

Comments of Mark A. Jamison¹

Regarding Docket No. EP 711 (Sub-No. 1) - Reciprocal Switching

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The U.S. Surface Transportation Board (STB) is considering mandating how American railroads provide reciprocal switching, which I understand to be a situation where a shipper with access to one freight railroad obtains access to a competing railroad's track, equipment, and facilities for transport between two points generally served by only one competing railroad. This access is available today under commercially negotiated agreements. My understanding is that the primary desire of proponents of the proposed mandate is for the STB to force railroads to charge less than the negotiated rates.

Such a reciprocal switching mandate has parallels in communications networking in the U.S. where industry regulators such as the Federal Communications Commission (FCC) imposed rules, including price constraints, on how incumbents would carry traffic for, or provide facilities for, rivals. I worked on many of these issues when employed in telecommunications regulation² and have studied them as an academic. The intentions of the telecommunications regulators and of many in the industry was that the regulations would enhance competition and improve market efficiency. Practice proved these beliefs to be wrong: My experiences and research by me and by others found that such rules generally slowed innovation and led network providers to compete less and invest less. Below I summarize the effects of two specific telecommunications policies – the requirement to provide unbundled network elements (UNEs) at cost-based prices and the requirement for net neutrality – that map to the proposed reciprocal switching mandate.

I begin with requirements for pricing of facilities leased to competitors. Under the Telecommunications Act of 1996 (Act), incumbent local telephone companies – called ILECs – were required to unbundle their networks and lease the UNEs to rivals, called CLECs. This requirement had roots in the essential facilities doctrine, which emerged from situations about two decades earlier where upstart rivals to AT&T's long distance services wanted to use AT&T's network facilities to originate and terminate long distance calls. The resulting regulations included mandates that AT&T allow rivals to use its networks, as well as restrictions on AT&T prices. The intent of these price restrictions was to prevent AT&T from engaging in price squeezes or other forms of anticompetitive pricing.

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² I worked for the Kansas Corporation Commission (1984-1987), the Iowa Utilities Board (1987-1993), and Sprint (1993-1996) before joining the University of Florida in 1996.

In implementing the Act, the regulators weighed two basic pricing options for UNEs. One would base the prices on an ILEC's costs of building and maintaining its facilities. An underlying theory of this cost-based approach was that it would emulate competitive markets. Proponents of the cost-based approach also argued that the prices would adequately compensate ILECs for their investments and ongoing expenses, and that the cost-based UNE prices would incentivize CLECs to choose whether to lease or build facilities based on whether their own costs were lower or higher than the ILECs' costs. Another underlying theory was that the pricing would encourage CLEC market entry because CLECs could lease facilities for a period of time until they could build their own networks.

The other pricing option would base prices on an ILEC's opportunity costs of allowing rivals to use the UNEs. This approach had various names over the years but was largely referred to as the efficient component pricing rule (ECPR) during the implementation of the Act. An underlying theory of the ECPR was that ILECs would be kept financially whole if rivals used their facilities, which would result in cooperative relationships at least with respect to network use. The ECPR, which would give higher UNE prices than the cost-based approach, was also characterized as the type of mutually beneficial pricing arrangement that one would expect in competitive markets as a firm would rarely be willing to sell services to a rival for less profit than what the firm could make selling the services at retail, all things considered. Regulators implementing the Act adopted the cost-based option.

Upon becoming an academic, I wrote three papers that included empirical tests of the pricing decision. (Jamison 2004; Hauge, Jamison, and Gentry 2008; Hauge, Jamison, and Jewell 2009) For this research I gathered data on ILEC prices and costs and on CLEC market entry. Pre-publication copies of these papers or abstracts are attached. As a regulatory practitioner I had advocated for the cost-based approach and, as a scholar, I expected my research to confirm the theories underlying it. I was wrong. Jamison (2004) and Hauge, Jamison, and Gentry (2008) found that greater ILEC profit margins in UNE prices stimulated CLEC entry. Hauge, Jamison, and Jewell (2009) found that the same result, but it was not statistically significant.

The bottom line was that the closer UNE prices were to underlying costs and farther from prices that would emerge from commercial negotiations, fewer were the companies that would compete to provide service. This parallels the proposal for the STB to override commercially negotiated prices for reciprocal switching: Mandating prices that are below what would be mutually beneficial for the commercial parties will lead to uneconomic shortfalls in quantities, qualities, or both for the regulated services. Both customers and suppliers would suffer.

Another communications networking policy that has parallels with the proposed mandate for reciprocal switching is net neutrality. Net neutrality is the name for a jumble of policies purportedly aimed to diminish discrimination – i.e., force all telecommunications traffic to be treated the same – but that in fact pressed broadband providers to slow innovation and diminish service. One element of net neutrality is a mandate that all traffic be transported in the same way regardless of the economic or technical needs of the traffic. For example, a broadband network would be required to transport video content the same as it would email content even

though the technical needs for quality video transport are different from those needed to economically transport email. Also under net neutrality, a network provider that was also a content provider would not be allowed to treat its own content services any differently than would treat services provided by others.

Net neutrality regulations vary across countries. With respect to the U.S., the 2015 FCC Open Internet Order (OIO) imposed net neutrality rules to control broadband providers' offers and traffic management. It did this by bringing broadband services under Title II of the Communications Act, i.e., the rules for utility-style regulation of telephone common carrier services. This reclassification not only provided the FCC with authority to impose net neutrality regulations, which would limit broadband profitability, but also empowered the FCC to force UNE-like unbundling and rate regulation of broadband services. In late 2017, the FCC vacated all but the broadband provider transparency provisions of the OIO and replaced it with the Restoring Internet Freedom Order, effectively ending Title II broadband regulations in the U.S. for the time being.

I published two papers on net neutrality that emphasized theoretical findings. In Jamison and Hauge (2009), we showed that net neutrality decreased competition among content providers because it favored large content providers over small ones. In Jamison (2019) I summarized the leading economics literature on net neutrality (which was all theory-based research at that time) and found that it did not support general net neutrality regulations, but instead supported regulators addressing competition issues on a case-by-case basis. Prepublication copies of both papers are attached.

Empirical research began emerging shortly after publication of Jamison (2019) and has shown that net neutrality regulations diminish investment and network performance. The empirical studies did not limit themselves to net neutrality, but rather considered light touch versus heavy-handed regulation in general.

The first empirical study to emerge was Briglauer et al. (2021). It examined 32 OECD countries from 2003 to 2019, finding evidence that more intensive regulations exert a direct negative impact on fiber optic investments and an indirect negative impact on numbers of customers subscribing to fiber-based services. A pre-publication version is attached.

Two other studies utilized the effect of the spread of COVID-19 on the internet usage to test network performance across countries. COVID-19 increased people's reliance on broadband. This increased reliance provided an opportunity to test how different countries' light-touch versus heavy-handed regulations might have affected networks' readiness to provide quality services. Noting that the U.S. had lifted its net neutrality regulations in 2017, studies by Kovacs (2020) and Ford (2020) found that U.S. customers fared better than their counterparts in countries that had more stringent regulatory controls.

Kovacs (2020) examined Ookla Speedtest data and concluded that "U.S. networks generally outperformed their peers" in other countries. She offered three possible explanations for these

differences between the U.S. and its peers. One was the higher levels of per customer investment in the U.S. A second was differences in technology mix. Her third reason was that the U.S. offered a more light-handed regulatory environment, which allowed greater variance in investment returns across customers and with differing service enhancements. This incentivized quality enhancements.

In the other study, Ford (2020) also used Ookla data to perform an econometric analysis comparing network speeds across countries. He found for fixed broadband that “54 of 108 countries experienced a speed reduction, and 33 of these changes are statistically different from zero at the 10% level or better...Fixed download speeds in the United States were stable with no statistically-significant changes in speed.”

Prepublication copies of the Kovacs (2020) and Ford (2020) papers are attached.

In summary, it appears from the experiences of telecommunications regulation that the proposed mandates for reciprocal switching would result in less competition between railroads, lower quality service, and less investment. Forcing prices below levels that commercial parties find mutually beneficial results in less supply of the regulated service. In telecommunications, this meant less competitive entry and less effective broadband services.

Of course, the railroad experience would be different from the telecommunications experience. In telecommunications, the consequences of heavy-handed regulations were serious because people relied heavily on broadband services during the pandemic. But in the case of railroads, the effects of counterproductive regulations could be even more serious. The present regulatory framework for railroads has enabled railroads to adapt quickly to the demands imposed on them during the pandemic (Schofer, Mahmassani, and Ng 2022). More heavy-handed regulations could lead to a less responsive industry, less safe conditions for transporting hazardous materials on rails as investment declines, and less safety for the nation’s highways as shippers find it necessary to increase their reliance on trucking. Also, if the European Commission (2020) is correct in its beliefs that rail transport results in lower CO2 emissions than truck transport, then increased U.S. rail regulation could have negative environmental impacts.

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Attachments

CHAPTER 16

Effects of Prices for Local Network Interconnection on Market Structure in the US

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Abstract. This chapter examines how incumbents and entrants respond to prices for network interconnection in telecommunications, including prices for unbundled network elements. Most studies of the effects of these prices find that lower prices encourage entry and encourage entrants to use more unbundled network elements. Missing from this literature are studies of how incumbents respond to the interconnection prices they charge. US telecommunications laws place an obligation on incumbents to provide interconnection at any technically feasible point, implying that interconnection prices should not affect incumbents' provision of interconnection services. Using data from 1998, evidence is found that low unbundled network element prices result in lower entry, perhaps indicating that US incumbents limit entry. No evidence is found that incumbents hinder entrants from gaining market share for customers who receive more calls than they make (such as Internet Service Providers) or from gaining market share using resold services.

1 INTRODUCTION

The situation often arises in which one firm sells an input to another firm and then competes against the other firm in the market for the final product. Examples include local exchange telephone companies selling access to long distance companies and then competing in the long distance business themselves (Willig, 1979), vertically integrated electricity companies or natural gas pipeline companies selling transport to their generating or gas supplier competitors (Economides and White, 1995), railroads providing trackage to other railroads (Baumol, 1983), Internet backbone providers competing with Internet Service Providers (Cr  mer et al., 2000; Kende, 2000) and incumbent local exchange telephone companies interconnecting their networks with and selling services to new entrants (Katz, 1997). The

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issue of how to price this input is often couched in the context of a regulated firm interconnecting its network with a new entrant, but the issue could also apply to an unregulated monopolist providing an essential facility to downstream competitors (Economides and White, 1995). For purposes of this chapter, I consider the inputs to be interconnection services, which include incumbent local exchange companies (incumbents) providing unbundled network elements (UNEs) and services for resale to new entrants (entrants), and incumbents and entrants terminating local telephone calls for each other. I explain UNEs, resale, and terminating calls in more detail below.

An extensive theoretical literature has developed on pricing these inputs. Most empirical studies in telecommunications examine entrants' responses to prices for interconnecting networks. Indicative of these studies, Ros and McDermott (2000) and Rosston and Wimmer (2000) find that low prices encourage entry and encourage entrants to expand their market shares.¹ Missing from this literature is an empirical test of whether and how incumbents respond to interconnection prices. This test is important because price signals that encourage more entrants to enter or to compete intensely to expand their market share may also encourage incumbents to hinder entrants in order to protect profits, contrary to regulatory policies that place an obligation on incumbents to provide interconnection services regardless of the price. In this chapter, I take an initial step to fill this void by testing how retail and interconnection prices in US telecommunications affected the early development of competition in local telephone networks.² Using data from 1998, my main findings indicate that greater positive differences between retail prices and prices for leasing incumbents' facilities result in fewer entrants, perhaps because incumbents hinder entry to protect profits. Higher prices for exchanging traffic increase entrants' market share, presumably because they successfully target customers who receive more calls than they make. Entrants appear to resell incumbent services as part of a strategy to gain customers while building networks. Before proceeding, I summarize entry under the US Telecommunications Act of 1996 (1996 Act).

The 1996 Act made allowing competition in almost all telecommunications markets a national policy and provides three methods of entry for local telephone service. Some entrants use more than one method. Entrants can build their own facility-based network, lease portions of an incumbent local exchange company's (incumbent) network, or buy an incumbent's services and resell them.³ The 1996 Act places an obligation on an incumbent to provide entrants with these interconnection services. Exchanging calls between competing networks is

¹ Jamison (2002) provides a partial survey. These studies did not examine the relationship between retail and interconnection prices.

² Telecommunications has traditionally been divided between long distance service and local exchange service. Local exchange service in the US consists of a telephone line and calling within a local calling area, which is typically a city or town. Long distance is calling between local exchange areas. This distinction between local and long distance was based on late 1800's technological limits and the original city-by-city franchising arrangements under which the US telephone system developed. These reasons lost their relevance long ago, but the distinction has remained for regulatory purposes. The AT&T divestiture agreement of 1982 restricted the Bell Operating Companies from providing long distance service, except in limited areas (called Local Access Transport Areas, or LATAs).

³ Traditional voice telecommunications networks consist of lines and switches. Lines either connect customers to the network or connect switches in the network. Switches route calls between customers. Switches are of two types: local switches (also called central offices) that customers connect to and that switch local calls, and long distance switches (also called tandem or toll offices) that route long distance calls from one local switch to another.

necessary for customers of one company to be able to call customers of another company. Payment for exchanging calls is called reciprocal compensation in the US.⁴

Leasing portions of an incumbent's network is called purchasing UNEs. For example, an entrant could lease a local telephone line from the incumbent. The line would connect to the incumbent's building. It could then connect to the incumbent's switch or the entrant's switch, depending on how the entrant wishes to use the incumbent's facilities. Entrants that have their own switches must interconnect their switches with those of an incumbent and pay reciprocal compensation for terminating telephone calls on the incumbent's network. Likewise, an incumbent must pay reciprocal compensation for terminating calls to an entrant.⁵ The 1996 Act states that prices for UNEs and for reciprocal compensation are to be cost-based, which regulators have generally concluded means that they should be based on incremental cost.⁶ Reselling is little more than rebranding the incumbent's service. The 1996 Act says that wholesale prices must be based upon retail prices minus the portion attributable to marketing, billing, collection, and other costs avoided by the incumbent when it does not provide the retail service. The percent discount given off of the retail price is called the wholesale discount.

The rest of this chapter is organized as follows. In section 2, I describe the hypotheses that I am testing. Section 3 describes my data and methods. Section 4 presents my findings and Section 5 is the conclusion.

2 THEORY AND HYPOTHESES

Assuming that entrants seek to maximize profits, I expect more entrants to seek to enter and for entrants to seek to expand their market shares in markets where regulatory policies are more favorable to entrant profits. This can be thought of in terms of an entrant demand curve for entry or interconnection services. Lower prices for UNEs and higher wholesale discounts encourage more entrants to enter and to buy more of these services. Higher prices for UNEs and lower wholesale discounts have the opposite effect. In the case of reciprocal compensation for exchanging calls, entrants are both buyers and sellers of interconnection. Some entrants are more successful at targeting customers (such as Internet Service Providers) who are net receivers of calls, making these entrants net sellers for reciprocal compensation. More of these entrants seek to enter and to expand in markets where reciprocal compensation prices

⁴ "Reciprocal" means that both companies involved in an interconnection are obligated to make payments. "Symmetric" reciprocal compensation means the companies charge the same prices to each other. Reciprocal compensation prices are generally symmetric in the US, so I assume symmetry in my models.

⁵ An exception to the payment of reciprocal compensation occurs in the case of bill and keep, the situation in which the service providers do not charge each other for exchanging traffic.

⁶ This is based on a review of state commission interconnection decisions located on the National Regulatory Research Institute's web site (NRRI, 1998) for 1998, the time period for my study, the FCC and all state regulators but Arkansas determined that incumbents' prices for UNEs should be based upon incremental cost. Arkansas chose an accounting cost allocation approach called fully distributed cost as its method. Twenty-nine percent of the states also chose to base reciprocal compensation prices on incremental cost and the rest chose bill and keep. The FCC's policies allow for bill and keep, but do not mandate it. Some states that adopted bill and keep applied the policy only as long as the traffic exchange is relatively balanced.

are higher. Other entrants are successful in the market for customers that make calls and so either pay as much or more reciprocal compensation than they receive.

Furthermore, the relationships between the retail prices and the prices entrants pay to incumbents affect entrant demand for interconnection services. Greater positive differences between retail prices and the prices for interconnection services that entrants purchase encourage more entrants to enter and to gain market share. The opposite holds if retail prices are lower. This conclusion should hold for UNEs and resold services for all entrants that use these services and for reciprocal compensation for entrants that are net payers. Higher retail prices and higher reciprocal compensation prices encourage more entrants that are net receivers of reciprocal compensation to enter and to increase their market share, so the effect of the relationship between retail prices and reciprocal compensation prices is ambiguous.

Interconnection prices also provide incentives to incumbents. If incumbents do not respond to these incentives, then an examination of the entrants' demand for interconnection services are adequate for predicting the effects of interconnection prices on the number of entrants and on entrant market share. If incumbents do respond, they might do so by changing the demand for their services relative to the demand for entrants' services. For example, if retail prices are higher relative to interconnection services that incumbents sell, such as UNEs and services for resale, then incumbents might respond by increasing their marketing activities or by improving the quality of their retail services relative to their interconnection services. Either response, if successful, would have the effect of decreasing the retail demand for entrants' services, which would in turn lower entrants' demand for interconnection services. Incumbents could also respond by restricting their supply of interconnection services, implying that incumbents have a supply curve for interconnection services that they provide and do not simply comply with their obligation to provide these services.⁷ Incumbents might restrict supply for interconnection services by delaying negotiations with entrants, making ordering of interconnection services difficult, or other means.

My first hypothesis (which I call H1) is that incumbents comply with their obligations to provide interconnection services. I test this hypothesis by examining the effects of incumbent marketing, incumbent service quality, and the relationship between retail prices and prices for UNEs, reciprocal compensation, and services to be resold on the number of entrants in a market, the volume of calls exchanged between incumbents and entrants, and the volume of resold services. For UNEs and reciprocal compensation, I express this relationship as the ratio of the interconnection price to the retail price. I place the UNE and reciprocal compensation prices in the numerator because in the case of Bill and Keep, the reciprocal compensation price is zero. For resale, I use the wholesale discount. I reject H1 if, controlling for incumbent marketing efforts and service quality, a lower ratio of UNE prices to retail prices or higher wholesale discounts lead to fewer entrants or smaller entrant market share.

My second hypothesis (H2) is that the volume of calls exchanged between the incumbent and entrants is primarily determined by entrants that are successful in attracting customers that are net receivers of calls. I reject H2 if higher reciprocal compensation prices result in lower volumes of exchanged calls. My third hypothesis (H3) is that most entrants are not of the type that attracts customers that are net receivers of calls. I reject H3 if higher reciprocal compensation prices result in a greater number of entrants.

⁷ I would like to thank William Taylor for this insight.

Some observers express concern that entrants take advantage of large wholesale discounts to simply resell services and not build networks. (Harris and Kraft, 1997) If entrants avoid building facilities when wholesale discounts are large, then large discounts should be associated with (i) a low market share for entrants using their own facilities or UNEs and (ii) higher levels of service resale. This leads to my last hypothesis (H4), which is that entrants resell services to gain customers with the intent of eventually serving those customers using UNEs or entrant facilities. I reject H4 if higher wholesale discounts increase the number of resold services and lower UNE prices have either no effect on or increase the volume of resold services.

3 METHODS AND DATA

I consider three types of models. The first describes the number of entrants, without distinguishing entry methods. The second describes how entrants expand their market share by constructing their own networks and using UNEs. The third describes how entrants expand their market share by reselling incumbents' services. Because my sample size is small, I use reduced form rather than structural form models. I first describe the models for number of entrants.

3.1 Models for Number of Entrants

I analyze entry by extending Bresnahan and Reiss's (1991) and Berry's (1992) ordered probit models for entry, which apply a zero-profit equilibrium for entrants. These models assume that markets that are more profitable for entrants attract a larger number of entrants than other markets, all other things being equal. Ordered probit models are used when dependent variables are discrete and represent ordered outcomes. Because of data restrictions, I consider each incumbent's traditional local exchange areas in a state to be a market.⁸ The number of entrants ranges from 0 to 164 in these 59 markets. A large range of values in the dependent variable in an ordered probit model causes the analysis to be computationally intensive. To remedy this problem, I take advantage of there being only 36 observed levels of entry – many markets have the same number of entrants (for example, five markets have four entrants each) and many levels of entry are unobserved (for example, no markets have entry levels in the 61- to 74-entrant range) – and create an ordinal variable with values from 0 to 35 that is a monotonic transformation of the observed number of entrants per market.

