speed)
- Technology (wireline vs. wireless)
- Number of providers
- Demographics (including: age, race, income, education, and population)

This study will examine the following four areas using data from the National Broadband Map:

- Market Structure
  - % of households with access to [≥ 1, 2, 3] (wireline) providers
- Technology
  - % of households with access to DSL service
  - % of households with access to cable service
- Demography
  - Ln (income)
  - Population Density[12]
- Access to Speed
  - % of households with access to [speed range (in kbps)]:
    - $768 \leq x \leq 3000$
    - $3000 \leq x \leq 6000$
    - $6000 \leq x \leq 10000$
    - $10000 \leq x \leq 25000$
    - ≥ 25000

Though the dataset included other variables, the preceding variables were chosen because they most closely fit the inquiry into market structure, demography, and technology.

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[12] Note: The census designates core census block groups or blocks that have a population density of at least 1,000 people per square mile and surrounding census blocks that have an overall density of at least 500 people per square mile as being 'urban.'[12] A binary designation such as this lacks usefulness in correlation-based analysis. Instead, 'urban-ness' will be included in this analysis through population density per square mile.

V. Methodology

This paper seeks to answer the question of what affects broadband diffusion and speed. Current research has shown that income and urbanization affect diffusion. This study seeks to determine if income affects offered speeds and if market structure affects both offered speed levels in communities as well as diffusion. The primary methodology will be the use of a multivariate regression.

This study uses two ways to examine the role of market structure in broadband access quality: first, it conducts an absolute measure to see *if* there are relationships extant in the data and then completes a relative comparison between speed ranges to determine to what *extent* market structure affects provision. Given that the National Broadband Plan is the first snapshot available for research at this level of granularity, it is impossible to conduct a time-series analysis as would normally be customary in order to determine causality. This paper acknowledges that simultaneity is an issue that is unable to be rectified in this study. The question of whether market structure causes higher speeds or whether higher speed cause changes in market structure is unable to be satisfactorily be answered. Two possible solutions that future research can apply would be to conduct a natural experiment or to complete a time-series analysis once another snapshot becomes available.

Examining the data by census tract is the most granular, and thus, most preferable level on which to examine the data offered by the National Broadband Map. In order to address the causal question raised previously, population density, number of providers, and income levels within a census tract will be correlated with maximum combined speed (upload and download speeds) alongside several interaction variables. The interaction variables chosen for inclusion in the regression analysis were those which proved to be significant after the application of a Bonferroni correction. This maintains the familywise error rate by correcting the statistical significance level for each individual hypothesis, according to the following equation, where *a* equals the number of independent variables present:[13]

Significance Level (Individual Test) = Familywise Error Rate / a

For this study, the interaction variables that were tested for significance were:

- Market Structure
  - Population Density * Number of providers
  - Income level (natural log) * Number of providers
- Technology
  - Population Density * Average offered speeds
  - Income level (natural log) * Average offered speeds

For the examination of the technologies available, the interaction variables are important as they show whether population density in a census tract or a consumer's ability to afford broadband drives speed. When initially examined, the residuals produced by the analysis lacked homoskedasticity. As inspired by Tukey's Rule, exponential transformations were applied to the various regressions completed as part of this research effort ranging between x^3 and x^5. Although the magnitude of these transformations may seem unconventional, they allowed the regressions to be completed given the lack of other statistical methods at the disposal of the researcher.

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[13] Note: For the purposes of this study, the familywise error rate was .05.

Upon reexamination of the residuals, after the transformation was performed, both normality and heteroskedasticity were apparent, as shown in the normal quantile-quantile plot, as well as the residual plot. It will also be assumed that data was collected in a manner to uphold the independence assumption. The presence of independent identically distributed residuals indicates that a linear regression analysis will produce viable results.

VI. Findings

The results show that both technology and demographics interact with each other to play a statistically significant role in affecting broadband service delivery. The following multivariate regression analysis resulted in this finding:

$$Y\ (Download\ Speed) = \beta_0 + \beta_1\ [\ln(income)] + \beta_2\ (\%\ HH\ Served\ by\ Cable) + \beta_3\ (\%\ HH\ Served\ by\ DSL) + \beta_4\ (Population\ Density) + \beta_i\ (interactions)\ldots$$

As seen in Exhibit 2, [ln(income)] was significant at the highest speed band tested[14] (≥2500 kbps download speed); its interaction with (% HH Served by Cable) was significant across this highest band, as well the second-highest (Exhibit 3),[15] (1000 kbps $\geq x \geq$ 2500kbps).[16] It is important to note that the strength of this interaction increased substantially from one band to the next as speed increased.

The inquiry as to whether market structure affects offered speeds or diffusion was inconclusive, though it is important to note that meaningful data analysis was only possible

[14] Note: The level of significance used was .007 = (.05/7), according to the Bonferroni correction.
[15] Note: The level of significance used was .006 = (.05/8), according to the Bonferroni correction.

in higher speed bands, even with the transformations described in the previous 'Methodology' section of this paper.