I control for other factors that may affect the number of entrants in a market. The 1996 Act mandates collocation, the process by which entrants locate their equipment in incumbents' buildings. Collocation can increase entry when it decreases entrants' costs of interconnection

⁸ This causes distortions because for a given incumbent, an entrant may choose to enter some of the incumbent's local exchanges and not enter others, and may choose to supply only some areas of a local exchange. Because regulators generally require incumbents to average retail prices across exchanges and to charge lower retail prices in rural areas than in urban areas, and because per customer costs are generally lower in high density, urban areas than in rural areas, I expect entrants to serve urban areas first. Therefore, regions with higher than average proportions of urban areas should have more entry than areas that are below average. To control for this effect, I include in my models a measure of customer density. Higher customer density indicates markets with higher than average proportions of urban areas.

and using UNEs, relative to entrants placing their equipment some distance away from the incumbents' facilities. I control for the effects of the availability of collocation by including in my models the percent of the incumbent's telephone lines that can be accessed through collocation arrangements.

The 1996 Act also requires competitively neutral means for subsidizing local telephone service. Some regulators have chosen to implement this policy in part by rebalancing prices, the process by which incumbents increase some prices and decrease other prices in order to remove implicit subsidies and align prices with incremental cost. Another common method for implementing this policy is for regulators to develop a "tax" on telephone services, the monies from which are distributed to companies based on their serving customers who the regulators determine should have subsidized prices. I control for the effects of rebalancing by including in my model the ratio of the incumbent's revenues from local telephone services to its cost of providing a telephone line. Higher ratios indicate higher profits for local telephone services. Higher ratios would be associated with (i) more entry and higher market share for entrants if they are willing and able to respond to this incentive or (ii) less entry and lower market share for entrants if incumbents protect these profits. Following Ros and McDermott (2000), I test for the effects of early reforms to the subsidy system by including in my models a dummy variable that indicates whether the state regulator for the market has begun reforming these subsidies.

More entrants are expected in larger and more densely populated markets. I control for market size by including as an explanatory variable the total revenues of the incumbent company in the market. I control for customer density by including the incumbent's number of telephone lines per central office. Because competition in local networks was new at the time of this study, it is unlikely that the data represent a long-run equilibrium. I adjust for this disequilibrium by including as an explanatory variable the amount of time that has elapsed since entrants were allowed to enter each market. Lastly, I include dummy variables for incumbent telephone companies. Table 1 summarizes the explanatory variables that I include in my models for number of entrants.

Table 1. Descriptions of Explanatory Variables for Models of Number of Entrants

Explanatory Variable	Description
UNE Price	The price per month for leasing a 2-wire local line in urban areas. ⁹ I choose local line prices to represent UNE prices because the sunk nature of line investment and the need for right-of-way and conduit space make lines the most difficult facilities for entrants to build. Two-wire lines are the most common technology used for local telephone service. I choose urban prices because I expect most entrants to serve urban areas.
Reciprocal Compensation Price	The price per minute for symmetric reciprocal compensation. This variable is zero in the case of bill and keep.
Residential Wholesale Discount	The wholesale discount regulators give entrants for buying wholesale services for residential customers. In states where discounts vary by service, I use the smallest percentage discount.
Lines per Central Office	The total number of billable telephone lines that the incumbent has in the market divided by the incumbents' number of central offices. This represents density.
Local Service Revenue to Cost Ratio	The ratio of the incumbent's local service per-line revenue to the incumbent's cost of providing a telephone line. This represents the incumbent's local service profit margin.
Percent of Voice Lines Assessable through Collocation	The percent of incumbent's voice telephone lines that could be accessed by entrants through collocation arrangements. This represents the ease of collocation.
Number of Quarters	For each market, the number of quarters prior to 1996 that the first entrant was given telephone numbers. This represents the amount of time that entrants have had to enter the market and gain market share.
Service Complaints in 1997	The total number of customer complaints to state and federal regulators about the incumbent's service in 1997. This indicates the incumbent's service quality.
Total Revenue	The incumbent's total operating revenue for 1998. This indicates market size.
Ratio of UNE Price to Retail Revenue per Line	The ratio of the incumbent's UNE price to the incumbent's average retail price.
Ratio of Reciprocal Compensation Price to Retail Revenue per Minute	The ratio of the incumbent's price for reciprocal compensation to the incumbent's average retail revenue per minute.
Universal Service Reform	A dummy variable indicating whether a state has taken steps to develop competitively neutral methods for subsidizing local telephone service. A value of 1 indicates that the state has done so.
Marketing Expenses per Line 1997	The ratio of Total Marketing Expenses in 1997 for regulated services to the number of billable telephone lines. I use 1997 data to ensure that the market expenses were not a response to the number of entrants in 1998.
Incumbent Indicators	Dummy variables that associate markets with incumbents. Incumbent dummy variables may reveal differences in how incumbents respond to entry.

⁹A two-wire local line has two wires twisted together that are used to connect the customer to the telephone company central office.

3.2 Models for Entrant Market Share

Now consider the second and third types of models, those that describe how entrants expand their market share. I use ordinary least squares regression and examine two measures of entrant output. The first measure is the number of entrant interconnections to the incumbent. These interconnections, called trunks, are necessary for exchanging calls between entrant and incumbent customers. Higher numbers of trunks indicate higher amounts of entrant output for customers that are net receivers of calls and that are served by entrant facilities or UNEs. Trunks understate traffic exchange if the entrants are large because, as an entrant grows, the number of minutes that stay on the entrant's network generally increase. This happens because the probability of a call originating on an entrant's network also terminating on that entrant's network generally increases as the entrant attracts more customers. Trunks overstate traffic exchange if there are many small entrants, or many entrants whose customers are dispersed geographically. This happens because these entrants' low traffic volumes keep them from making efficient use of their local interconnection trunks. I do not include incumbent marketing expenses per line as an explanatory variable in the entrant interconnection models because the variable is too broad of a measure of incumbent marketing to reasonably measure incumbent marketing efforts to Internet Service Providers. My second measure of entrant supply is the proportion of business local telephone lines that are resold by entrants.

For models of entrant market share, I divide the dependent variables and certain explanatory variables by the number of incumbent telephone lines in the market. This indexes these variables according to market size. Table 2 describes the explanatory variables in my market share models that are not also in my entry models.

Table 2. Descriptions of Explanatory Variables for Market Share Models

Explanatory Variable	Description
Business Wholesale Discount	The discount regulators give entrants for buying wholesale business services. In states where discounts vary by service, I use the smallest percentage discount. This variable is used in the model of resold business lines.
Local Revenue Per Line	The incumbent's per-line revenue from local service.
Service Complaints in 1998 Per Line	The total number of customer complaints to state and federal regulators about the incumbent's service in 1998 divided by the number incumbent telephone lines.
Total Revenue Per Line	The incumbent's total operating revenue for 1998 divided by the number of incumbent telephone lines.
Total Plant in Service Per Line	The net book value of the incumbent's assets in the market divided by the number of incumbent telephone lines.
Minutes of Use Per Line	The number of telephone minutes of use for the incumbent in 1998.
Central Office Total Plant in Service Per Line	The net book value of the incumbent's central office assets divided by the number of incumbent telephone lines.

3.3 Data

Table 3 describes the data I use for my dependent variables, which are from the United States Telephone Association's (USTA) report to Congressman Thomas Bliley on December 9, 1998 (USTA, 1998).¹⁰ Data are for 1998. There were no reported entrants in West Virginia in Bell Atlantic's territories in 1998, so I omit this market from the market share models. Table 4 describes the data for the explanatory variables for my entry models. Table 5 describes data for the market share model explanatory variables that are not also used in the entry models.

Table 3. Descriptions of Dependent Variables

Variable	Name in Model	Mean	Minimum	Maximum	Standard Deviation	Observations
Number of Entrants	COMPT	13.898	0	35	10.22	59
Number of Interconnection Trunks	NA	30,536.4	0	289,299	50,946.3	58
Interconnection Trunks Per Line	TRNKPLN	0.0096	0	0.0243	0.0066	58
Number of Business Resold Lines	NA	27,474.7	0	183,594	42,918.38	58
Fraction Business Lines Resold	RSLBSPR	0.0336	0	0.3303	0.0524	58

Data for UNE and reciprocal compensation prices and wholesale discounts are from state commissions (NRRI, 1998; Alabama, 1998), X-Change (1998-1999), and interviews with incumbents.¹¹ Some states have separate prices for terminating minutes at a central office or a tandem office and for different times of the day. To express these prices as a single price, I follow the convention of assuming 6.25% of the minutes terminate at local central offices and the remaining minutes terminate in a tandem. In states where residential service discounts are different from business service discounts, I use the residential discount for the models explaining number of entrants and market share using UNEs and entrant-owned facilities. Business and residential discounts are highly correlated ($R^2 = 0.88$). In tests of various models, business and residential discounts have similar results. To avoid multicollinearity, I use only the residential discount for these models.

¹⁰ Observations include Ameritech (all states), Bell Atlantic (all states), BellSouth (all states), GTE (California, Florida, Hawaii, Illinois, Indiana, Kentucky, Michigan, North Carolina, Ohio, Oregon, Texas, Virginia, Washington, and Wisconsin), SBC (Arkansas, California, Oklahoma, and Texas), and US West (all states) for 1998.

¹¹ In cases where there are discrepancies, I employ the data provided in state commissions' decisions (NRRI, 1998) when available, and other public data when the commission data are not available.

Table 4. Descriptions of Explanatory Variables for Models of Number of Entrants

Variable	Name in Model	Mean	Minimum	Maximum	Standard Deviation	Observations
UNE Price	UNEPRC	\$16.82	\$3.72	\$32.00	\$6.16	59
Reciprocal Compensation Price	RCP	\$0.0057	\$0	\$0.0283	\$0.0067	59
Residential Wholesale Discount	RESRSL	0.1788	0.0700	0.2500	0.0405	59
Incumbent Total Billable Lines	NA	2,286,606	235,862	16,071,707	2,785,059	59
Number of Incumbent Central Offices	NA	230.1	29	752	174.2	59
Lines Per Central Office	LNSPRCO	10,424.9	881.1	29,786.8	6,851.7	59
Incumbent Local Service Revenues (000)	NA	\$749,773	\$71,863	\$4,731,829	\$902,587	59
Incumbent Line Cost Level	NA	\$265.72	\$65.68	\$408.81	\$57.71	59
Local Service Revenue to Cost Ratio	LCLPUSF	1.3290	0.7967	5.0431	0.5551	59
Percent of Voice Lines Assessable through Collocation	COLCV98	23.66%	0%	72.62%	17.54	59
Number of Quarters Service Quality	NUMQRT	10.75	0	18	15.44	59
Complaints in 1997	SCMPAM-97	274.29	6	2,637	466.18	59
Total Revenue (000)	REVT	\$1,511,887	\$170,463	\$8,460,236	\$1,721,406	59
Ratio of UNE Price to Retail Revenue per Line	PRCST-UNE	0.1969	0.0546	0.4460	0.0739	59
Local Calling Minutes for Incumbent (000)	NA	7,056,890	820,771	36,441,427	7,740,706	59
Ratio of Reciprocal Compensation Price to Retail Revenue per Minute	PRCST-RCP	0.1601	0	0.8236	0.1919	59
Universal Service Reform	USFFUND	0.2881	0	1	0.4568	59
Marketing Expenses per Line in 1997	MKTGSTS97 pl	\$25.76	\$13.75	\$37.90	\$5.72	59

Table 5. Descriptions of Explanatory Variables in Market Share Models and not in Models of Number of Entrants

Variable	Name in Model	Mean	Minimum	Maximum	Standard Deviation	Observations
Business Wholesale Discount	BUSRSL	0.1792	0.0800	0.2601	0.0377	58
Local Revenue Per Line	LCLPRLN	\$329.98	\$228.47	\$458.84	\$49.69	58
Service Complaints in 1998 Per Line	SCMP98-PL	0.00016	9.03 x 10 ⁻⁶	0.00097	0.00019	58
Total Revenue Per Line ¹²	REVTPL	\$678.02	\$502.90	\$955.18	\$98.80	58
Incumbent Total Assets (000)	NA	\$4,532,754	\$493,351	\$27,585,598	\$5,118,892	58
Total Plant in Service Per Line	TPISPL	\$206.07	\$140.24	\$305.62	\$37.87	58
Minutes of Use Per Line	MOUPL	3,288.7	2,188.4	4,592.0	599.3	58
Central Office Total Plant in Service Per Line	COTPILPL	\$364.44	\$225.44	\$639.74	\$89.82	58

Data for incumbent total billable lines, number of central offices, local service revenues, service quality complaints, total revenues, local calling minutes, marketing expenses, and total plant in service are from FCC ARMIS reports.¹³ I use the ratio of total revenues for basic local telephone services and total billable lines to indicate incumbents' price levels for local exchange services. Firms charge many prices, so using a single price is inappropriate. I use incumbents' Universal Service Fund costs per line reported to the FCC in 1998 to represent incumbents' costs for telephone lines.¹⁴ I use total numbers of customer complaints to state and federal regulators for 1997 and 1998 in metropolitan statistical areas as my measure of incumbent service quality. Data for 1997 are used to examine number of entrants because these data represent ex ante entry information. Per line data for 1998 are used in models for entrant market share because these data represent the quality that customers and entrants experienced at the time supply and purchasing decisions were put into effect. I use the incumbent's total operating revenues for 1998 for the market, to indicate market size.

I use the percent of incumbent voice telephone lines accessible by entrants through collocation in 1998 to represent the ease of collocation. Data are from Tables 3.6 and 3.7 of the FCC's 1998 Local Competition report. (FCC, 1998) There is a risk of endogeneity because higher entrant interest in a market should increase entrant demand for collocation. Higher demand for collocation should increase the incidence of collocation, which could cause a

¹² Total revenue per line, total plant in service per line, and central office total plant in service per lines are expressed as \$1000 per line in the model. Minutes of use per line is expressed as 1000s of minutes per line in the model.

¹³ All ARMIS data are from <http://fcc.gov> and were downloaded between March 1999 and December 2002.

¹⁴ USF costs are based on incumbents' regulatory accounting records and provide an average cost for all of an incumbent's operations in a state. Regulatory costs are an imperfect measure of economic costs. The accounting processes (Gabel, 1967) and distortive efficiency incentives caused by methods of regulation (Sappington and Weisman, 1996) cause these regulatory costs to deviate from economic costs.

higher percentage of incumbent lines to be in central offices with collocation. However, differences between markets should also reflect the ease of obtaining collocation.

I use the number of quarters in a state from the time the first entrant was given telephone numbers until the 1996 Act took affect to represent the amount of time that entrants have been operating in a state. Data are from Table 4.8 of the FCC's December 1998 Local Competition report (FCC, 1998).

For the models for number of entrants, I include two price ratios, PRCSTUNE and PRCSTRCP, as explanatory variables. PRCSTUNE is the ratio of the incumbent's UNE price to the incumbent's 1998 total operating revenues. PRCSTRCP is the ratio of the incumbent's reciprocal compensation price to the incumbent's average retail revenue per minute.

I use dummy variables to indicate state efforts to reform universal service subsidies and to identify incumbents. According to a National Regulatory Research Institute survey (Rosenberg and Wilhelm, 1998), fourteen states had revised or were revising their subsidy policies in 1998. I have a dummy variable for each incumbent, but omit the Ameritech dummy from models to avoid multicollinearity.

Multicollinearity problems occur between the reciprocal compensation variables RCP and PRCSTRCP ($R^2 = 0.97$), between the service complaint variables SCMPAM97 and SCMPAM98 ($R^2 = 0.92$), among variables that indicate market size (for example, REVT and TPIS), and between PRCSTUNE and the variables that are included in it. To avoid multicollinearity in the models for number of entrants, I include no more than one variable from each of the collinear groups, with the exception of collinear groups involving PRCSTUNE and PRCSTRCP. I need these variables in some entry analyses to perform likelihood ratio tests of entrant and incumbent incentives. Regarding multicollinearity in the entrant market share models, dividing market size indicators such as REVT by LINES resolves much of the multicollinearity. Otherwise, I include in each model no more than one variable from each collinear group.

4 MODEL RESULTS

In this section I examine the results of my models. I examine the number-of-entrants models first. I then investigate the models for market share with respect to calls exchanged. Lastly, I examine models for resale. Tests of log linear models did not improve the overall fit, so I report only the linear results.

4.1 Results for Models of Number of Entrants

Table 6 provides the coefficients and t-statistics for these models. One asterisk (*) indicates significance at the 0.10 level. Two asterisks (**) indicate significance at the 0.05 level. Three asterisks (***) indicate significance at the 0.01 level. I estimate two models. Model 1 examines how UNE prices, reciprocal compensation prices, wholesale discounts, customer density, local service price-cost margins, service quality, market size, and UNE price-cost margins affect the number of entrants. The signs of coefficients can be misleading in ordered probit models, so I calculate the marginal effects of explanatory variables on each level of entry in Table 7. A negative marginal effect for a particular explanatory variable and entry level indicates that a higher value for the explanatory variable decreases the probability of a market having that level of entry. A positive marginal effect indicates that a higher value for

the explanatory variable increases the probability of a market having that level of entry. For example, the marginal effects for UNE price imply that a higher UNE price would increase the probability that a market would have less entry and decrease the probability that the market would have more entry. Before reviewing the marginal effects further, I examine whether other explanatory variables should be included in entry models.

Model 2 in Table 6 provides the results of adding other variables to Model 1. Using a likelihood-ratio test, I fail to reject at the 0.10 level the joint hypothesis that the coefficients for these variables are all zero ($\chi^2(3) = 1.75$). I conclude that Model 1 is the most appropriate model for examining how regulatory policies affect entry decisions.

Table 6. Regression Results for Entry (COMPT)

Explanatory Variable	Model 1	Model 2
	*-0.1370	*-0.1347
UNE Price	(-1.89)	(-1.81)
	** -57.4441	-55.4438
Reciprocal Compensation Price	(-1.96)	(-0.56)
	***12.1078	***12.2769
Residential Wholesale Discount	(2.85)	(2.85)
	*0.0001	0.0001
Lines Per Central Office	(1.90)	(1.16)
	** -1.4155	*-1.1159
Local Service Revenue to Cost Ratio	(-2.49)	(-1.82)
Percent of Voice Line Assessable through Collocation		0.0147
		(1.18)
		-0.0164
Number of Quarters		(-0.31)
	** -0.0010	** -0.0011
Service Quality Complaints in 1997	(-2.01)	(-2.04)
	***1.25e-06	***1.35e-06
Total Revenue	(4.88)	(4.99)
	*10.9565	8.8917
Ratio of UNE Price to Retail Revenue per Lines	(1.86)	(1.45)
Ratio of Reciprocal Compensation Price to Retail Revenue per Minute		0.4409
		(0.12)
	0.4581	0.4967
Universal Service Reform	(1.15)	(1.23)
	0.0087	-0.0083
Marketing Expenses per Line in 1997	(0.27)	(-0.23)
		0.3410
GTE dummy variable		(0.41)
	*0.9818	**1.2968
Bell Atlantic dummy variable	(1.84)	(1.98)
	***2.2178	***2.6699
BellSouth dummy variable	(3.77)	(3.35)
	***3.6751	***4.1259
SBC dummy variable	(4.22)	(3.93)
		0.9301
US West dummy variable		(1.13)
	107.77	109.52
χ^2	d.f. = 15	d.f. = 18
Log Likelihood	-147.7770	-146.9014

The marginal effects in Table 7 show that there is less entry if the ratio of UNE prices to retail revenue per line is lower, so I reject H1. This result implies that incumbents do not simply comply with their obligations to provide interconnection services to entrants, at least to the extent that these services affect the number of entrants. The marginal effects also show that entry is lower if UNE prices are higher, wholesale discounts are lower, and incumbent ratios of local service revenue to cost are higher, which supports my conclusion that incumbents have a supply curve for interconnection services. The marginal effects also show that there is less entry if reciprocal compensation is higher, so I fail to reject H3 and conclude that most entrants are net payers of reciprocal compensation. Universal service reform and incumbent marketing have no significant effects on entry.

4.2 Entrant Market Share Model Results

Tables 8 and 9 provide the results for the entrant market share models. Model 3 in Table 8 shows the results of including most of the explanatory variables in a model for number of interconnection trunks. This model forms the basis for testing hypotheses. Using an F-test, I fail to reject the hypothesis at the 0.10 level that coefficients for the ratio of UNE prices to incumbent retail revenue per line, incumbent local revenue per line, universal service reform, and the GTE, BellSouth, and US West dummy variables are equal to zero ($F(7, 38) = 0.41$). Model 4 shows the Model 3 with these variables. This F-test does not form a basis for rejecting H1, but H1 is already rejected based on the results of Model 1. This difference in model results implies that incumbents may not hinder entrants from gaining market share for customers that are net receivers of calls. The coefficient for reciprocal compensation prices is positive and significant, so I fail to reject H2, that the volume of calls exchanged between incumbents and entrants is largely determined by the calls received by entrants who are successful in attracting customers who are net receivers of calls. Taken together, the analysis of H1 and H2 may explain why incumbents asked regulators to prohibit entrants from receiving reciprocal compensation for terminating calls to Internet Service Providers; i.e., it may be that incumbents were unsuccessful in targeting Internet Service Providers as customers and so sought to prevent entrants from benefiting from their successful marketing to Internet Service Providers.

Table 7. Marginal Effects for Model 1

Entry Level	Selected Explanatory Variables							
	UNE Price	Reciprocal Compensati on Price	Residential Wholesale Discount	Local Service Revenue to Cost Ratio	Service Quality Complaints in 1997	Ratio of UNE Price to Retail Revenue per Lines	Universal Service Reform	Marketing Expenses per Line in 1997
0	0.0002079	0.08714273	-0.0183675	0.00214736	1.55371E-06	-0.0166211	-0.000695	-1.324E-05
1	-0.0002026	-0.0849369	0.01790258	-0.002093	-1.51438E-06	0.01620034	0.00067742	1.2901E-05
2	0.00019417	0.08138683	-0.0171543	0.00200552	1.45109E-06	-0.0155232	-0.0006491	-1.236E-05
3	0.00047191	0.19780883	-0.0416932	0.00487438	3.52683E-06	-0.0377288	-0.0015776	-3.005E-05
4	0.00111252	0.46632562	-0.0982898	0.01149114	8.31435E-06	-0.0889441	-0.0037192	-7.083E-05
5	0.00525195	2.20141952	-0.4640044	0.05424711	3.92502E-05	-0.4198853	-0.0175575	-0.0003344
6	0.00372893	1.56302578	-0.3294469	0.03851589	2.7868E-05	-0.298122	-0.0124659	-0.0002374
7	0.00704959	2.95491979	-0.6228235	0.07281477	5.26847E-05	-0.5636033	-0.023567	-0.0004488
8	0.0027985	1.17302616	-0.2472447	0.02890557	2.09145E-05	-0.2237358	-0.0093555	-0.0001782
9	0.00332454	1.39351967	-0.2937192	0.03433894	2.48458E-05	-0.2657914	-0.011114	-0.0002117
10	0.00388077	1.62667387	-0.3428623	0.0400843	2.90028E-05	-0.3102618	-0.0129736	-0.0002471
11	0.00409192	1.71517802	-0.3615168	0.04226521	3.05808E-05	-0.3271426	-0.0136794	-0.0002605
12	0.00387262	1.62325594	-0.3421419	0.04000007	2.89418E-05	-0.3096099	-0.0129463	-0.0002466
13	0.00359386	1.50640886	-0.3175135	0.03712074	2.68585E-05	-0.2873232	-0.0120144	-0.0002288
14	0.00943033	3.95283904	-0.83316	0.09740538	7.04771E-05	-0.7539403	-0.0315259	-0.0006004
15	0.00231213	0.96915698	-0.2042742	0.02388185	1.72796E-05	-0.1848511	-0.0077295	-0.0001472
16	0.00351692	1.47415973	-0.3107162	0.03632606	2.62835E-05	-0.2811722	-0.0117572	-0.0002239
17	-0.0032167	-1.3483284	0.28419405	-0.0332253	-2.404E-05	0.25717191	0.01075361	0.0002048
18	-0.0060902	-2.5527707	0.5380605	-0.0629051	-4.55146E-05	0.48689987	0.02035966	0.00038775
19	-0.0035091	-1.4708912	0.31002723	-0.0362455	-2.62253E-05	0.28054878	0.01173111	0.00022342
20	-0.0084286	-3.5329685	0.74466178	-0.087059	-6.29911E-05	0.67385679	0.02817724	0.00053663
21	-0.0088631	-3.7150951	0.78304952	-0.0915469	-6.62383E-05	0.7085945	0.02962979	0.00056429
22	-0.0044362	-1.8594891	0.39193401	-0.0458213	-3.31538E-05	0.35466758	0.01483038	0.00028244
23	-0.0042759	-1.792314	0.37777516	-0.044166	-3.19561E-05	0.341855	0.01429463	0.00027224
24	-0.0037688	-1.579742	0.33297028	-0.0389278	-2.8166E-05	0.30131033	0.01259926	0.00023995
25	-0.0033006	-1.3834727	0.29160159	-0.0340914	-2.46666E-05	0.26387512	0.01103391	0.00021014
26	-0.0030118	-1.2624322	0.26608927	-0.0311087	-2.25085E-05	0.24078859	0.01006855	0.00019175
27	-0.0027359	-1.1467857	0.24171387	-0.028259	-2.04466E-05	0.21873089	0.00914621	0.00017419
28	-0.0015836	-0.6637898	0.13991036	-0.016357	-1.1835E-05	0.1266072	0.00529406	0.00010082
29	-0.000658	-0.275795	0.05813071	-0.0067961	-4.91729E-06	0.05260344	0.00219961	4.1891E-05
30	-0.0003601	-0.1509229	0.0318108	-0.003719	-2.69088E-06	0.02878612	0.00120369	2.2924E-05
31	-0.0002909	-0.1219366	0.02570121	-0.0030047	-2.17407E-06	0.02325745	0.00097251	1.8521E-05
32	-0.0001047	-0.0438816	0.00924914	-0.0010813	-7.82386E-07	0.0083697	0.00034998	6.6653E-06
33	-1.657E-06	-0.0006947	0.00014643	-1.712E-05	-1.23862E-08	0.0001325	5.5406E-06	1.0552E-07
34	-8.812E-10	-3.694E-07	7.7853E-08	-9.102E-09	-6.58561E-12	7.0451E-08	2.9459E-09	5.6104E-11
35	-7.962E-20	-3.338E-17	7.0346E-18	-8.224E-19	-5.9506E-22	6.3657E-18	2.6618E-19	5.0694E-21

Table 8. Regression Results for Entrants Using UNEs and Facilities (TRNKPLN)

Explanatory Variable	Model 3	Model 4
	-0.0002	-0.0002
UNE Price	(-1.25)	(-1.47)
	*0.1966	*0.2158
Reciprocal Compensation Price	(1.92)	(1.77)
		0.0134
Residential Wholesale Discount		(0.79)
		0.00002
Local Revenue Per Line		(0.81)
Percent of Voice Lines Assessable through Collocation	***0.0002	***0.0002
	(3.79)	(3.22)
	***0.0006	***0.0006
Number of Quarters	(3.36)	(2.69)
Service Complaints in 1998 Per Line	**7.4731	7.2727
	(2.02)	(1.65)
	**0.0350	0.0303
Total Revenue Per Line	(2.55)	(1.56)
	**0.0079	*0.0083
Total Plant in Service Per Line	(-2.19)	(-1.76)
	***0.0043	**0.0037
Minutes of Use Per Line	(2.95)	(2.10)
Central Office Total Plant in Service Per Line	***0.0416	*0.0338
	(3.05)	(1.85)
		0.0007
Universal Service Reform		(0.37)
Ratio of UNE Price to Retail Revenue per Lines		0.0036
		(0.36)
	***-14.6356	**11.6152
Central Offices per Line ¹⁵	(-3.48)	(-2.18)
		0.0033
GTE dummy variable		(0.68)
	***-0.0071	-0.0049
Bell Atlantic dummy variable	(-3.68)	(-1.36)
		0.0024
BellSouth dummy variable		(0.62)
	**0.0055	*0.0063
SBC dummy variable	(2.21)	(1.92)
		0.0027
US West dummy variable		(0.61)
	***-0.0337	***-0.0358
Constant	(-4.26)	(-4.01)
	7.57	4.49
F	d.f. = 12, 45	d.f. = 19, 38
R2	0.6688	0.6919

Table 9 shows the results for entrant market share using resold business services. Model 5 forms the basis for testing hypotheses. The coefficient for the business wholesale discount is insignificant and the coefficient for UNE prices is negative and significant, so I fail to reject H4, that entrants resell incumbent services to gain customers with the intent of eventually serving these customers using UNEs or entrant facilities. This conclusion is further supported by the coefficient for the percent of lines that are assessable through collocation. This coefficient is negative and significant, indicating that entrants use fewer resold lines if they

¹⁵ This is the inverse of the explanatory variable Lines per Central Office. I use the inverse for convenience.

can use collocation to interconnect their facilities with incumbent facilities. The results from Model 5 support the rejection of H1 – the coefficient for business wholesale discount is insignificant, which is counter to the incentive the discount provides to entrants. Incumbent marketing does not appear to affect entrant market share from resold business lines and, as one would expect, lower incumbent service quality causes entrants to resell fewer business lines.

Model 6 shows the effects of including additional incumbent dummy variables. Using an F-statistic, I fail to reject at the 0.10 level the null hypothesis that the coefficients for these variables are zero ($F(4, 38) = 0.52$).

5 CONCLUSION

This chapter shows that incumbents are able to hinder entry in newly opened markets when incumbents' profit margins for inputs sold to entrants are lower than incumbents' retail profit margins. This confirms the theories of Shepherd (1997), Noll (1995), Gulati et al. (2000), and Ordover et al. (1985). I do not find evidence that incumbents in local telephone markets have limited entrants' abilities to gain market share for serving customers that are net receivers of calls, such as Internet Service Providers. I do find that most entrants are not of the type entrant that serves primarily customers who are net receivers of calls. Lastly, I find that entrants resell business lines to gain market share with the intent of eventually serving its customers using UNEs or entrant facilities.

Table 9. Regression Results for Resold Business Lines (RSLDBPLN)

Explanatory Variable	Model 5	Model 6
	***-0.0012	** -0.0010
UNE Price	(-2.70)	(-2.02)
	0.3115	0.2506
Reciprocal Compensation Price	(0.88)	(0.64)
	0.0278	0.0234
Business Wholesale Discount	(0.55)	(0.43)
	0.0001	0.00004
Local Revenue Per Line	(1.67)	(0.56)
Percent of Voice Lines	** -0.0003	** -0.0004
Assessable through Collocation	(-2.04)	(-2.27)
	0.0007	0.0011
Number of Quarters	(1.19)	(1.65)
Service Complaints in 1998 Per Line	* -24.4591	* -24.2993
	(-1.85)	(-1.78)
	** -0.1208	* -0.0997
Total Revenue Per Line	(-2.45)	(-1.71)
	0.0141	0.0096
Total Plant in Service Per Line	(1.16)	(0.70)
	-0.0029	-0.0020
Minutes of Use Per Line	(-0.74)	(-0.04)
Central Office Total Plant in Service Per Line	-0.0299	0.0271
	(-0.71)	(0.46)
	** -0.0120	** -0.0123
Universal Service Reform	(-2.47)	(-2.29)
Marketing Expenses per Line in 1997	0.0007	0.0006
	(1.47)	(1.10)
	15.8692	11.2574
Central Offices per Line	(1.07)	(0.67)
		-0.0179
GTE dummy variable		(-1.24)
		-0.0092
Bell Atlantic dummy variable		(-0.86)
		-0.0046
BellSouth dummy variable		(-0.41)
		-0.0003
SBC dummy variable		(-0.02)
	***0.0256	0.0171
US West dummy variable	(3.40)	(1.38)
	*0.0474	0.0367
Constant	(1.94)	(1.37)
	3.31	2.61
F	d.f. = 15, 42	d.f. = 19, 38
R2	0.5421	0.5660

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Bureaucrats as Entrepreneurs: Do Municipal
Telecommunications Providers Hinder Private Entrepreneurs?

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Abstract: We consider how government-owned enterprises affect privately owned rivals. Specifically, we compare the types of markets that municipally owned telecommunications providers in the United States serve to the types of markets that competitive local exchange carriers (CLECs) serve. We find that CLECs focus on potential profitability while municipalities appear to respond to other factors, such as political considerations or the desire to provide competition to incumbents. As a result, municipal providers tend to serve markets that CLECs do not. We also find that the presence of a municipal provider in a market does not affect the probability that a CLEC also serves that market. Our results suggest municipalities may not pose a significant competitive threat to CLECs and do not preclude CLEC participation.

JEL classification: D40; L13; L96

Keywords: municipality; entry; telecommunications

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I. Introduction

Situations arise in which government-owned enterprises compete against privately owned firms. Examples include the state-run postal services competing against package carriers such as Federal Express, government-owned lotteries competing against private gambling businesses, and public schools in many countries that compete with privately owned schools. For the government, which sets the rules for competitive markets, to also be a competitor raises issues of whether the government will play fairly. In a recent paper analyzing such competition, Sappington and Sidak (2003) show that government-owned enterprises may have greater incentives to create barriers to entry than do private firms. Similarly, Edwards and Waverman (2006) show that European national regulatory authorities have a greater tendency to favor incumbent telecommunications providers in issues related to competition when the providers are at least partially government owned. There are also concerns that simply the presence of a government-owned enterprise may dissuade a legitimate, private entrepreneur from entering a market.

On the other hand, a government-owned enterprise may provide a service that the citizens view as important, but that may not be commercially feasible for a private operator if at all. For example, the American Public Power Association (APPA) holds that a municipally owned utility providing telecommunications services enjoys unique cost advantages over a private company and, in some instances, may be the only commercially viable rival to an incumbent local exchange telephone company.¹

¹ See APPA, "Community Broadband: Separating Fact from Fiction," available at <http://www.appanet.org>.

In this paper, we consider how government-owned enterprises choose markets and how they affect privately owned rivals. Specifically, we compare the types of markets that municipally owned telecommunications providers in the United States serve to the types of markets that competitive local exchange carriers (CLECs) serve. A CLEC is a privately owned telecommunications provider that enters a local telecommunications market in competition with an incumbent provider. We also examine how the presence of a municipally owned provider in a market affects the probability that a CLEC will also serve that market. We find that municipalities make their decisions on whether to provide telecommunications services differently than do private firms. As a result, municipal providers tend to serve markets that privately owned CLECs generally do not serve. We also find that the presence of a municipal provider in a market does not affect the probability that a CLEC also serves that market, indicating that CLECs do not view municipal providers as commercial rivals. We do not address questions about the effects of municipal provision of telecommunications on incumbent companies, customers, or taxpayers.

The literature describing changes within the telecommunications industry subsequent to The Telecommunications Act of 1996 is abundant.² Zolnierrek, Eisner, and Burton (2001) find that CLECs are more likely to enter more urbanized areas and jurisdictions with more favorable CLEC entry policies. Roycroft (2005) also examines CLEC entry, but focuses on a subset of California markets, uses a different measure of geographic market boundaries, and uses a different measure of regulatory influence. Jamison (2004) finds that when regulators require incumbents to earn lower profit margins on unbundled network elements than on retail services,

² For a concise summary, see the Introduction in Jamison (2004) or Roycroft (2005).

incumbents act to limit CLEC entry.³ Other studies find that CLECs building their own networks are more successful than those that do not.⁴

Currently there is controversy in the United States over whether municipalities should be permitted to offer telecommunications services in competition with private companies. Some observers believe that municipal investment in broadband telecommunications affords important competition for incumbent telecommunications providers and cable television providers. For example, the cities of Spokane, Washington and Concord, Massachusetts began offering broadband telecommunications for the stated purpose of providing citizens with more advanced broadband services than the incumbent telecommunications providers were offering.⁵ There are a myriad of reasons municipalities have asserted for entering the telecommunications market; however, this positive motivation is not without question. Some observers raise concerns that government-owned service providers have an unfair advantage over private operators due to the government-owned providers' relationship to the government, are essentially subsidized by captive taxpayers, and crowd out more efficient private investment. Based on these or similar concerns, 14 states have adopted either a complete ban on municipal entry in telecommunications, or have created significant barriers to entry.

This paper addresses a gap in the literature by analyzing whether municipalities' increasing propensity to offer telecommunications services appears to affect participation of private firms. Using logit models of the decisions of CLECs and municipal providers to provide

³ Unbundled network elements are portions of an incumbent's network that CLECs are allowed to lease and use for providing service in competition with the incumbent.

⁴ See Foreman (2002). See also Crandall (2002) as referenced by Roycroft (2005).

⁵ APPA Quarterly Communicator, Summer 2004, Volume 20 Number 3.

telecommunications services in various markets, we seek to determine the characteristics of cities in which municipalities offer telecommunications services and, in so doing, address the question of whether municipal provision affects CLECs. Our primary finding is that while municipal entry increased during the years of the study, it appears that municipalities and CLECs are rarely in direct competition in that they tend to serve areas that are demographically and economically different. The presence of a municipal provider in a market does not appear to influence the probability of a CLEC also serving that market. Moreover, it seems that restrictions that various states have imposed have not deterred municipalities from providing telecommunications services.

II. Background

In August of 1996 following passage of the Telecommunications Act of 1996 that was designed to open telecommunications markets to local competition, the General Assembly of Missouri enacted a law preventing municipalities from offering telecommunications services.⁶ In the years that followed, municipalities continued to enter markets. Many private telecommunications providers sought to suppress this competitive threat and began lobbying states to restrict municipal provision of telecommunications services. U.S. statutes provide that no state regulation should prohibit any entity from providing telecommunications services, but in 2004, the U.S. Supreme Court ruled that this does not prohibit states from adopting restrictions on local governments providing telecommunications services.⁷ Although the main reason for allowing

⁶ Missouri Revised Statutes, Chapter 392 Telephone and Telegraph Companies, Section 392.410(7) (2006). “No political subdivision of this state shall provide or offer for sale, either to the public or to a telecommunications provider, a telecommunications service or telecommunications facility used to provide a telecommunications service for which a certificate of service authority is required pursuant to this section.”

⁷ U.S. Supreme Court, 541 U.S. (2004), Numbers: 02-1238, 02-1386, 02-1405. March 24, 2004.

states to restrict municipal provision is a states' rights argument and the government generally remains concerned about suppressing competition, the result of the ruling is still the same: states may restrict municipal provision of telecommunications services. As of December 2004, the following states had passed laws restricting municipal entry: Arkansas, Florida, Mississippi, Minnesota, Nebraska, Nevada, Pennsylvania, South Carolina, Tennessee, Texas, Utah, Virginia, Washington, and Wisconsin. The setback for municipalities is not complete, however, as the Federal Communications Commission (FCC) has indicated that while states may have the right to restrict municipalities, states should not inhibit competition.

It is becoming increasingly important to address the question of restrictions on municipal provision of telecommunications as the number of municipalities doing so steadily increases despite restrictions.⁸ The number of municipalities providing telecommunications services to public consumers has grown from 210 in 1998 to 665 in 2006.⁹ During the years of our study (1998-2002), a total of 675 municipalities participated in providing some form of communications service. Given that the number of CLECs decreased from 1,426 in 2000 to 804 in 2002, one might wonder whether some of these CLECs were displaced by municipal providers. Figure 1 shows the total number of municipal and CLEC providers per year for 1998 through 2002.

[INSERT FIGURE 1 ABOUT HERE]

⁸ Following the 2004 decision, 14 new bills were put forth in state legislatures, although only one was successful in 2005 (in Nebraska, which already had a barrier to entry). In 2006, Indiana and Tennessee each proposed a restrictive law, but neither bill was passed. Municipalities continue to enter telecommunications markets.

⁹ Data from the APPA Annual Directory and Statistical Reports covering years 1998 to 2002 and the APPA Annual Directory and Statistical Report, 2006-2007.