VII. Recommendations

It has long been a known fact that technological limitations prevent DSL from reaching the same upper-bound speed limitations as cable broadband service. Though DSL providers are introducing services that match – and often outpace – their coaxial competitors, these offerings are usually seen in metropolitan, high-income areas. Since a meaningful interaction has been found between technology and income, it is now appropriate to revisit the policy options mentioned earlier in this paper. If further research is able to show a casual relationship between area demographics and community broadband technologies offered (most likely through the use of a time-series), then it is reasonable for the government to pursue *direct* subsidies in a program similar to the Lifeline program if faster cable broadband alternatives to DSL service are available locally to a consumer, but at a price premium.

Besides directly subsidizing broadband service, the government could alternatively attempt to increase market competition. Just as it has done through the 2009 Recovery Act, the government could incentivize the development of alternative non-wireline technologies, such as the 3 and 4G networks that wireless carriers are currently investing in the deployment of. Though one could argue that these programs are already well on their way to penetrating America's largest cities, it is clear that there has been no significant development in rural or semi-rural areas. Though this inquiry was unable to draw meaningful conclusions from the analysis of market structure in relation to service provision, it is reasonable to consider what the effects would be of direct market intervention. The test for whether government should address this is: 1) if there is a public policy interest in encouraging a market structure marked by increased competition, and if so, 2) whether market economics are compelling enough to support governmental intervention. This paper has already shown that broadband provision is an issue of national importance and as such there is a public policy interest, but recently published literature and judicial opinions relating to the issue of 'Net Neutrality' suggest that existing market economics do not justify governmental intervention. This paper agrees with Faulhaber's finding that absent market failure regulatory intervention is not appropriate.[17] He asserts that markets that are "competitive, innovative, and transparent" are vital to full customer sovereignty, but it is clear that market failure has not occurred in this case.[18] In an *ex parte* submission to the Federal Communications Commission, the Department of Justice stated that "in markets such as this, with differentiated products subject to large economies of scale, the Department does not expect to see a large number of suppliers. Nor do we expect prices to be equated with incremental costs. If they were, suppliers could not earn a normal, risk-adjusted rate of return on their investments in R&D and infrastructure."[19] Exhibit 1 clearly supports this point of view in showing how the inverse relationship between loop density and corporate cost per line.[20] It is important to return to Wallsten's criticism that the Universal Service Fund disproportionately directs its funds to rural customers, which

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[17] Faulhaber, G. R. (2009a). "A Broadband National Plan for Our Future: A Customer-Centric Framework." *International Journal of Communication, 3*, pp. 742-779.

[18] Faulhaber, G. R. (2010). "Innovation in the Wireless Ecosystem: A Customer-Centric Framework." *International Journal of Communication, 4*. p. 74.

[19] *In the Matter of Economic Issues in Broadband Competition: A National Broadband Plan for Our Future* (2009) (testimony of United States Department of Justice (ex parte)). Online. http://voices.washingtonpost.com/posttech/dojbroadband.pdf.

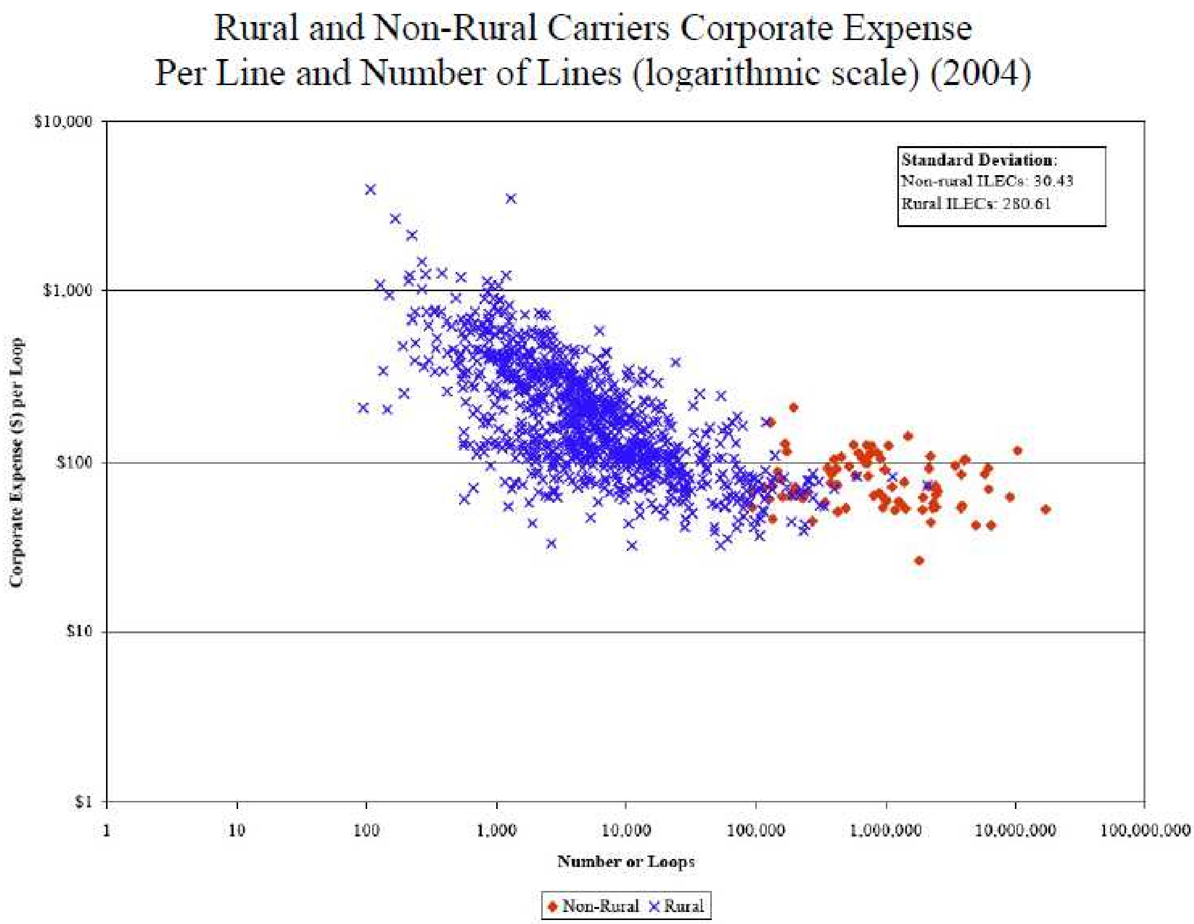
[20] Note: Exhibit 1 is displayed on a logarithmic scale, so the relationship seen in the chart presented is actually more pronounced than it appears at first glance.