For their part, state and local governments have been taking up the question and addressing related concerns often through consideration of studies of municipalities that have already allowed municipal entry. Such case studies are often well documented and the results hotly contested. One article, titled “Government-Owned Networks – the Wrong Plan at the Wrong Time for Broadband,” states: “These projects frequently go sour. In fact, all across the country, cities are beginning to suffer from ill-fated municipal broadband projects.”¹⁰ The article continues to cite an instance in which “millions of dollars of cost overruns have forced the city to borrow from other city funds in order to cover the overruns.” The Progress and Freedom Foundation has reported similar findings.¹¹ Countering the objections are groups like the APPA, which maintains a database of public power companies that have entered the broadband market, and the organization publishes both a brief fact sheet and a booklet titled “Community Broadband: Separating Fact from Fiction,” in which many of the concerns raised by private executives and public officials are addressed.¹²

III. Theory, Hypotheses, and Measures

We presuppose that a CLEC decides whether to enter a market based on its expected profit in that market. These profit expectations are determined by anticipated customer demand, projected costs, regulatory policies, and expected number of rivals. As a result, we predict greater customer demand, lower service provider costs, pro-CLEC regulatory policies, and fewer rivals to result in a higher probability of a CLEC serving a market. Typically, researchers have estimated models of CLEC entry using ordered probits with the number of CLECs per

¹⁰ Tom Giovanetti, Institute for Policy Innovation, “Government-Owned Networks – the Wrong Plan at the Wrong Time for Broadband,” page 1.

¹¹ See Progress on Point Releases 9.7, 10.17, and 11.3 for additional details.

¹² See <http://www.appanet.org> for the fact sheet and to download or order the booklet.

geographic area as the dependent variable.¹³ Following Greenstein and Mazzeo, we assume that profitability of entry in any particular county is dependent upon demand for telecommunications services and the costs of providing such services. Specifically,

$$\pi_{it} = \beta X_{it} + \gamma C_{it} + \delta R_{it} + (n)\theta_{it} + \varepsilon_{it}, \quad (1)$$

where X is a vector of demand characteristics, C is a vector of cost characteristics, R is a vector of regulatory characteristics, and θ represents the effect of commercial rivals in market i in year t . n represents the number of firms currently in the market. We assume that ε is an independent unobserved error term with standard normal distribution. We can then estimate the parameters of the profit function given that for any positive n we observe:

$$\pi_{it} = \beta X_{it} + \gamma C_{it} + \delta R_{it} + (n)\theta_{it} + \varepsilon_{it} \geq 0 \quad (2)$$

$$\text{and } \pi_{it} = \beta X_{it} + \gamma C_{it} + \delta R_{it} + (n+1)\theta_{it} + \varepsilon_{it} < 0. \quad (3)$$

We assume that a greater number of participants is associated with lower profit per provider. As noted by Greenstein and Mazzeo, under this assumption, as long as a decrease in profit is larger when an entrant is of the same type than when an entrant is of a different type, a unique equilibrium exists. We estimate the parameters of the profit function with maximum likelihood estimation using observations of participation at the county level. The likelihood function is given by: $L = \prod_{i=1}^I \text{Prob}[\text{CLEC}, \text{Muni}]_i$ where CLEC refers to a CLEC provider in any particular market and Muni refers to a municipal provider.¹⁴

¹³ Greenstein and Mazzeo (2006) provide a succinct overview of the design of these models and extend the models to account for markets in which there are two types of firms. While Greenstein and Mazzeo do not specifically address municipal entrants, their model clearly allows for this “type” of entrant.

¹⁴ The incumbent provider is assumed to exist in each market and may affect competitive providers of both types. The existence of the incumbent, however, is assumed to be exogenous. We account for the effects of the incumbent through regulatory characteristics and by including the average revenue per loop in the estimation. In our dataset, in eight cases a municipality served as an incumbent (Sylacauga, AL; Palo Alto, CA; Taunton, MA; Windom, MN; Kutztown, PA; Jackson, TN; Provo, UT; and Bristol, VA). These observations were not used in the estimations.

Given our model, we put forward four hypotheses. First, if CLECs view a municipal provider as a competitor, then we would expect the presence of a municipal provider in a market to decrease the probability of CLEC presence in that market. Therefore our first hypothesis is that CLECs do not view a municipal provider as a commercial rival in a market. We test this hypothesis using the model that predicts whether CLECs serve a market. We reject this hypothesis if the presence of a municipal provider is significantly and negatively correlated with the probability of CLEC providers.

Next, we consider whether municipal providers are motivated by profit, public interests such as economic development, political interests, or some combination. If the municipal provider is motivated by profit like a CLEC, the municipal provider may be considered as simply another “type” of telecommunications provider (similar to the local and national types described by Greenstein and Mazzeo, 2006). In this case, expected profit for a municipal provider should be determined by the same factors that determine expected profit for a CLEC, namely expected customer demand, costs, government policy, and number of rivals. This leads to our second hypothesis, which is that municipal operators have the same motivations as do CLECs, namely, that they are motivated by profit and not by other considerations. We test this hypothesis with a model that predicts whether a market will be served by a municipal provider. We reject this hypothesis if the coefficients for explanatory variables reflecting customer demand and provider costs in our municipal provider model have signs opposite those of the corresponding coefficients in our CLEC model.

If we reject our second hypothesis, we conclude that other factors play a role in predicting the presence of a municipal telecommunications provider. For example, a city may become a telecommunications provider if it believes that its citizens would benefit from competition with the incumbent telecommunications provider and that competition from a CLEC is unlikely. Examples of such benefits could include greater availability of new technologies, greater output, and lower prices. Such outcomes might benefit citizens directly and could stimulate economic development.

On the other hand, even if a municipality chooses to be a telecommunications provider, its competitive effect might be negligible if, for example, government ownership makes the municipal provider ineffective as a competitive service provider. This leads to our third hypothesis, namely, that municipalities choose to become service providers in order to provide competition to incumbents when CLEC competition is not forthcoming. If this hypothesis is true, then we would expect markets with municipal providers not to have CLECs. Therefore, we reject this hypothesis if the presence of a CLEC has no effect on whether a municipal provider also serves the market.¹⁵

An argument is sometimes offered that municipal providers have cost advantages over CLECs in situations where the municipal government already owns a power utility. Our fourth hypothesis is that such municipal providers have a cost advantage over CLECs. This cost advantage could result from scope economies, such as the opportunity to share billing information or customer contacts. We reject the hypothesis that such a cost advantage exists if we find a significant,

¹⁵ This complements our first hypothesis concerning whether the presence of a municipal provider increases the level of competition in a market if CLECs are present.

negative correlation between the presence of a municipally owned power utility and the presence of a municipally owned telecommunications provider. However, a statistically significant and positive correlation is insufficient to accept the hypothesis because other reasons could exist for a positive correlation. For example, it may be that the presence of a municipally owned power utility suggests to city leaders that they can be successful in other municipally owned businesses and so are more inclined than city leaders elsewhere to compete with privately owned telecommunications businesses. It may also be that managers of municipally owned power utilities wish to expand into telecommunications for purely personal reasons and that they exert influence over city leaders to be allowed to expand their product line. We do not have sufficient data to test these alternative explanations, but we are able to examine data on telecommunications services offered by privately owned power companies to see whether they support the cost advantage argument.

IV. The Dataset

We compiled a dataset that includes all CLEC and municipal providers in the U.S. telecommunications market for five years (1998 – 2002). Services supplied by municipal providers include those used for the city's own operations (meter reading, municipal data network, supervisory control and data acquisition, and voice) and those provided to others (cable television, long distance telephone, Internet access, broadband, fiber leasing, and local telephone). Municipal provider data is from the APPA. CLEC data is from the annual CLEC Reports from New Paradigm Resources Group, Inc., and includes both planned and operational voice and data network services provided by CLECs.

Tables 1 and 2 describe and summarize the variables for our models, in addition to listing the data sources.¹⁶ The variables can be categorized as indicators of demand, indicators of cost, and regulatory factors. With respect to those variables affecting demand, we expect the median age of the heads of household (medage) to be inversely related to demand. Furthermore, we expect the median household income (hhincome), the percentage of heads of households who are white (whitehh), and the percentage of heads of households who are college educated (educ) to be positively correlated with demand. We do not predict the effects of the proportion of households receiving public assistance (help). This variable may indicate low demand, but it may also imply urbanization and so indicate low costs.¹⁷ We expect service provider costs to be negatively correlated with population density (poppersqmi), our indicator of relative costs. As we described above, the presence of a municipal electric utility should increase the probability of the presence of a municipal telecommunications provider for a variety of reasons.

[INSERT TABLES 1 AND 2 ABOUT HERE.]

We also include variables that reflect the regulatory environment. We expect flexible regulation for CLECs (clec_flex) – the situation where regulators provide CLECs with broad latitude to change prices¹⁸ – to increase the probability of the presence of CLECs in a market, but we cannot predict in advance how this might affect municipal providers. We are unable to predict the possible effects of public service commissioners being appointed rather than elected

¹⁶ We considered other population characteristics, such as other races, ethnicity, and language. We also included other measures of population density, such as urban classification, and various demographic indicators, such as employment growth rate and personal bankruptcy rate. However, these variables proved to be insignificant and did not affect results, so we excluded them from the model.

¹⁷ There are a number of papers that address low-income households' demand for telecommunications services, for example, Burton et al. (forthcoming), Tucker, Brick, and Meekins (2007), and Garbacz and Thompson (2003). Further related studies may provide additional insight into municipal telecommunications provision.

¹⁸ In some markets regulators impose price floors on CLECs.

(pscappoint)¹⁹ and the political affiliation of the governor of the state (RepGov). Presumably elected commissioners are more responsive to immediate citizen concerns, but it is unclear whether this means that the commissioners might favor CLECs, incumbents, municipal providers, or none of the above. Also, while Republicans are reputed to generally favor market forces over regulation, it is unclear what this might mean for CLECs and municipal providers. One possibility is that a Republican governor will pursue policies that favor CLECs, municipal providers, or both, presumably based on the belief that these policies lead to competition in the long run. Another possibility is that a Republican governor will adopt a more hands-off approach, presumably in the belief that such an approach will encourage competitors to focus on markets and not on regulation to obtain a competitive advantage. We also include a variable indicating the presence of state restrictions on municipal provision of telecommunications (muniban). Examples of such limitations include accounting separation requirements, public hearings, voter approval, and reporting requirements. We do not predict the effect of such restrictions. On the one hand, we would expect the presence of effective restrictions to decrease the probability of the presence of a municipal provider. However, the presence of such restrictions might increase municipal provision if the restrictions clarify the rules for municipalities. Such clarification should decrease municipalities' risk. Said another way, the absence of state policies might discourage municipal provision if cities are concerned that municipal entry might trigger state rules that opportunistically limit the effectiveness of municipal investment.

¹⁹ We generically refer to state regulatory agencies as public service commissions. Some states elect their commissioners. In other states, commissioners are appointed. The appointment processes vary across the states, but the processes generally involve both the governor and the legislatures.

Lastly, following Jamison (2004), we include a variable to capture the potentially conflicting effects of regulation on incumbent and CLEC incentives. During the time period for our data, regulators required incumbents to provide unbundled network elements²⁰ to rivals. If an incumbent finds it more (conversely, less) profitable to provide retail services than to provide unbundled network elements, we would expect the incumbent to try to limit (conversely, promote) CLEC entry. To capture this effect, we include as a variable the ratio of incumbents' revenues per line to the price charged for unbundled local telephone lines (avgrev/loop). If incumbents are able to affect entry, then we would expect a negative relationship between this variable and the probability of CLEC presence in a market.

A cursory look at the data suggests that municipal providers and CLECs differ in how they choose their markets. A greater proportion of municipal providers serve markets not in designated Metropolitan Service Areas (MSAs) than in MSAs (53 percent versus 47 percent). In contrast, CLECs serve more MSA markets than non-MSA markets (93 percent versus 7 percent). Also during the time period for this study, a greater proportion of municipal providers than CLECs had served their markets for a number of years (i.e., fewer exits).²¹ Table 3 summarizes these statistics.

[INSERT TABLE 3 ABOUT HERE]

Data in Tables 4 and 5 further support the supposition that CLECs and municipal providers select markets differently. Table 4 shows that in 2002 most cities (98 percent) had no CLECs

²⁰ Our variable is a state-wide average based on the loop, port, and switching rates per month.

²¹ The majority of municipal providers entered markets in which the municipality was providing electric. These providers may have been able to take advantage of economies of scale and scope so that their association with the municipal utility company enabled them to be less vulnerable to risk and the effects of competition.

and most municipal providers (86 percent) were in these cities. However, seven percent of municipal providers were in cities with one CLEC, and slightly more than three percent of municipal providers were in cities with six or more CLECs.

[INSERT TABLE 4 ABOUT HERE]

Columns in Table 5 represent types of markets, where markets are characterized by the presence of a type of provider. The first column of data provides statistics for markets with neither a municipal provider nor CLECs. The second column of data represents markets with a municipal provider but no CLECs. The third data column characterizes markets with no municipal provider and at least one CLEC, and the last column denotes markets with a municipal provider and at least one CLEC. The numbers in the rows show the means of various market characteristics listed for each type of market. A cursory look at the means suggests significant differences in market characteristics among the different categories of telecommunications provision. We formally test for such differences and indicate with asterisks each case in which the mean value represented in a cell is significantly different from the corresponding mean value for the markets with no municipal provider and no CLECs. In other words, asterisks indicate a statistically significant difference between means in data columns one and two, and data columns one and three. These mean values indicate that municipal providers and CLECs differed in how population density, household income, urbanization, public assistance programs, and municipal restrictions affected market entry decisions. We find that cities with a municipal provider and no CLECs were generally not significantly different in market characteristics from those cities with no municipal or CLEC providers; however, cities with no municipal provider and at least one

CLEC were generally significantly different from those cities with no municipal or CLEC providers. Furthermore, if we compare market characteristics of cities with a municipal provider and no CLECs (data column 2) with market characteristics of cities with no municipal provider and at least one CLEC (data column 3), we find that each is significantly different at the .001 level with the exception of Average UNE Loop Rate, which is significantly different at the .10 significance level. In sum, cities with no municipal provider and at least one CLEC were significantly different from cities without a CLEC, whether there was a municipal provider or not. We examine these issues more fully in the Results section of this paper.

[INSERT TABLE 5 ABOUT HERE]

Table 6 further illustrates competition between CLECs and municipal providers. It shows that in relative terms CLECs were more frequently rivals to municipal providers than municipal providers were rivals to CLECs. From 1998 through 2002, the percentage of municipal providers that competed with CLECs grew from 13 percent to 28 percent and then declined to 16 percent. The decline corresponds to the decline in the number of CLECs. The relative number of markets in which CLECs competed with municipal providers was much smaller and declined over the period: the percent of markets with CLECs that also had a municipal provider was highest in 1998 (2.7 percent) and declined to 1.7 percent by 2002.

[INSERT TABLE 6 ABOUT HERE]

Lastly, analysis of the data indicates that restrictions on municipal providers may be ineffective in limiting their number. In states without restrictions on municipal telecommunications provision, the total number of municipalities in the telecommunications market increased by 21.1 percent from 2000 to 2001 and by 4.7 percent from 2001 to 2002. In states restricting municipal provision, the corresponding percentages were almost as high: 14.1 percent and 7.3 percent, respectively. Overall, from 1998 to 2002, the number of municipal providers almost doubled. Conversely, the total number of CLECs fell on average 4.1 percent in 2001 and 2002 after initially increasing rather dramatically prior to 2001.

V. Empirical Models

We estimate discrete choice models of each type of provider's market choice to test our hypotheses as presented in Section III. For each city within the United States, the analysis considers whether there is a municipal provider, a CLEC, neither, or both. Because most variation in the data results from cross-sectional differences between markets, we use only 2002 data for our regression analysis.²²

We assume the decision to provide telecommunications service in any particular market is based on some unobservable utility index that is determined as indicated by the profit model described above. Each provider participates in a market in a given year based on the expected profitability of that market. While we do not observe profitability, we do observe a provider's choice. This

²² Interestingly, when using data from 1999 through 2002, the results are remarkably similar in both sign and significance. Differences include a loss of significance on the coefficients for *white heads of household* and *pscapoint* and a gain in significance for *medage* in the municipal specification. The coefficients for *help* in both models change to positive and significant for the municipal specification and negative and significant for the CLEC specification.

would suggest the use of a discrete choice model, such as a logit model. Our basic model is given

$$\text{by: } Y_{ji}^* = \alpha_j + \beta_j X_i + \gamma_j C_i + \delta_j R_i + \theta_j \hat{j}_i + \varepsilon_{ji} \quad (4)$$

where Y_{ji}^* is the probability that an operator of type j , where $j = m$ if municipal provider and $j = c$ if CLEC provider, serves market i . $Y_{ji}^* = 1$ if $\pi_{ji} \geq 0$ and $Y_{ji}^* = 0$ otherwise. Let X_i represent the vector of demographic and other variables that indicate market demand and C_i represent the vector of factors reflecting operator costs; R_i represents a vector of regulatory variables, including state restrictions on municipal provision of telecommunications services. ε_{ji} is the error term. $\hat{j} = m_i$ applies only within the CLEC equation and $\hat{j} = c_i$ applies only within the municipal provider equation.

Our logit models use maximum likelihood estimation to predict CLEC and municipal provider participation using a reduced form with exclusion restrictions. We endogenize the presence of municipal providers or CLECs. We then use these models to predict the probability of CLEC presence in a market and the probability of municipal provider presence in a market.

VI. Results

Table 7 provides the results of our regressions.

[INSERT TABLE 7 ABOUT HERE]

The coefficients for the CLEC logit model have the expected signs, namely, higher population density, household income, and education increase the probability of CLEC presence in a market; furthermore, higher median age of the head of a household lowers the probability of

CLEC presence as does a higher ratio of retail revenue per line to the UNE loop price. We assert that the latter is due to an incumbent's incentive to prohibit entry the greater the retail profitability of the area relative to the profitability of providing UNEs, which is consistent with Jamison's (2004) finding. The proportion of the population receiving public assistance is positively correlated with CLEC presence suggesting this variable might reflect urbanization. Appointed commissioners decrease the probability of CLEC presence, and Republican governors increase the probability of CLEC presence, indicating that elected commissioners and Republican governors were more likely to make policy decisions considered favorable by CLECs. Flexible regulation for CLECs and greater proportion of white households are both positive and significant, as expected.

The coefficient for the presence of a municipal provider in the CLEC model is positive but insignificant. Therefore we fail to reject our first hypothesis that CLECs do not view a municipal provider as a commercial rival. We interpret this as meaning that a CLEC views a market with one CLEC, one municipal provider, and one incumbent to be no more competitive than a market with one CLEC and one incumbent but no municipal provider. This calls into question whether the presence of a municipal provider adds to the intensity of competition in a market. We do not fully examine this question in this paper because we do not consider incumbent and customer responses to the presence of a municipal provider.

We now turn our attention to the results of our municipal provider model shown in Table 7. We first observe that some of the coefficients for demand and cost indicators have signs that are opposite those for CLECs, namely, the proportion of white households, population density,

population on public assistance, and median age and whether regulatory commissioners are appointed or elected. Therefore we reject our second hypothesis that municipal providers are motivated by profits in a like manner as CLECs. We suggest this result indicates that cities may be motivated by something other than profit when deciding whether to provide telecommunications services.

Furthermore, the coefficient for the presence of a CLEC is significant and negative, indicating that a municipal provider is more likely to be in a market where there are no CLECs than in a market competing with CLECs. Based on this evidence, we fail to reject our third hypothesis that cities generally provide telecommunications services to provide competition for incumbents when competition from CLECs is not forthcoming.

The coefficient for the presence of a municipal electric provider is positive and significant, so we fail to reject our fourth hypothesis, namely that there are economies of scope between municipal power providers and municipal telecommunications providers. This issue needs further analysis. A review of data in Gentry and Jamison (2005a, 2005b) indicates that few privately owned power companies become telecommunications providers (2.36% on average between 1998 and 2002). It would seem that if such scope economies existed that they would exist also for investor-owned utilities. There are at least two possible explanations for this apparent difference between decisions by municipal power utilities and investor-owned power utilities with respect to becoming telecommunications providers. One explanation might be that rate regulation of the private utilities discourages them from entering competitive local telecommunications markets. Another explanation might be that some city leaders, municipal power utility managers, or both,

extend into telecommunications for personal reasons and cost economies do not play a role in these decisions.

Lastly, we observe that the coefficients for municipal provider restrictions are positive and significant. One explanation of the restriction coefficient is that restrictions on municipal entry are more likely in states where significant numbers of municipal providers are present.

However, endogenizing the restriction variable does not affect the results, so we conclude that state rules on municipal entry provide certainty for municipalities and encourage entry even if the rules impose entry restrictions.

VII. Conclusion

This research indicates that municipalities may not pose a significant competitive threat to CLECs, due primarily to differences in the objectives of private and publicly owned providers. CLECs locate in more urban areas where incomes are higher and the possibility for higher revenues through selling more services to those interested in expanded capabilities is greater. Municipalities provide telecommunications services in areas largely unserved by CLECs, in which profits are limited by both costs and demand. Anecdotal evidence suggests municipalities participate in markets in which some residents believe services provided by the incumbent are either inadequate (typically too slow a pace of innovation to attract businesses) or too expensive. It appears further that municipal participation does not preclude CLEC participation, although the reverse may be true. These results, and the finding that entry restrictions have had little deterrent effect, are the first step in a more thorough analysis of municipal telecommunications provision. Additionally, the incorporation of prices and complementary offerings (for example

combining local telecommunications services with cable and Internet access) might provide greater insight into motivations for the different types of providers. To more comprehensively analyze the possibility of crowding out, this research might be extended to incorporate effects on prices and investment, and should then be tied to theoretical research regarding the relative efficiency of private versus public entities.

An important further step is to consider who (the municipal provider, the municipality's citizens, or someone else) absorbs the commercial risk when the city becomes a telecommunications provider. Cities have claimed they do not need the high rates of return that private companies need in order to justify their investment. Considering revenues, prices and municipal funding of telecommunications investments should allow us to empirically answer the question of whether public or private entities are better able to manage risk.

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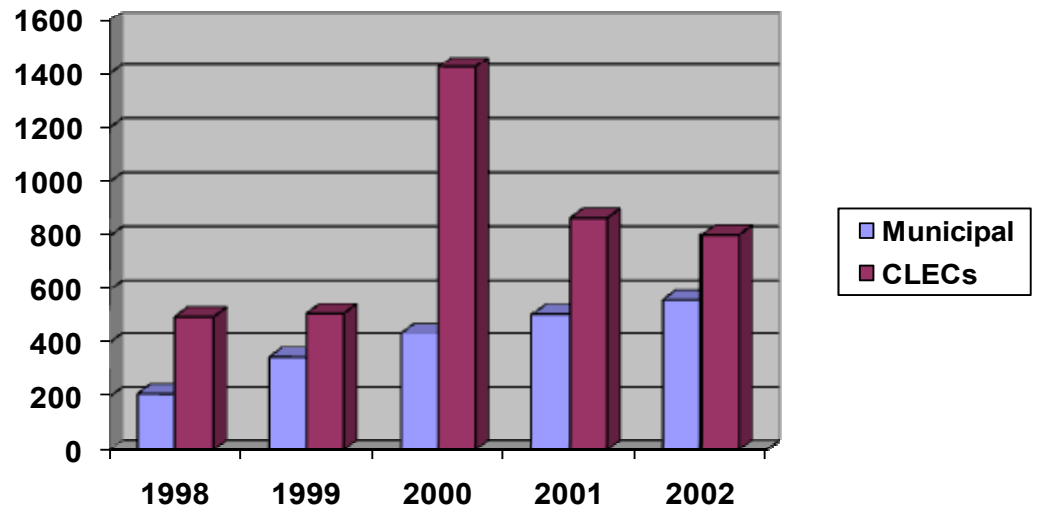


Figure 1. Total Municipal Telecommunications Providers and CLECs in the United States by year, 1998-2002.

Table 1. Variable Names, Descriptions, and Sources

Variable Name	Variable Description	Source
pCLEC	Equals 1 if one or more CLECs are operating within that city in the given year	New Paradigm Resources Group publications
pmunicipal	Equals 1 if the municipality provides any external services to consumers in the given year	American Public Power Association http://www.appanet.org .
avgrev / loop	Average revenue per line / average local loop rate (UNE price) by state by year	Public Service Commission of West Virginia http://www.cad.state.wv.us/ ; Federal Communications Commission http://www.fcc.gov
clec_flex	Equals 1 if CLEC regulation reported as “flexible regulation” in 2002	<i>State Telephone Regulation Report</i> , - multiple issues - published by Warren News
educ	Percent of population with college education or higher, by county in the year 2000	US Census Bureau http://www.census.gov
electric	Equals 1 if municipality provides electric within that city	American Public Power Association http://www.appanet.org .
help	Percent of households receiving public assistance, by county in the year 2000	US Census Bureau http://www.census.gov
hhincome	Median annual household income by county, year 1999	US Census Bureau http://www.census.gov
UNE loop	Average local loop rate (UNE price) by state by year	Public Service Commission of West Virginia
medage	Median age of the county in year 2000	US Census Bureau http://factfinder.census.gov
muniban	Equals 1 if the state has any restrictions on municipal provision of telecom services in the given year	State’s legislative Web sites
poppersqmi	Population per square mile, by county in year 2000	US Census Bureau http://www.census.gov
pscappoint	Equals 1 if the state’s public service commissioners are appointed; 0 if elected, by year	State public utility commission Web sites
RepGov	Equals 1 if the state’s governor is Republican in the given year	National Governors Association http://www.nga.org/cda/files/biobook.pdf
whitehh	Proportion of white households per county in 2000	US Census Bureau http://www.census.gov

Table 2. Variable Summary Statistics, 1999 – 2002

Variable Name	Obs	Mean	Std. Dev.	Min	Max
pCLEC	203,252	0.05	0.72	0.00	48.00
pmunicipal	203,252	0.01	0.09	0.00	1.00
avgrev	203,252	34.28	4.99	25.28	45.88
clec_flex	203,248	0.54	0.50	0.00	1.00
educ	203,252	0.85	0.08	0.47	1.00
electric	203,252	0.04	0.19	0.00	1.00
help	203,248	0.03	0.02	0.00	0.37
hhincome	203,248	48.28	12.81	15.17	108.76
UNE loop	203,248	15.70	4.35	7.01	27.75
medage	203,248	37.03	3.68	20.00	58.60
muniban	203,248	0.05	0.21	0.00	1.00
poppersqmi	203,252	0.37	1.39	0.00	52.42
pscappoint	203,252	0.81	0.39	0.00	1.00
RepGov	203,252	0.56	0.50	0.00	1.00
whitehh	203,248	0.87	0.14	0.01	1.00
year	203,252	2001	1.11	1999	2002

Table 3. Total Number of Providers by MSA, 1998 - 2002

Municipal Providers						
Number of Years in the Market	Markets in MSAs		Markets not in MSAs		All Markets	
	No. of Providers	Percent of Total	No. of Providers	Percent of Total	No. of Providers	Percent of Total
One Year Only	57	18.04%	83	23.12%	140	20.74%
Two Years Only	52	16.46%	69	19.22%	121	17.93%
Three Years Only	70	22.15%	59	16.43%	129	19.11%
Four Years Only	57	18.04%	81	22.56%	138	20.44%
All Five Years	80	25.32%	67	18.66%	147	21.78%
Total	316	46.81%	359	53.19%	675	100.00%
CLECs						
Number of Years in the Market	Markets in MSAs		Markets not in MSAs		All Markets	
	No. of Providers	Percent of Total	No. of Providers	Percent of Total	No. of Providers	Percent of Total
One Year Only	4507	64.52%	387	68.50%	4894	64.82%
Two Years Only	1150	16.46%	134	23.72%	1284	17.01%
Three Years Only	1237	17.71%	44	7.79%	1281	16.97%
Four Years Only	79	1.13%	0	0.00%	79	1.05%
All Five Years	12	0.17%	0	0.00%	12	0.16%
Total	6985	92.52%	565	7.48%	7550	100.00%

Total = Total number of cities with telecommunications services provided by a municipality or CLEC.
 By definition, municipal providers serve only one city each.
 A CLEC may appear in more than one city per year.

**Table 4. Number of Cities with Indicated Number of CLECs and Municipal Providers, 2002
(51,148 cities total)**

Number of CLECs per City	Number of Cities with given Number of CLECs	Percentage of Observations	Number of Municipal Providers given Number of CLECs	Percentage of Observations
0	50,101	97.95	520	86.09
1	634	1.24	42	6.95
2	141	0.28	11	1.82
3	74	0.14	1	0.17
4	30	0.06	5	0.83
5	35	0.07	5	0.83
>5	131	0.26	20	3.31
6	22	0.04	5	0.83
7	14	0.03	4	0.66
8	12	0.02	1	0.17
9	7	0.01	2	0.33
10	8	0.02	1	0.17
>10	70	0.14	7	1.16

Table 5. Differences Between CLEC and Municipal Provider Markets for Selected Variables, 2002

Market Characteristics	Cities with no municipal provider and no CLECs	Cities with a municipal provider and no CLECs	Cities with no municipal provider and at least one CLEC	Cities with a municipal provider and at least one CLEC
Number of Cities	49,581	520	961	84
Average Population per Square Mile	350.34	236.22	1,135.49 ***	514.29
Average Median Household Income	37,586.91	38,501.91	46,906.68 ***	42,466.05 ***
Average Number of Housing Units - Urban	83,543.10	78,288.94	26,007.10 ***	162,945.10 **
Average Number of Housing Units - Rural	12,397.82	11,887.98	13,456.29 ***	14,410.74
Average Number of Cities with a Municipal Telecom Provision Ban	0.35	0.44 ***	0.317	0.42
Average Number of States in which PSC is Appointed vs. Elected	0.81	0.75 ***	0.87 ***	0.77
Average Local Loop Rate	15.41	15.33	15 **	15.69
Average Number of Households on Public Assistance	3,367.13	3,128.07	9,617.16 ***	6,184.17

Table 6. Cities with Competition between CLECs and Municipal Providers vs. Cities without such Competition, 1998 – 2002

Year	Markets with a Municipal Provider			Markets with CLECs	
	Number of Markets Competing with CLECs	Number of Markets without CLECs	Percentage of Markets with CLECs	Number of Markets without a Municipal Provider	Percentage of Markets with a Municipal Provider
1998	36	270	13.33%	492	2.71%
1999	51	418	12.20%	501	2.44%
2000	101	365	27.67%	1033	2.68%
2001	97	472	20.55%	988	2.08%
2002	84	520	16.15%	963	1.68%

Table 7. Logit Model Results

Variable	Year 2002; 49,746 observations	
	Municipal Provider	CLEC
	Coefficient (standard error)	Coefficient (standard error)
pelec	-6.353 * (3.104)	
pmunicipal		0.487 (0.524)
muniban	0.462 ** (0.194)	
electric	5.271 *** (0.107)	
avgrev / loop		-0.520 *** (0.091)
CLEC_flex		1.484 ** (0.526)
poppersqmi	-0.207 (0.154)	0.160 *** (0.033)
hhincome	0.027 (0.008)	0.064 *** (0.003)
whitehh	-7.868 *** (0.391)	1.268 ** (0.485)
help	-38.710 *** (4.907)	8.756 * (3.573)
educ	5.079 *** (0.920)	2.192 ** (0.800)
medage	0.033 (0.015)	-0.098 *** (0.015)
pscappoint	0.486 ** (0.181)	-0.955 *** (0.142)
RepGov	0.705 *** (0.142)	0.717 *** (0.101)
<i>constant</i>	-5.101 *** (1.053)	-5.779 *** (0.941)

Significance levels:

* = .05

** = .01

*** = .001

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Abstract

We consider the effect of government-owned telecommunications providers on privately owned rivals by comparing the presence of private telecommunications services providers alongside municipal competitors in the US telecommunications industry from 1999 through 2002. Our primary finding is that the presence of a municipal provider is negatively correlated with a city's having private providers. However, the marginal effects indicate that the effect of municipal competition on private provision is largely concentrated on the first entrant, suggesting cities may choose to provide telecommunications services in areas with inadequate demand to support private provision.

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Dumbing Down the Net: A Further Look at the Net Neutrality Debate

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I. Introduction

It is commonplace for sellers of goods and services to enhance the value of their products by paying extra for premium delivery service. For example package delivery services such as Federal Express and the U.S. Postal Service offer shippers a variety of delivery speeds and insurance programs. Web content providers such as Yahoo! and MSN Live Earth can purchase web-enhancing services from companies such as Akamai to speed the delivery of their web content to customers.¹

Recently there has been concern over the desires of some Internet Service Providers (ISPs) such as AT&T and Verizon to offer Internet content providers faster, premium delivery of content and services to end user customers and to charge the content providers for the superior transmission. This is part of what has been termed the net neutrality issue, which is actually a loose collection of issues that vary in their mixture and meaning over time.² However, the provision of and charging for premium transmission speed of Internet packets consistently appear in the public debate.³ Proponents of net neutrality argue that the network itself is simply infrastructure that should not add value to the service, and thus innovation should occur only at the edges of the network.⁴ Net neutrality advocates also hold that the network should be a commons that broadband users are allowed to use in ways that are not illegal and that do not harm the network and that networks should not discriminate between uses, users, and content. In contrast, network providers such as AT&T argue that offering premium transmission

¹ http://www.akamai.com/html/customers/customer_list.html, downloaded July 1, 2008.

² See Wu (2004) for an explanation of the various issues included under the general name of net neutrality.

³ See Hahn and Wallsten (2006).

⁴ Net neutrality proponents have pressed their case at the Federal Communications Commission and, as of the time of this writing, are seeking federal legislation to impose mandatory net neutrality. See <http://www.google.com/help/netneutrality.html>, downloaded July 5, 2008.

services will improve customer choice and that ISPs would not degrade service to content providers not purchasing the premium transmission speed.⁵

In order to analyze the potential effects of policy proposals to ensure net neutrality, it is important to consider positively (rather than normatively) conditions under which the various hypothesized outcomes might occur. In this chapter, we focus on the findings of analytical research on the effects of networks offering and charging for premium transmission service, and on the effect of regulation on network providers' offerings. In Section II we provide background on the Internet and on the net neutrality debate. Section III considers how premium transmission is provided and priced, and how content providers provide their services. Section IV addresses how the offering and provision of premium transmission affects network innovation, network subscription, and incentives for the network provider to hinder rivals. Section V is the conclusion.

II. Background

Net neutrality became part of the public debate over the roles of networks in 2003 with the Supreme Court reversal of the Ninth Circuit court ruling in *Brand X Internet Services v. FCC*.⁶ The decision upheld the Federal Communications Commission's (FCC's) conclusion that cable modems, as an information service, are not subject to the regulation as telecommunications carriers.⁷ This decision resulted in asymmetric regulatory treatment of two substitutable services: Internet access via cable modems and Internet access via DSL (digital subscriber line), which is offered by telephone

⁵ See Whitacre (2006).

⁶ Case filed October 6, 2003.

⁷ National Cable & Telecommunications Assn. V. Brand X Internet Services (04-277) 345 F.3d 1120. The Supreme Court stated that the FCC had the authority, under its Title I jurisdiction, to impose regulation on the Internet industry in the future, if necessary.

companies. This led to intense lobbying on the part of telephone companies to have DSL treated in a manner similar to cable access. The FCC issued a ruling in 2005⁸ that exempted DSL from the “statutory access requirements applied to traditional telephone [service]”.⁹ This effectively deregulated methods of Internet access in the United States, at least with respect to traditional telecommunications regulation.

Currently ISPs and Internet backbone providers carry traffic on a best effort basis, which in general means that the first packets into a switching point are the first packets out. Net neutrality proponents see this best-effort approach as central principle for an application-blind Internet, which they apparently believe is important for content development and innovation. They fear that network providers might exercise market power to “pick and choose” what Internet users would “be able to see and do on the Internet.”¹⁰ Recent quotes by telephone company executives have provided fuel for this fear: Verizon CEO Ivan Seidenberg stated, “We have to make sure that they [application providers] don’t sit on our network and chew up bandwidth... We need to pay for the pipe.”¹¹ The FCC under Chairman Powell and Chairman Martin has believed that it is doing an adequate job of overseeing and promoting competition among ISPs,¹² but net neutrality proponents believe that the FCC and the federal courts will not exercise rigorous oversight of ISPs absent legislation.¹³ They believe that the FCC’s actions to

⁸ See *Appropriate Framework for Broadband Access to the Internet over Wireline Facilities, Report and Order and Notice of Proposed Rulemaking*, 20 FCCR 14853.

⁹ Yoo (2006), pg. 1858.

¹⁰ See statement of Google CEO Eric Schmidt, http://www.google.com/help/netneutrality_letter.html, downloaded July 5, 2008.

¹¹ Quoted on arstechnica.com website, January 6, 2006.

¹² See *High-Speed Services for Internet Access: Status as of June 30, 2006* available at www.fcc.gov/wcb/stats for data supporting the FCC assertion that the broadband market is competitive.

¹³ For a more detailed discussion of the lack of oversight from the federal courts and FCC see Prepared Statement of Earl W. Comstock for United States House of Representatives Committee on the Judiciary Telecommunications and Antitrust Task Force, submitted 25 April 2006. See also the testimony of Paul

date are inadequate, and they fear that without legislative or regulatory safeguards the phone companies will determine which content providers are to be successful and which are not.

The broader debate is over what regulations if any are to be imposed on the Internet industry. Content providers (such as Google and Microsoft) are concerned about ISPs offering preferred delivery of data. Such offerings would be designed so that for a fee, the ISPs would guarantee “head of the line” privileges for a customer’s data,¹⁴ even though there is some doubt as to the technical feasibility of such a plan if it were implemented.¹⁵ From these content providers’ perspectives, there are two basic implications: (1) Any content provider that did not pay the extra fee might have the quality of service for its data degraded;¹⁶ and (2) ISPs that are vertically integrated into the content business might give their own packets priority service or otherwise deliberately disadvantage their content rivals. Said another way, priority delivery of content could be a means by which ISPs could use price discrimination to earn higher profits while compelling content providers to pay the additional fee or risk degradation of service. Furthermore, network neutrality proponents believe that such an exercise of market power in infrastructure would stifle application-level innovation and harm consumers. Proponents of net neutrality use the case of Madison River Communications to illustrate their point. Madison River Communications is a rural telecommunications

Misener, Earl W. Comstock and Timothy Wu before United States House of Representatives Committee on the Judiciary Telecommunications and Antitrust Task Force, 26 April 2006.

¹⁴ As we explain below, “head of the line” is reference to one approach to providing some packets with premium transmission. There are other approaches as well.

¹⁵ See testimony of Gary R. Bachula, Vice President, Internet2 before the United States Senate Committee on Commerce, Science and Transportation. Testimony given 7 February 2006.

¹⁶ See Paul Misener’s testimony before the United States House of Representatives Committee on the Judiciary Telecommunications and Antitrust Task Force, 26 April 2006.

company that blocked its DSL customers from accessing VoIP¹⁷ service. After these actions were brought to regulators' attention, the FCC issued an order directing Madison River to allow its DSL customers to access VoIP service.¹⁸

The FCC also responded more broadly to concerns about net neutrality in other proceedings. Even though the FCC does not apply traditional telephone-like regulation to Internet access providers, it does retain some ancillary authority over Internet providers under its current statutes. Using that authority, the FCC recently adopted a set of policy principles applicable to Internet providers, namely:

- “To encourage broadband deployment and preserve and promote the open and interconnected nature of the public Internet, consumers are entitled to access the lawful Internet content of their choice.
- To encourage broadband deployment and preserve and promote the open and interconnected nature of the public Internet, consumers are entitled to run applications and use services of their choice, subject to the needs of law enforcement.
- To encourage broadband deployment and preserve and promote the open and interconnected nature of the public Internet, consumers are entitled to connect their choice of legal devices that do not harm the network.
- To encourage broadband deployment and preserve and promote the open and interconnected nature of the public Internet, consumers are entitled to competition among network providers, application and service providers, and content providers.”¹⁹

The FCC did note that these principles are “...subject to reasonable network management,”²⁰ which means that the principles did not necessarily bind the FCC to agree with net neutrality proponents.

¹⁷ VoIP is the acronym for Voice over Internet Protocol. VoIP allows people to use the Internet for telephone calls by sending voice data using IP (Internet Protocol) technology rather than via the traditional (copper wire) method of telecommunications.

¹⁸ See *Madison River Communications* Order FCC 4295 (2005).