supports the DOJ's conclusion. This paper recommends strongly against direct market intervention on the behalf of government given the substantially negative effects on market efficiency.

Beyond extending direct subsidies to the consumer and encouraging the spread of alternative technologies (such as wireless), this paper advocates government support of technological innovation in geographies where there is adequate diffusion, but service quality levels could be improved. Faster networks could be incentivized through the use of tax credits or advantageous depreciation schedules for broadband providers. Additionally, increased support of research and development of advanced broadband technologies would bolster private industry work to produce prototypes for both wireless and wireline technologies.

VIII. Exhibits

Exhibit 1



Source[21]: Hazlett (2006), Thomas. 2006. *"Universal Service" Telephone Subsidies: What Does $7 Billion Buy?* Figure 8, Data from NECA file USFLC05.xls; http://www.fcc.gov/wcb/iatd/neca.html

[21] Hazlett (2006), Thomas. 2006. *"Universal Service" Telephone Subsidies: What Does $7 Billion Buy?* Figure 8, Data from NECA file USFLC05.xls; http://www.fcc.gov/wcb/iatd/neca.html

Exhibit 2

Fit Group

Response Transformed 25000+

Summary of Fit

RSquare	0.514964
RSquare Adj	0.512723
Root Mean Square Error	0.238252
Mean of Response	0.25284
Observations (or Sum Wgts)	1088

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	65.20863	13.0417	229.7526
Error	1082	61.41888	0.0568	**Prob > F**
C. Total	1087	126.62751		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.415062	0.068764	-6.04	<.0001*
Cable Transformation	0.729071	0.051259	14.22	<.0001*
Ln (Income) Transformation	2.402e-6	4.737e-7	5.07	<.0001*
Population Density Transformation	-2.64e-22	8.78e-23	-3.00	0.0027*
(Cable Transformation-0.39554)*(Ln (Income) Transformation-145878)	9.6733e-6	1.189e-6	8.14	<.0001*
(Cable Transformation-0.39554)*(Population Density Transformation-2.7e+20)	5.247e-22	1.74e-22	3.01	0.0026*

Exhibit 3

Fit Group

Response Transformed 10000-25000

Summary of Fit

RSquare	0.448544
RSquare Adj	0.447125
Root Mean Square Error	0.218804
Mean of Response	0.296726
Observations (or Sum Wgts)	1559

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	60.51376	15.1284	315.9988
Error	1554	74.39774	0.0479	**Prob > F**
C. Total	1558	134.91150		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.1027463	0.050506	2.03	0.0421*
DSL Transformation	0.1194592	0.021189	5.64	<.0001*
Cable Transformation	0.6499621	0.022827	28.47	<.0001*
Ln (Income) Transformation	-5.002e-8	3.8e-7	-0.13	0.8953
(Cable Transformation-0.24504)*(Ln (Income) Transformation-135960)	-6.097e-6	1.308e-6	-4.66	<.0001*

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Hazlett, Thomas. 2006. *“Universal Service” Telephone Subsidies: What Does $7 Billion Buy?* Figure 8, Data from NECA file USFLC05.xls; http://www.fcc.gov/wcb/iatd/neca.html

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