¹⁹ *Policy Statement*, FCC 05-151, released September 23, 2005

²⁰ *Policy Statement*, p. 3, footnote 15

However, the FCC's policy statement may produce more questions than clarity.²¹ Consider the controversy over Comcast's management of P2P (peer to peer) traffic. Vuze, a company providing a platform for the downloading of high quality video (e.g., from National Geographic and PBS), has filed a petition for rulemaking requesting the FCC to prevent broadband network operators from degrading or blocking Internet content, a practice Vuze calls "throttling".²² Specifically, Vuze alleges that Comcast, a large cable operator, was throttling bandwidth-intensive traffic such as video distribution. Comcast used deep packet analysis to identify bandwidth-intensive applications, and then used that information to 'shape' or manage network traffic by delaying or disrupting those applications.²³ Comcast defended the practice, stating that it only delayed P2P traffic where the end user's computer was being used only for uploads even when the user was not present, and that this was done only when the network traffic reached specified levels of congestion.²⁴ Comcast also pointed out that its actions protected the quality of other consumer applications, such as VoIP and Internet gaming.

In support of their position, the ISPs also argue that that under the status quo they have no incentive to upgrade their networks, and limited ability to recoup costs of initial investments in the Internet. Conversely, if ISPs are able to offer (and charge for) premium transmission, the incentive and ability to invest in the network would be greater. Although these arguments may be overstated, we explain below that offering premium transmission improves overall network performance.

²¹ Jamison and Sichter (2008).

²² Vuze Petition for Rulemaking, November 14, 2007.

²³ A coalition of parties, including Free Press and the Consumer Federation of America filed a Petition for Declaratory Ruling on November 1, 2007, requesting the FCC to rule that Comcast's practices violated the Commission's Policy Principles.

²⁴ Comments of Comcast, FCC WC Docket 07-52, February 12, 2008.

Thus far much of the net neutrality debate has been more rhetorical than rigorous. Relying upon the analytical research that does exist, we consider in the following sections the implications of net neutrality policies on network capacity, innovation, network subscription, and incentives for the network provider to hinder rivals.

III. Provision of Transmission and Content

A. Transmission Speed

In this section we describe how network providers can provide premium transmission services alongside standard transmission services. Consider what happens when consumers visit web sites. Each visit or hit triggers the delivery of the site's content to the consumer. The speed with which the content's packets transverse the network is determined by the physical speeds of the transmission and switching facilities of the network and by the amount of congestion that the packets encounter. Congestion occurs when more packets enter a point in the network during a given period of time than the point can process. With current technologies, the physical speeds are barely consequential; however, packets do encounter congestion in the network.

The amount of time that a packet takes to clear a point of congestion, called the wait time, is determined by the capacity of the network at that point, the number of packets that are trying to pass through that point, and the priorities given to the packets that are in the queue waiting to be processed. The capacity of the network at a particular point is defined as the number of packets the point can process during a unit of time. In some sense the net neutrality debate is about what happens at these congestion points or in their associated queues.

To understand this aspect of the debate, consider the situation where all packets are treated the same.²⁵ In this situation every packet entering a queue during a given time experiences the same expected wait time: the packets simply line up in the queue as they arrive and wait to be processed. Mathematically, the expected or average wait time is represented as the number one divided by the difference between the network capacity and the arrival rate of packets during the time period, where the arrival rate is defined as the number of packets to arrive during the time period divided by the number of units of time during the period. As this formula illustrates average wait time decreases (conversely, increases) if the difference between network capacity and arrival rate increases (conversely, decreases).²⁶

Now consider what happens if some packets are given preferential treatment, i.e., some packets receive the standard transmission service and others receive a premium service. There are various methods by which this could be done.²⁷ One method is called the one processing rate system with priority. In this system the premium group's content moves ahead of the standard group's content in the queue, but does not stop the standard group's content from being delivered once the standard group's content is in the service process. Another method is a two processing rate situation. In this method each group is given its own processing rate and these rates are chosen such that the average wait time

²⁵ To simplify discussion, we consider an $M/M/1$ queuing system, which is a queuing system where interval and distribution times are exponentially distributed and there is one server. The first M represents that the arrival process for packets is random, the second M represents that the processing service time is exponential, and the 1 represents that there is one server. For more detailed explanations, see Gross and Harris (1998).

²⁶ Other implications of this formula for wait time are: (1) Average wait time approaches infinity as the arrival rate of the packets approaches the network capacity; and (2) At least some congestion is expected unless the network capacity is such that the network can simultaneously process the maximum number of packets that content providers and consumers can send at one time. When average wait time is infinity, the average packet does not expect to make it through this network point during the time period. This does not mean that no packets make it through – clearly some do make it through because the network processes information – but the queue continues to grow in length throughout the time period.

²⁷ For more detailed explanations, see Chapter 3 in Gross and Harris (1998).

for the premium service is less than the average wait time for the standard service. In either the one-rate system or the two-rate system, or indeed in any system, the packets with premium transmission experience less wait time than the packets receiving standard transmission. Providing premium transmission for some content may affect the average wait time in a network and may affect the average wait time for content not receiving premium service, depending on how the premium service is provided.²⁸ Some network providers have committed to not degrading service for any content provider if premium service is offered. We call this the non-degradation condition.

Non-Degradation Condition. Under this condition, the network operator keeps its commitment that standard transmission service will be the same regardless of whether premium service is offered.

When the non-degradation condition holds, a network provider will increase network capacity when providing premium transmission service.²⁹ This result follows directly from queuing theory.³⁰ In the one-rate system, the premium group always gets ahead in line and the second group experiences a decrease in its service speed because it loses its place in line unless the total system speeds up. Thus network capacity has to be increased if the first group experiences an improvement in service while the second group experiences no degradation in its service. With the two-rate system the standard group would experience an increase in wait time unless total network capacity was increased so that the second group's access to delivery capacity was not diminished. Thus when the

²⁸ See Gross and Harris, 1998, p. 150.

²⁹ See Jamison and Hauge (2008a).

³⁰ See Gross and Harris, 1998, pp. 141-151.

non-degradation condition holds, the network's provision of premium transmission results in an increase in network capacity, all other things remaining equal.

B. Content Provision

There are many ways of categorizing the content on the Internet, but there are basically two ways that have been shown to be relevant for analyzing the net neutrality issue. One type of content is that whose value decays as it passes through the network because the value of the content is time sensitive. We call this d-content, for decaying-content. Examples of d-content include auction sites such as e-Bay and sites for trading financial securities. For auction sites, some bidders wait until near the close of the auction before entering their final bids. Timely information on other bids is valuable because it decreases uncertainty about what others are willing to pay for the item that is offered for auction. This value provides an incentive for a bidder to purchase broadband Internet access so that information is not delayed by her connection to the network, and it provides an incentive for an auction site to seek ways to speed its delivery of bid data so as to attract bidders. Similarly, securities traders such as day traders depend on timely price information as they attempt to profit from small changes in securities prices. A site that offers timelier price information and faster trades would be more valuable to traders than a site that provided slower service, all other things being equal.

The second type of content is that which does not decay with the time it takes to transit the network. We call this n-content, for non-decaying content. Examples include the Social Science Research Network (SSRN) and news sites. For these types of sites, visitors value their time and so prefer faster delivery to slower delivery, but the value of

the substance of a research paper downloaded from SSRN and the value of the substance of a news article on a recent court decision are unaffected whether it takes 3 seconds or 10 seconds to download the information.

The type of content affects how consumers receive value from the content site. In the case of n-content, the value is simply the difference between the positive value of the content and the value of the time consumed to obtain the information. This is the consumer utility function developed by Mendelson (1985) to represent the value consumers receive from computing services. It has been further applied to analyzing broadband pricing and net neutrality issues.³¹ In the case of d-content, wait time affects consumer utility in two ways. First, wait time decreases consumer utility directly by the time consumed to obtain the information, just as with n-content. Second, wait time decreases consumer utility indirectly by causing decay in the value of the content.

Why does it matter whether content is d-content or n-content? The content type affects which sites have greater preferences for premium transmission. Consider the situation for providers of d-content. When a d-content provider considers whether to purchase premium transmission, she compares the impact of her choice on her revenue to the impact of her choice on her costs. She chooses to purchase the premium transmission if she believes the revenue impact is greater than the cost impact because this improves her overall profit. But d-content providers vary in their abilities to provide useful d-content. For example one auction site might have proprietary algorithms that make it easier to use than rival sites. This raises the question of whether all d-content sites experience the same marginal impacts on revenue and cost. They do not. In situations

³¹ See Bandyopadhyay and Cheng (2006) for applications in analyzing broadband pricing, and Jamison and Hauge (2008a, 2008b) for applications in analyzing net neutrality issues.

where the marginal effect of wait time on the value d-content is positively correlated with the content provider's innate ability to provide content and its investment in content, then lower value sites have a higher preference for premium service than do higher value sites. If instead the marginal effect of wait time on d-content value is negatively correlated with innate ability and content investment, then preferences for premium service depend on the relationship between these marginal effects and how the amount paid for premium service varies with wait time and the number of visits to the site.³²

Now consider how n-content sites would view the choice between premium and standard transmission. An n-content provider would perform the same marginal analysis as a d-content provider: The n-content provider chooses to purchase the premium transmission if he believes the revenue impact is greater than the cost impact because this improves his overall profit. But innate abilities of n-content providers do not affect transmission preferences in the same way that they affect d-content providers.³³ The n-content providers with lower innate abilities consistently value premium transmission more than do n-content providers with greater innate abilities. The reason is that the extra cost of premium transmission to the high-ability n-content provider is greater relative to the extra revenue than for the low-ability n-content provider.

C. Transmission Tariff

There are two issues with the transmission tariff that affect analyses of net neutrality. One issue is whether content providers are able to extract what is called an

³² These relationships have not been worked out in the literature, so we provide an analytical proof in the Appendix.

³³ Jamison and Hauge (2008a, 2008b) formally illustrate this result.

information rent. The other issue is the design of the tariff. We discuss these issues in this section.

An information rent is a net benefit that a seller (conversely, buyer) can obtain because she has information about either her ability or her effort that the buyer (conversely, seller) does not have, or if he does have the information he cannot use it. To illustrate this situation, consider how a network provider might design a tariff for premium transmission. If the network provider gives each content provider a choice between standard transmission and premium transmission, and if the tariff is generally available to all content providers, then in order to induce a particular content provider to purchase premium transmission the tariff prices for premium transmission must allow the content provider to receive just as much profit when she uses premium transmission as when she uses standard transmission. This profit is called the information rent.

Why would a network provider design its tariffs this way? Why not simply force each content provider to use the type of transmission that maximizes profit for the network provider? There are two reasons. First, recall that content providers vary in their innate abilities and that these abilities affect the value of premium transmission. The network provider might not know enough about each content provider's innate ability to know which type of transmission service would be preferred from the network provider's perspective. Second, the network provider might be regulated in the sense that either a sector or competition regulator requires the network provider to offer the same tariff to all content providers. In either case the network provider's tariff must induce content providers to self select the appropriate service.

Studies differ in whether it is reasonable to assume that content providers will receive an information rent. We assert that it is unreasonable to assume an information rent for two reasons. First, economic models of network content assume that customers are able to assess content value, which reveals each content site's innate ability. It seems reasonable to conclude that managers of the network operator also are able to observe content value given that they, too, are consumers. Furthermore, there are no regulations that require network operators to offer generally available tariffs to content providers; network providers and content providers negotiate individual contracts.³⁴

The issue of tariff design is also important because the conclusions about how content providers' abilities affect their preferences for premium transmission depend upon tariff design. The profit maximizing tariff design, given the assumption that there are no information rents, charges for premium delivery of packets based on the advertising revenue that the packets generate for content providers. This tariff structure is profit maximizing for the network provider because it exacts all of the content providers' profits.³⁵

IV. Effects of Premium Transmission on Innovation, Subscription, and Incentives to Harm Rivals

A. Innovation at the Edges

Net neutrality advocates hold that allowing network providers to supply and charge for premium transmission would hinder innovation at the edges of the network, including content sites. Interpreting innovation to mean an increase in the value and

³⁴ Neither Hermalin and Katz (2007) nor Jamison and Hauge (2008a, 2008b) investigate how their information rent assumptions affects their analyses.

³⁵ See Jamison and Hauge (2008b) for formal presentation of this result.

diversity of content available at the edges of the network, we assert the opposite is true for n-content. More specifically, the variety of n-content at the edges of the network increases when the network provider provides premium transmission services, and the value that consumers receive from the sites that purchase the premium transmission service is greater than it would be otherwise.³⁶

To understand why this holds, recall that premium transmission improves the profitability of n-content providers with innately lower value content. This means that there are potential n-content providers who have such low innate abilities that they are unprofitable unless premium transmission is available. So, one result of premium transmission is an increase in the variety of content made available on the network. Furthermore consumers receive greater utility from content sites that purchase the premium speed than they would receive if the premium service were not available. This happens because content providers will purchase the premium speed only if it increases revenues, which happens only if the premium speed increases consumer visits on these sites by increasing the utility that consumers receive from the sites that purchase the premium service.

A corollary from the finding that premium transmission stimulates innovation at the edges is that when lower value n-content sites purchase the premium speed, profits decrease for the sites that do not purchase it. This occurs because, with a downward sloping demand curve for advertising on content sites, advertising prices decline. This price decrease lowers revenue, and thus profits, for every content site that does not increase its hits by purchasing the premium transmission service. The declining price of advertizing and subsequent reduction in content provider profits helps us understand why

³⁶ See Jamison and Hauge (2008a and 2008b) for formal presentation of this result.

content providers with very large web presence are some of the strongest proponents of net neutrality. Although they may have numerous reasons for advocating net neutrality, at least one effect of premium transmission is that high-ability incumbent providers of n-content stand to lose market share and advertising revenue to smaller web sites that are the more likely purchasers of premium services.

The corollary does not mean that all content providers purchase the premium service. From revealed preferences we know that a network provider that had optimally chosen a standard speed when offering only one speed, and that had optimally chosen a premium speed when choosing to provide more than one speed, would choose a premium speed that not all content providers would purchase.

B. Network Subscription

We now turn our attention to the effects of premium transmission service on demand for network subscription. Research indicates that more consumers subscribe to the network service when premium transmission service is offered and at least one content site purchases the service than if the network provider did not offer the premium service.³⁷ We assert that this is simply a consequence of network effects. More consumers subscribe to the network service because the value of the network is greater when premium service is provided than when it is not. The network provider benefits in two ways from the premium transmission service. First, it receives greater profit by being able to charge premium prices for something that at least some content providers value, whereas without the premium prices there would be no direct benefit to offering a higher speed service. Second, the number of consumers subscribing to network access is greater,

³⁷ Both Hermalin and Katz (2007) and Jamison and Hauge (2008a) find this result.

which in turn leads to more hits on the content sites, which stimulates the demand for premium transmission. The greater diversity of content sites also stimulates demand by consumers for network access and increases the number of content sites interested in purchasing the premium transmission service.³⁸

C. Incentives to Harm Rivals

Finally, a common concern of net neutrality proponents is that a vertically integrated network provider, i.e., one that provides both content and network services, would discriminate against its content rivals. We argue that this would not be the case at least for n-content. The network provider's profit from being the content provider is no greater than its profit from selling premium transmission to a non-affiliated entity providing that same content.³⁹ Indeed this may be a situation in which regulation would lead to incentives to discriminate: if regulation were to impose a non-discriminatory tariff requirement on the network and such a tariff requirement resulted in an information rent for content providers, then the network provider might be able to decrease the information rent and improve its profit by vertically integrating and discriminating against its content rivals.

VI. Conclusion

In this chapter, we have analyzed the effects of a network provider offering premium transmission speeds for content providers. We have found that at least some of the claims of the net neutrality advocates do not hold. Specifically, we find that offering

³⁸ Jamison and Hauge (2008b).

³⁹ See Jamison and Hauge (2008b) for formal derivation of this result.

premium service stimulates innovation on the edges of the network because lower-value content sites are better able to compete with higher-value sites with the availability of the premium service. The greater diversity of content and the greater value created by sites that purchase the premium service benefit advertisers because consumers visit content sites more frequently. Consumers also benefit from lower network access prices. We also explain that a vertically integrated network provider does not have an incentive to discriminate against its n-content rivals.

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Appendix

Following the model we develop in Jamison and Hauge (2008a), content provider i 's profit function is

$$\max_{I,S} \pi_i \equiv v(i) \cdot n(a - r(S)) - w \cdot I \quad (\text{A1})$$

Where $v(i)$ is the value a consumer experiences when she visits i 's site, n is the number of consumers with access to the network, a is the revenue per hit that i receives from advertisers, $r(S)$ is the price per hit charged by the network operator for providing speed S for i 's packets, I is the amount of information that i places on its site, and w is i 's cost per unit of information. Normalizing the number of hits per consumer to the value each consumer receives from the site, $v(i) \cdot n$ represents the number of hits that i receives from all consumers. For ease of exposition in this proof, we treat S as a continuous variable. We deviate from our earlier model by assuming that information value decays with delay.

Assuming that content providers are price takers, first order conditions from (A1) for an internal solution include

$$v_I \cdot n(a - r) - w = 0 \quad (\text{A2})$$

and

$$v_S \cdot n(a - r) - r_S v \cdot n = 0. \quad (\text{A3})$$

Taking the total derivatives of (A2) and (A3) with respect to I , S , and i and applying Cramer's rule gives us

$$\begin{bmatrix} v_{I,I} \cdot n(a - r) & n[v_{I,S}(a - r) - r_S v_I] \\ n[v_{S,I}(a - r) - r_S v_I] & n(v_{S,S}(a - r) - 2r_S v_S - r_{S,S} v) \end{bmatrix} \cdot \begin{bmatrix} dI \\ dS \end{bmatrix} = \begin{bmatrix} -v_{I,I} \cdot n(a - r) \\ n[v_{S,I}(a - r) - r_S v_I] \end{bmatrix} \cdot di$$

and

$$\frac{dS}{di} = \frac{v_{I,I}(a - r)[v_{S,I}(a - r) - r_S v_I] + v_{I,I}(a - r)[v_{S,I}(a - r) - r_S v_I]}{v_{I,I}(a - r)(v_{S,S}(a - r) - 2r_S v_S - r_{S,S} v) - (v_{I,S}(a - r) - r_S v_I)^2}. \quad (\text{A4})$$

The denominator in (A4) is positive because of the assumption that second order conditions are met. But, the sign of the numerator is ambiguous. Note that $v_{I,I}(a - r) < 0$ because $v_{I,I} < 0$ by assumption and $a - r > 0$ from (A2), making $v_{I,I}(a - r) > 0$. Furthermore $v_{I,I}(a - r) > 0$ because $v_{I,I} > 0$ by assumption and $a - r > 0$. If $v_{S,I}(a - r) - r_S v_I > 0$ and $v_{S,I}(a - r) - r_S v_I > 0$, then the numerator is positive and higher ability content providers have a greater preference for premium service than do lower types, i.e., $\frac{dS}{di} > 0$. More generally, $\frac{dS}{di} > 0$ if

$$v_{I,I}[v_{S,I}(a - r) - r_S v_I] > -v_{I,I}[v_{S,I}(a - r) - r_S v_I]. \quad (\text{A5})$$

Net Neutrality Policies and Regulation in the United States

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1. Introduction

The US has engaged in an increasingly contentious policy debate about net neutrality for more than a decade. The debate was effectively launched by Wu (2003), who made the case for regulatory restrictions on how internet service providers (ISPs) might structure their service offerings. The idea was perhaps given legs by Yoo (2004) and Wu and Yoo (2007), where Yoo effectively took the opposite view of Wu and the visibility of the articles lent the issue legitimacy.

The nature of the conflict on net neutrality has been unusually partisan and combative for an information technology issue. It has included the usual scholarly articles, articles for the general public, regulatory proceedings, Congressional hearings, and social media postings. But there have been unusually intemperate statements, such as *Investor's Business Daily* referring to advocates of net neutrality regulations as snake oil salesmen¹ and Senator Ted Cruz referred to the regulations as “Obamacare for the internet.”² And there are political exaggerations and confusions, such as the Senate Democrats tweet on February 27, 2018, stating that absent net neutrality regulations, the internet will deliver content one word at a time, implying that the internet would slow down to a crawl.³ Partly as a good-humored response to doomsday-like predictions of the Federal Communications Commission (FCC) voting to 2017 drop net neutrality regulations, the current FCC chairman's chief of staff, Matthew Berry, tweets

¹ “Net Neutrality Advocates Are Modern-Day Snake Oil Salesmen,” *Investor's Business Daily*, November 22, 2017 <https://www.investors.com/politics/editorials/fcc-ajit-pai-net-neutrality-repeal/> (accessed August 27, 2018).

² Chen, Angela. May 16, 2018. “Why is Net Neutrality a Political Issue? Democrats & Republicans Won't Settle For A Compromise,” *Bustle* <https://www.bustle.com/p/why-is-net-neutrality-a-political-issue-democrats-republicans-wont-settle-for-a-compromise-9099979> (accessed August 27, 2018).

³ @SenateDems, February 27, 2018, <https://twitter.com/SenateDems/status/968525820410122240> (accessed August 24, 2018). The internet delivers everything one bit at a time regardless of speed.

almost daily counting the days since the decision went into effect and noting the continued thriving of the internet.⁴

The back and forth has been quite uncivil. There have been numerous protests against the FCC⁵ and two of its chairmen,⁶ bomb threats against the agency,⁷ and threats of violence against the current FCC chairman and his family.⁸ Activism of this nature is unusual for a telecommunications issue, perhaps indicating that some of the oversized rhetoric has been taken literally by some people, that the activism is part of a larger political agenda, or both. Resolving the motives behind these aspects of the conflict is beyond the scope of this paper.

Something that is puzzling about the intensity of the conflict is it appears to be about means rather than goals. Jamison and Layton (2016) conclude that both proponents and opponents of net neutrality regulations have the same stated goal: Robust and open networks so that entrepreneurs can thrive and benefit consumers. If the stated goals are the actual goals, then where the regulatory proponents and opponents differ is the role of regulation. Some believe that ISPs should be regulated in ways similar to those of monopoly telephone companies. Others believe that the FCC should play a limited role as a resolver of disputes.

⁴ See, for example, @matthewberryfcc, August 22, 2018, <https://twitter.com/matthewberryfcc/status/1032365032225497088> (accessed August 24, 2018). This particular tweet says, “Day 73 of the post-Title II era: The Internet is free and open, and 86 years ago today, the BBC aired its first experimental television program, featuring jiu-jitsu, a performing sea lion, and a painting demonstration. I don't believe that the sea lion performed jiu-jitsu . . .”

⁵ Fung, Brian. May 9, 2018. “Why the Internet is suddenly protesting on net neutrality all over again,” *The Washington Post* https://www.washingtonpost.com/news/the-switch/wp/2018/05/08/senate-democrats-have-been-pushing-a-big-vote-on-net-neutrality-all-year-its-here/?noredirect=on&utm_term=.d451194aefda (accessed August 27, 2018).

⁶ Protestors were at then-Chairman Wheeler’s house before the 2015 decision (Fung, Brian. November 10, 2014. “Protesters descend on FCC chairman’s house over net neutrality,” *The Washington Post* https://www.washingtonpost.com/news/the-switch/wp/2014/11/10/protesters-descend-on-fcc-chairmans-house-over-net-neutrality/?utm_term=.31ad2ee3b82d, accessed August 27, 2018) and at Chairman Pai’s home (“In Net Neutrality Protests, US Regulator Ajit Pai Bombarded With Pizzas,” NDTV <https://www.ndtv.com/world-news/protest-outside-us-telecom-regulator-head-ajit-pais-home-over-net-neutrality-1780769>, accessed August 27, 2018).

⁷ Mak, Aaron. December 14, 2017. “The FCC Had to Pause Its Net-Neutrality Hearing Because of a Bomb Threat,” *Slate* http://www.slate.com/blogs/future_tense/2017/12/14/fcc_vote_on_net_neutrality_was_interrupted_by_a_security_threat.html (accessed August 27, 2018).

⁸ Kang, Cecilia. June 30, 2018. “Man arrested for ‘threatening to kill’ Ajit Pai’s family over net neutrality,” *Independent* <https://www.independent.co.uk/news/world/americas/net-neutrality-threaten-to-kill-ajit-pai-family-fcc-us-justice-a8424256.html> (accessed August 27, 2018).

Still others believe that market pressures will appropriately incentivize ISPs and that consumer harms should be addressed with *ex post* regulations.

The divide has led to wide swings in how regulators and policy makers have approached the issue and defined it. One extreme has been the effectively hands-off approach adopted first during the administration of President Clinton and now followed by the Trump administration. The other extreme was the Obama administration's adoption of what is called Title II regulation, which is the regulatory framework contained in the Communications Act of 1934 to regulate monopoly telephone companies. In between these are the light-handed policies attempted during the George W. Bush administration and early in the Obama administration.

This paper describes how the US has approached net neutrality, the scholarly research regarding the effects of such regulations, and the current situation. Section 2 describes the various regulatory approaches, including how regulation has defined internet services, the hands-off approach of the FCC under former-President Clinton, how the FCC under former-Chairman Michael Powell and former-Chairman Julius Genachowski attempted to address discrimination concerns while maintaining a light-handed approach, the turn to Title II regulation under former-Chairman Tom Wheeler, and the reversal of that policy under Chairman Ajit Pai. Section 3 explores the economic research on net neutrality, emphasizing articles published in leading economic journals. Section 4 is the conclusion.

2. Regulatory Approaches in the US

The FCC has been the locus of activity on how to properly address net neutrality issues in the US. But the agency has struggled to develop a consistent course of action that courts would accept as appropriate given the agency's authorizing statutes. This section reviews the regulatory framework that existed prior to the FCC's attempts to address net neutrality and then examines the attempts themselves.

a. The Development of the Regulatory Philosophy

The regulatory story underlying net neutrality began over 60 years ago. In 1956, the Department of Justice and AT&T entered into a consent decree⁹ that prohibited AT&T from serving unregulated markets and confining it to common-

⁹ *United States v. Western Electric Co.*, 13 Rad. Reg. (P&F) 2143, 1956 Trade Cas. (CCH) 71,134 (D.N.J. 1956).

carrier communication services and government projects. Also in 1956 the DC Circuit Court issued a decision in *Hush-A-Phone*,¹⁰ which allowed customers to attach a plastic device to AT&T phones, which AT&T had attempted to prohibit. Following up in 1968 the FCC decided in *Carterfone*¹¹ that anyone could connect any privately-beneficial equipment to AT&T's telephone network as long as the equipment was not publically harmful. This triggered the development of technical standards for equipment so that customers could choose any equipment they wanted that met the standards. This became part of the paradigm for net neutrality regulations.

The principles underlying the 1956 Consent Decree, *Hush-A-Phone*, and *Carterfone*, combined with rapidly changing computing and telecommunications technologies, led the FCC into a series of decisions collectively known as the Computer Inquiries. These decisions created the regulatory framework that led the agency to define the internet as an information service, not a common carrier service. This designation determined the nature of the agency's jurisdiction over the internet.

The first of these inquiries, *Computer I*,¹² created a dichotomy between "basic" and "enhanced" telecommunications services.¹³ In its *Second Computer Inquiry*, the FCC defined basic services as "pure transmission capability over a communications path that is virtually transparent in terms of its interaction with customer supplied information"¹⁴ that were "regulated under Title II of the [Communications] Act."¹⁵ Enhanced services were "any offering over the telecommunications network which is more than a basic transmission service. In an enhanced service, for example, computer processing applications are used to act on the content, code, protocol, and other aspects of the subscriber's information."¹⁶ The FCC concluded that "enhanced services should not be regulated under the Act."¹⁷

This line between basic and enhanced found its way into the Modification of Final Judgment (MFJ) that broke up AT&T in 1984. The MFJ distinguished

¹⁰ *Hush-A-Phone Corp. v. United States*, 238 F.2d 266 (D.C. Cir. 1956).

¹¹ *Use of the Carterfone Device in Message Toll Tel. Serv.*, 31 F.C.C.2d 420 (1968).

¹² *Regulatory and Policy Problems Presented by the Interdependence of Computer and Communication Services*, Notice of Inquiry, 7 FCC 2d 11 (1966).

¹³ *Amendment of Section 64.702 of the Commission's Rules and Regulations (Second Computer Inquiry)*, Docket No. 20828, Final Decision, 77 FCC 2d 384, 420, para. 97 (1980) (*Computer II Final Decision*).

¹⁴ *Id.* at 420, para. 96.

¹⁵ *Id.* at 428, para. 114.

¹⁶ *Id.* at 420, para. 97.

¹⁷ *Id.* at 428, para. 114.

between “telecommunications services” that were “actually regulated by tariff,”¹⁸ and “information services,” which included “data processing and other computer-related services,”¹⁹ and “electronic publishing services.”²⁰ The Telecommunications Act of 1996 (the 1996 Act) picked up this terminology, defining “information service” the same as in the MFJ.²¹

With the 1996 Act, Congress intended to “promote competition and reduce regulation.”²² In doing so it distinguished between the lightly regulated “information services” and “telecommunications services,”²³ which were regulated as common carrier services. Congress also found that the “Internet and other interactive computer services have flourished, to the benefit of all Americans, with a minimum of government regulation”²⁴ and made it the policy of the United States to “promote the continued development of the Internet and other interactive computer services and other interactive media” and “to preserve the vibrant and competitive free market that presently exists for the Internet and other interactive computer services, unfettered by Federal or State regulation.”²⁵

The FCC followed this basic-information dichotomy and also kept to the 1996 Act’s preference for an internet unfettered by Federal or State regulation throughout most of its work on net neutrality, with the exception being the 2015 Open Internet Order.²⁶ For example, in the Commission’s review the 1996 Act’s definitions as they applied to the internet, it concluded that internet access services were properly classified as an information service.²⁷ It also concluded that subjecting ISPs to “the broad range of Title II constraints,” would “seriously curtail the regulatory freedom that the Commission concluded in *Computer II* was

¹⁸ *U.S. v. Am. Tel. & Tel. Co.*, 552 F. Supp. 131, 228-29 (D.D.C. 1982) (*MFJ Initial Decision*), *aff’d sub nom. Maryland v. U.S.*, 460 U.S. 1001 (1983).

¹⁹ *Id.* at 179.

²⁰ *Id.* at 180.

²¹ *Implementation of the Non-Accounting Safeguards of Section 271 and 272 of the Communications Act of 1934, as amended*, CC Docket No. 96-149, First Report and Order and Further Notice of Proposed Rulemaking, 11 FCC Rcd 21905, 21954, para. 99 (1996) (*Non-Accounting Safeguards Order*); *see also, e.g.*, H.R. Conf. Rep. No. 104-458 at 126 (Jan. 31, 1996) (“‘Information service’ and ‘telecommunications’ are defined based on the definition used in the Modification of Final Judgment.”); *see also Federal-State Joint Board on Universal Service*, CC Docket No. 96-45, Report to Congress, 13 FCC Rcd 11501, 11514, para. 28 (1998) (*Stevens Report*) (citing *MFJ Initial Decision*, 552 F. Supp. at 226-32).

²² Preamble, Telecommunications Act of 1996, Pub. L. No. 104-104, 110 Stat. 56 (1996).

²³ 47 U.S.C. § 153(24), (53).

²⁴ 47 U.S.C. § 230(a)(4).

²⁵ 47 U.S.C. § 230(b)(1), (2).

²⁶ FCC, *In the Matter of Protecting and Promoting the Open Internet, Report and Order*.

²⁷ *Federal-State Joint Board on Universal Service*, CC Docket No. 96-45, Report to Congress, 13 FCC Rcd 11501, 11536, para. 73 (1998) (*Stevens Report*).

important to the healthy and competitive development of the enhanced-services industry.”²⁸

b. Decisions on Net Neutrality and their Aftermaths

The FCC’s first attempt to address net neutrality was in 2005 – three years after Wu’s article -- when the Commission adopted an Internet Policy Statement intended “to ensure that broadband networks are widely deployed, open, affordable, and accessible to all consumers”.²⁹ The statement provided four consumer-centric guiding principles, also referred to as “Four Freedoms.” (Powell 2004)

- Consumers are entitled to access the lawful Internet content of their choice.
- Consumers are entitled to run applications and use services of their choice, subject to law enforcement’s needs.
- Consumers are entitled to connect their choice of legal devices that do not harm the network.
- Consumers are entitled to competition among network providers, application and service providers, and content providers.

The last principle should probably be read as a statement that regulators should not create barriers to competition: While it is meaningful to say that customers have a right to choose, it is another thing to say that they are entitled to multiple choices because the latter implies that someone has an obligation to create additional providers in otherwise monopoly markets. That is not something the FCC has taken upon itself to do.

The first three principles would be consistent with common carrier obligations if they had been imposed on ISPs. But the principles were framed like consumer protection. If the FCC had stopped there and simply (1) pressured ISPs to always offer a broadband service package that included access to all lawful content and apps, and allowed customers use of any device of their choosing, while (2) not prohibiting ISPs from offering other services packages, the net neutrality debate might have ended there in the US because ISPs rarely violated the three principles and most ISPs never violated them. But that isn’t what the FCC did.

In response to a complaint that Comcast was degrading peer-to-peer internet traffic, the FCC chose to impose its principles as obligations.³⁰ Comcast

²⁸ *Id.* at 11524, para. 46.

²⁹ Preserving the Open Internet, 20 FCC Rcd 14986.

³⁰ *In re Formal Compl. of Free Press & Public Knowledge Against Comcast Corp. for Secretly Degrading Peer-to-Peer Applications*, 23 F.C.C.R. 13,028 (2008).

appealed and the DC Circuit Court rejected the FCC's decision, stating that the FCC had failed to provide statutory authority for imposing obligations.³¹

With the ball back in its court, the FCC launched a second light-handed attempt to address net neutrality in 2010 when the agency tried to write administrative rules regarding net neutrality.³² This was early in President Obama's first term. In this decision, the FCC adopted three basic rules:

1. Transparency. Fixed and mobile broadband providers must disclose the network management practices, performance characteristics, and terms and conditions of their broadband services;
2. No blocking. Fixed broadband providers may not block lawful content, applications, services, or non-harmful devices; mobile broadband providers may not block lawful websites, or block applications that compete with their voice or video telephony services; and
3. No unreasonable discrimination. Fixed broadband providers may not unreasonably discriminate in transmitting lawful network traffic.

As part of this 2010 attempt to define rules for ISPs, the FCC adopted a light-handed, multistakeholder approach for resolving net neutrality issues. This approach was short-lived, as the FCC never utilized the multistakeholder group. (Jamison and Layton, 2016)

The agency failed to implement its multistakeholder approach in part because, in 2014, the DC Circuit Court again reversed the FCC on jurisdictional grounds, finding that the 2010 rules were effectively common carrier obligations. This was a problem because the FCC had determined that ISPs were not common carriers and so not subject to common carrier requirements.³³

In its ruling, the DC Circuit Court effectively provided the FCC with a roadmap for how to classify ISPs as common carriers and then impose net neutrality rules. The FCC followed the court's advice in its 2015 Open Internet Order,³⁴ in which the agency took the heavy-handed approach of applying its 1930s-era rules for regulating monopoly telephone companies. More specifically, the Commission, under the prompting of then-President Obama,³⁵ classified consumer broadband service as common carrier services under Title II of its

³¹ Comcast Corp. v. FCC, 600 F.3d 642 (DC Cir. 2010)

³² *Preserving the Open Internet, Report and Order*, 25 FCC Rcd 17905.

³³ Verizon v. FCC, 740 F.3d 623 (DC Cir. 2014).

³⁴ Federal Communications Commission, *In the Matter of Protecting and Promoting the Open Internet, Report and Order*, FCC 15-24, March 12, 2015.

³⁵ President Obama, Statement on Net Neutrality (Nov. 10, 2014), <https://obamawhitehouse.archives.gov/the-press-office/2014/11/10/statement-president-net-neutrality>.

enabling statutes and reclassified mobile broadband Internet access service as a commercial mobile service. The Commission also adopted three bright-line rules that had the effect of prohibiting blocking, throttling, and paid-prioritization. It also adopted a general Internet conduct standard,³⁶ as well as “enhancements” to the transparency rule developed in the 2010 decision.

The FCC’s stated rationale for adopting the Title II approach included a belief that the country needed more and better broadband; that the rules adopted in 2010 appeared to not hinder internet development, so rules under Title II should not either; indeed regulatory rules might even stimulate investment; it needed to use its authority under Title II in order to impose net neutrality rules; and that “broadband providers hold all the tools necessary to deceive consumers, degrade content, or disfavor the content that they don’t like.” The DC Circuit Court upheld the decision, although Judge Williams issued a strongly worded dissent.³⁷

Members of Congress and former FCC chief economists criticized the agency’s 2015 decision and the process used to reach it. The FCC’s chief economist at the time of the decision called the rulemaking process and subsequent order an “economics free zone” because the agency excluded input from its own economists when developing the decision, thus getting its economic analysis wrong. (Brennan 2016) Another former chief economist was critical of the decision’s lack of economic rationale, stating that while he appreciated the agency citing his work in the order, but that the substance of his articles were the opposite of what the order claims.³⁸

Two important dissenters from the FCC’s 2015 decision were the two Republican commissioners, then-Commissioner Ajit Pai and Commissioner Michael O’Rielly. The Commission’s 2015 split over net neutrality – the three Democrat commissioners voted for the 2015 decision and the two Republican commissioners voted against it – reflected not just a disagreement on regulation, but a partisan divide that had emerged under then-Chairman Tom Wheeler. (Wallsten 2016) So it was no surprise that when Republicans gained a majority at the Commission in 2017 that they voted to effectively vacate the 2015 decision, stating, “We reverse the Commission’s abrupt shift two years ago to heavy-handed utility-style regulation of broadband Internet access service and return to

³⁶ General conduct standards can take many forms. The standard adopted by the FCC in 2015 appears sufficiently vague to provide little guidance on what the agency might have done applying the rule.

³⁷ *United States Telecom Ass’n v. FCC*, 825 F.3d 674 (D.C. Cir. 2016)

³⁸ See comments of Michael Katz in “The Future of the Internet Ecosystem in a Post-Open Internet Order World: Part 1,” Technology Policy Institute symposium January 12, 2016 <https://www.youtube.com/watch?v=Gz4W0sDxkfs&t=834s>, at 13:40 (accessed August 27, 2018).

the light-touch framework under which a free and open Internet underwent rapid and unprecedented growth for almost two decades.”³⁹ More specifically, the FCC:

- Ended “utility-style regulation of the Internet in favor of the market-based policies”;
- Reclassified consumer broadband services as an information service and not as a common carrier service; and
- Reinstated the private mobile service classification of mobile broadband Internet access service.

In reversing the 2015 decision, the FCC also restored the authority of the “Federal Trade Commission to police the privacy practices of Internet Service Providers (ISPs).” By statute, the Federal Trade Commission (FTC) does not have authority over common carriers, so the 2015 decision caused the FTC to lose jurisdiction over privacy with respect to ISPs.

The FCC’s rationale for its 2017 decision included beliefs that laws other than Title II were better suited for protecting consumers and competition, that Title II regulations suppressed infrastructure investment, that classifying internet as a common carrier service was unsound as a legal matter, and that the costs of the 2015 decision outweighed the benefits. In its 2015 decision, the FCC deliberately chose to not conduct a cost-benefit analysis.

c. Responses to the 2017 Decision

The supporters of imposing common carrier regulations on ISPs reacted in opposition to the new FCC decision. In May 2018 the US Senate voted to overrule the FCC’s 2017 decision, but the US House of Representatives failed to go along. Under the Congressional Review Act, Congress can cancel an agency decision within 60 days after the rule is reported to Congress.⁴⁰ With a divided Congress effectively siding with the FCC in the 2017 decision, the decision went into effect on June 11, 2018.

Some state governments sprang into action. Governors in Hawaii, New Jersey, Montana and New York issued executive orders stating that their governments would not do business with broadband providers that did not follow net neutrality regulations. State legislatures in California, Oregon, and Massachusetts took up legislation to impose net neutrality requirements on broadband providers. And over 20 state attorneys general, plus the District of Columbia, sued the FCC, arguing that the 2017 decision was arbitrary, capricious, an abuse of procedure, and a violation of applicable laws. (Layton 2018) These

³⁹ FCC, *Restoring Internet Freedom, Declaratory Ruling, Order, Report and Order*. 33 FCC Rcd 311 (1).

⁴⁰ 5 U.S. Code § 802.

state actions map to the partisan divide that has come to be part of net neutrality in the U.S. as all of the governor offices, states attorney general offices, and state legislators that have acted are controlled by Democrats.

As of the time of this writing, these state responses have not been resolved. They all have legal problems. The governors' actions might violate the Supreme Court's marketplace-participant doctrine, which holds that a state cannot use procurement practices that are tantamount to regulating an industry. (Cooper 2018) Actions by state legislatures might be viewed as regulating interstate commerce, which states do not have authority to do. In order to avoid this problem, states would likely have to separate internet traffic that has its beginning and end points within the state from interstate and international traffic, something that might be impossible to do in any practical way. The legal appeals of the FCC's 2017 decision face the problem of judicial deference: Courts in the US largely accept regulatory agencies' claims regarding jurisdiction based on interpretation of their statutes, and the FCC in 2017 appeared to map its decision both to the evidence it had and to its enabling statute. So while it may seem strange that an agency would make a decision and then reverse itself within a span of two years, courts in the past have upheld their authority to do so. (Hurwitz 2017)

3. Economic Research on Net Neutrality

Most of the substantive arguments offered in the net neutrality debate are about the economic effects of *ex ante* regulation versus those of *ex post* regulation. These issues have been researched in the scholarly economics literature, so this section reviews that literature. With one exception, the focus here is on what has been demonstrated in articles that use explicit economic models and that appear in higher-level, peer-reviewed economics journals.⁴¹ The exception is a law review article. It is included because it is the only US empirical study of net neutrality in an academic journal. There have been other empirical analyses, but they are unpublished white papers or blogs. Including them would require extensive review of their academic merits, which is beyond the scope of this paper.

In general, economic research on net neutrality has found that the impacts of regulations depend on the conditions in the marketplace. Under various conditions such regulations can be harmful to consumers, harmful to network

⁴¹ The search for articles was limited to those appearing in economics journals ranked in the top 300 in IDEAS/RePEc Aggregate Rankings for Journals (<https://ideas.repec.org/top/top.journals.all.html>). The search was not exhaustive of these journals, so it is possible that articles were omitted that are relevant to the topic.

providers, harmful to content providers, or hinder investment. But there are also conditions under which opposite effects might occur. Most but not all of the articles conclude that regulatory restrictions on ISPs offering advanced features can lower economic efficiency. A notable exception is blocking customer access to content that customers find valuable. Such blocking is generally found to be harmful, based on the assumption that consumers do not want blocking.

What should readers make of studies with conflicting findings? Each study relies on specific assumptions about technologies and markets. The assumptions drive the findings. The challenge for readers who want to apply these studies is to determine which conditions are most applicable in their situations. Because of this, the review below highlights studies' basic assumptions.

The remainder of this section is organized into sub-questions: (1) How regulations restricting ISPs from offering enhanced network features might affect (a) total welfare, (b) network investment, and (c) the variety of content on the internet and content provider investment; (2) How prohibitions on network termination fees affect total welfare; and (3) How prohibiting ISPs from blocking content affects total welfare.

a. Effects of *ex ante* restrictions prohibiting features such as fast lanes on welfare⁴²

The literature finds that the welfare effects of prohibitions on features such as fast lanes depend on market conditions, such as whether ISPs are monopolies, how charges might be implemented, network engineering, customer valuation of content, and the types and variety of content provided on the internet. Most articles find that the *ex ante* regulations decrease welfare.

One of the earliest papers, Hermalin and Katz (2007) addresses the situation of a monopoly ISP that does not provide its own content, but provides network services to competing content providers and to consumers. (In contrast to most other papers, this paper analyzes transmission differences as quality differences as opposed to explicit fast lanes or paid prioritization.) The paper finds that *ex ante* regulations can either increase or decrease total welfare, but are most likely to reduce it: The restrictions lower total welfare when content providers who would prefer low-quality connections are excluded from the market because ISPs are not allowed to offer lower quality services, or when

⁴² Total welfare is generally defined as the sum of consumer surplus and producer surplus. Sometimes the surpluses are weighted, for example, by giving a certain amount of preference to consumers. Consumer surplus is the net value that consumers receive from consuming a product or products over and above what the consumers pay. Producer surplus is the revenue producers receive over and above their production costs. Some papers reviewed in this section use different definitions of welfare. Those instances are noted in the text.

content providers who would prefer high-quality service have to settle for lesser quality service. The paper finds similar conclusions for a duopoly ISP market.

Choi and Kim (2010) examines a situation where there is a monopoly ISP and two content providers that differ in the quality of their content. It allows only one content provider to purchase a fast lane. The research finds that *ex ante* regulation lowers welfare when content providers vary greatly in what they provide.

Njoroge et al. (2014) examines a situation where there are two ISPs and neither provides its own content. There is a large number of competing content providers that vary in the quality of their individual services and that receive money only from advertising. The paper assumes a content provider might connect directly to one ISP and then reach consumers that are connected to a second ISP, and that the second ISP might charge the content providers for reaching its consumers. The paper finds that if an ISP imposes fees on content providers that connect through another ISP, *ex ante* regulations lower total welfare. It also finds that such regulations can increase welfare if content providers vary greatly in the types of content that they provide.

Njoroge et al. (2014) finds that *ex ante* regulations lower total welfare, but can increase welfare if content providers vary greatly in the types of content that they provide. These results are different from those of Choi and Kim (2010) regarding the effects of content differentiation in part because Choi and Kim allows only one content provider to purchase the fast lane. Choi and Kim also assumes a monopoly ISP and that the ISP offers fast lanes by offering paid prioritization. Njoroge et al. assumes that the ISP offers separate fast and slow lanes. This is an example where technology choice matters to model results.

Most economic analyses assume that ISPs can vary the amount of bandwidth that they provide, which appears to align with actual ISP practice to choose network capacity based in part on the amount of traffic. In contrast, Economides and Hermalin (2012) examines a situation where there is a single ISP whose total bandwidth is fixed, the ISP does not provide its own content, and there is a large number of content providers, but each is a monopoly.⁴³ The paper states that *ex ante* regulations improve total welfare in monopoly situations, but appears to omit industry profits from the welfare calculation.

Economides and Tåg (2012) also makes an unusual assumption, namely that content providers may not necessarily benefit from advanced network features such as fast lanes. The paper considers both monopoly ISP and duopoly ISP situations where there are many content providers that obtain revenue from advertising and that differ in their costs of setting up their services. The model omits considering how ISPs might alter their investment and requires that all

⁴³ The assumption of monopoly content providers is unusual.

consumers purchase ISP service. The paper finds that the effects of *ex ante* regulations on total welfare depend on a variety of market conditions, but the paper restricts its welfare calculation to only the value of content. Economides and Tåg also finds that consumers are always worse off with *ex ante* regulations. In a related article, Caves (2012) uses the Economides and Tåg model and finds that such regulation decreases total welfare under the most common market conditions.

In a more generally applicable paper, Bourreau, Kourandi, and Valletti (2015) finds that *ex ante* regulations lower welfare. They assume there are two competing ISPs, which aligns with the situation in many US markets, and content providers vary in their preferences for fast lanes, which also seems appropriate.

Choi, Jeon and Kim (2015) find that the effects of *ex ante* regulations on welfare are sensitive to the degree to which content providers receive revenue from advertising versus payments from consumers for accessing content. This paper is more general in that it allows that content providers are heterogeneous in the value of their content and vary in how much they value fast lanes. Also, content providers receive revenue from advertising and may charge customers for accessing content. It examines monopoly and duopoly ISP markets and finds that it makes no difference as long as the ISPs determine interconnection charges and subscribers pay a single subscription price.

Reggiani and Valletti (2016) examines a situation where there is a single ISP and multiple content providers. Unusually, there is only one large content provider, which is defined as one that sells multiple applications. All other content providers are small and provide only a single application. An important feature of this paper is that the ISP charges a fixed price for prioritization and that prioritization is not a substitute for any other input that a content provider might use. These mean that buying prioritization is more profitable for the large content provider than for the small content providers. Therefore the effects of fast lanes are driven by the response of the large content provider. The finding is that *ex ante* regulations lower welfare if they lower content innovation, which the paper defines as the amount of content provided.

Greenstein, Peitz and Valletti (2016) offers a summary of the economics literature with respect to net neutrality and provides basic analyses to address the core issues. The paper shows that general *ex ante* restrictions on ISPs charging content providers (that depend on advertising for revenue) for access to consumers may increase or decrease total welfare, but the restrictions do result in higher consumer prices for ISP services. The paper also explains that if content providers charge customers for services, such as in the cases of Netflix and Amazon Prime, then the regulations decrease market efficiency if ISPs are able to charge different service fees to lower-value content providers than to higher-value content providers. The regulations can increase efficiency if ISPs are unable to

discriminate between content providers. Finally, the paper finds that recent theoretical contributions generally support the idea that *ex ante* net neutrality regulation on competing platforms is welfare decreasing, but states that this is an under-researched area.

b. Effects of *ex ante* restrictions prohibiting features such as fast lanes on investment

The literature gives mixed results, showing that the investment incentive is sensitive to how content providers and consumers respond to prices and to how consumers value content. Choi and Kim (2010) find that ISPs' incentives to invest depend on the value that customers place on network services relative to the value that some content providers might place on faster delivery speeds, so the effects of *ex ante* regulation is ambiguous.

Several models find that *ex ante* regulations lower ISP investment. These include Economides and Hermalin (2012), Njoroge et al. (2014), and Bourreau, Kourandi, and Valletti (2015). Reggiani and Valletti (2016) find that the regulations lower network investment if fast lanes stimulate content provision by a large content provider enough to overcome any decline in the number of small content providers, which the *ex ante* regulations would cause.

c. Effects of *ex ante* restrictions prohibiting features such as fast lanes on the variety of content on the internet and content provider investment

The literature gives mixed results. Most articles find that *ex ante* regulations lower content value when some content providers value the features that ISPs would offer absent the regulations.

Hermalin and Katz (2007) finds that *ex ante* regulations reduce the number and variety of content providers because regulations eliminate content providers that would prefer a lower quality service. It also finds that the regulations induce some content providers to buy a higher quality service than they would prefer, and others to purchase lower quality service than they would prefer. This lowers economic efficiency for those content providers.

Bourreau, Kourandi, and Valletti (2015) finds that *ex ante* regulations result in lower content innovations. Reggiani and Valletti (2016) finds that *ex ante* regulations lower the amount of content provided by a large content provider if its advertising fees are low relative to its content production costs and high relative to the smaller content providers' production costs. Greenstein, Peitz and Valletti (2016) describes how an ISP might price the enhanced service in such a way as to

exclude some lower-end content providers if lower-end and higher-end content providers would both pay for terminating their content.

Peitz and Schuett (2016) examines a situation where a monopoly ISP serves two types of content providers: Some that offer content whose quality suffers if delivery is delayed, while others whose quality is not sensitive to delay. The paper assumes that content providers can make investments to improve traffic management. The paper finds that *ex ante* regulations cause content providers to underinvest in technology that could efficiently manage the amount of traffic they put on the network. As a result, strict *ex ante* net neutrality restrictions often lead to socially inefficient allocation of traffic and traffic inflation in this paper.⁴⁴ *Ex ante* net neutrality regulations that would allow some differences in traffic treatment by ISPs do not necessarily improve the situation.

d. The effects on total welfare of regulations prohibiting ISPs from charging content providers for terminating traffic

This question has received little attention in the literature. Papers find that the effect depends upon how ISPs charge consumers and the value that customers obtain from content.

Musacchio et al. (2009) examines a situation with multiple ISPs of equal size, but each is a monopoly for its customer base. There are multiple content providers. It finds that *ex ante* regulations against such charging for terminating traffic lower total welfare in situations where consumers' price sensitivity to prices for clicks is low or high (as opposed to nearly the same) relative to content providers' charges for advertising. It also finds that the regulations can improve total welfare in situations where consumers' price sensitivity is nearly the same as content providers' charges for advertising.

Njoroge et al. (2014) finds the *ex ante* regulations lower total welfare in situations where an ISP imposes fees on content providers that connect through another ISP. Greenstein, Peitz and Valletti (2016) finds that restricting ISPs from charging termination fees reduces total welfare.

Boliek (2009) provides the only academic empirical study of the effects of net neutrality. The research addresses two questions. The first issue is whether wireless ISPs should be allowed to use consumption-based billing for residential consumers. This restriction is rarely included in net neutrality, but is sometimes mentioned. The second issue is whether ISPs can charge content providers for accessing customers, such as by charging termination fees. The paper found that regulation of prices was often associated with higher retail and wholesale prices,

⁴⁴ "Traffic inflation" means that the content providers underinvest in technologies that lower the amount of traffic that is needed to deliver their content.

and not with lower prices. This implies that *ex ante* regulation of terminating traffic prices could result in higher prices for consumers.

e. The welfare effects of regulations prohibiting ISPs from blocking content

Few economists have investigated this issue. In general the papers find that blocking content providers that customers want to access decreases welfare. *Ex ante* prohibitions on blocking improve total welfare in Economides and Hermalin (2012). Greenstein, Peitz and Valletti (2016) confirm this result.

Broos and Gautier (2017) examines a situation where there are up to two ISPs that compete for customers. The ISPs offer traditional phone service and internet service, and the phone service competes with an app that offers voice services over the internet (VoIP). It finds that the ISPs have incentives to exclude VoIP competes with the ISPs' own services. A monopoly ISP may want to exclude a competing internet app if the app is of inferior quality relative to the ISP's own service and if the ISP cannot ask for a surcharge for its use. However, this is not always profitable. In both the monopoly and duopoly situations, prohibiting the exclusion of the app and surcharges for its use has ambiguous effects on welfare.

4. Conclusion

The US debate about net neutrality has been unusually contentious for a telecommunications regulatory issue, especially given that all sides appear to have the same stated objective. The substantive difference appears to be over whether to apply *ex ante* or *ex post* regulations. On this, the economics literature gives varying answers regarding how *ex ante* and *ex post* regulations differ in their effects on welfare and investment. The assumptions of the models are key. But when the answer to the question of the effects of *ex ante* regulation is "it depends," and the scenarios that give different answers are realistic, it would seem that the policy decision should be in favor of addressing problems when they occur because *ex ante* regulations would clearly do some harm and *ex post* regulations, properly conducted, would do little harm. That appears to be an unacceptable answer for regulatory advocates.

Perhaps the persistence of contention arises from the way the issue entered the regulatory landscape. The US has a long history of dealing with the anticompetitive conduct of AT&T's regulated monopoly. The company took what could be viewed as extreme measures to protect that monopoly, including denying customers the opportunity to place even a plastic Hush-A-Phone cup on their

telephone receivers to block noise. The body of regulatory activity against AT&T provided the intellectual foundation for that Wu (2003) and others built upon for net neutrality, including device connection standards, drawing bright lines between telecommunications and enhanced services, and regulating wholesale pricing.

The advocates for an *ex post* approach, beginning with Yoo (2004), appear to adopt a post-monopoly mindset, emphasizing the dynamics of rapidly changing technologies, the value of customer choice, and diversity of situations.

Given the partisan nature of the issue, what happens next is likely to depend more on elections than on analysis.

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Net Neutrality and High-Speed Broadband Networks: Evidence from OECD Countries

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Abstract

Network neutrality regulations are intended to preserve the Internet as a non-discriminatory, public network and an open platform for innovation. Whereas the U.S. recently reversed its regulations, thus returning to a less strict regime, the EU has maintained its course and recently revised implementation guidelines for its strict and rather interventionist net neutrality regulations. To this day, there exist only a few U.S.-focused empirical investigations on the impact of network neutrality regulations, based on rather broad measures of investment activities. Our paper provides the first estimation results on the causal impact of net neutrality regulations on new high-speed (fiber-optic cable-based) infrastructure investment by Internet service providers (ISPs) and on related consumer subscription to fiber-based broadband connection services. We use a comprehensive OECD panel data set for 32 countries for the period from 2003 to 2019 and various panel estimation techniques, including instrumental variables estimation. Our empirical analysis is based on theoretical underpinnings derived from a simplified model in a two-sided market framework. Based on our theoretical analysis, we derive testable propositions for monopolistic and duopolistic ISPs. We find empirical evidence that net neutrality regulations exert a direct negative impact on fiber investments and an indirect negative impact on fiber subscriptions. Our results, which are in line with our theoretical propositions, strongly suggest that policymakers should refrain from imposing strict net neutrality regulations.

Keywords

Net neutrality, high-speed broadband, investment, consumer subscriptions, OECD panel data

JEL

L52; L96; L98

1 Introduction

What regulatory rules are required to preserve the Internet as a non-discriminatory, public network and a platform for innovation? For almost two decades, this question has been at the centre of one of the most protracted controversies in the history of modern telecommunications: the network neutrality debate. While the origins of the debate can be traced back to the late 1990s and discussions about open access, it was law scholar Tim Wu (2002, 2003) who coined the term ‘network neutrality’ and the underlying narrative that the codification of non-discrimination principles is necessary to safeguard an open Internet.

While there has never been a generally accepted definition of what network neutrality entails (Krämer et al., 2013), a continuum of interpretations and a variety of regulations have emerged over time. While proponents of network neutrality regulations argue that the introduction of such rules is imperative in order to prevent gatekeeping broadband Internet service providers (ISPs) from selectively discriminating against (unaffiliated) content providers (CPs) by means of unreasonable network management and/or pricing, opponents contend that such harmful behaviour cannot be expected. Rather, they argue, such regulations would unduly restrict the entrepreneurial freedom and lead to distorted investment decisions and innovation incentives. By 2015, after almost a decade of back-and-forth, both the EU and the U.S. had imposed strict forms of network neutrality regulations. Beyond imposing transparency rules, these regulations codified rules to prevent discriminatory behaviour and thus unreasonable network management. While some developed countries, like New Zealand and Australia, never implemented network neutrality regulations in the first place, the U.S. reversed their regulations in 2017, thus returning to a less strict regime based mainly on transparency obligations. The EU, however, has maintained its course and recently published the second version of its net neutrality implementation guidelines (BEREC, 2020).

In contrast to the strong visions embedded in strict network neutrality regulations in the EU and some other OECD countries, clear evidence of the impact of net neutrality regulation on firm decisions does not exist thus far. This is remarkable, as net neutrality regulations represent a major market intervention with unknown welfare effects for key economic stakeholders in the Internet ecosystem (CPs, ISPs, and end-users). Numerous theoretical contributions from economists have examined the welfare-related effects of different features of net neutrality regulations (Greenstein et al., 2016; Easley et al., 2018). However, there

exist only very few (and only U.S.-based) empirical investigations with rather broad measures of network investment. This paper tries to close this gap by providing first empirical results concerning the causal impact of net neutrality regulations on ISP platforms' investment using a comprehensive and recent OECD panel data set for 32 countries spanning the period from 2003 to 2019. Our main dependent variables measure (input-oriented) investment activities by ISPs in terms of newly installed fiber-based broadband connections and (output-oriented) subscriptions by users who show sufficient willingness to pay for fiber-based broadband connections at home or at business in order to access new content. To obtain our main variable of interest, i.e., net neutrality regulations implemented in a particular OECD country, we reviewed past regulatory decisions and constructed indicator variables measuring the year of implementation of net neutrality regulations as well as the year of the first official announcement of intended measures in proposals or other official draft documents.

In order to identify causal effects, we employ panel data estimation techniques, including instrumental variables. We first argue that decisions to implement or withdraw net neutrality regulations have been made by politicians who do not observe on a day-to-day basis relevant market outcome variables, but rather decide according to ideological and partisan views and in light of bureaucratic goals. We then relax the assumption that net neutrality regulations are uncorrelated with idiosyncratic error terms and re-estimate our empirical specification using two-stage least square estimation. Since net neutrality regulations have been implemented on the basis of political decisions, political economy variables should have strong predictive power. Accordingly, we employ measures of political orientation, government intervention, and the international state of net neutrality regulations as exogenous sources of variation.

In view of the core arguments of net neutrality proponents and opponents, as well as the main trade-offs identified in the economics literature, we aim to investigate two research questions: i) Do net neutrality regulations lower the incentives of ISPs to invest in new network infrastructure (as suggested by net neutrality opponents)? ii) Do net neutrality regulations stimulate subscriptions by consumers and hence boost utilization of innovative services and applications (as suggested by net neutrality proponents)?

We find that net neutrality exerts a negative impact on both fiber investment as well as on consumers' willingness to subscribe to new services as reflected by the number of fiber connections actually subscribed

to. In view of the substantial transaction costs and market distortions associated with net neutrality regulations, this empirical result – which is in line with our theoretical propositions – casts serious doubts on the current regulations imposed in Europe and other developed countries and raises new questions in the currently reemerging debates on reimposing net neutrality regulations in the U.S. The growing essentiality of general-purpose broadband platforms for participation and success of consumers and firms and the considerable externalities they generate across a wide range of sectors of the economy (Czernich et al., 2011; Akerman et al., 2015) emphasize that our results have broad and profound implications.

The remainder of this article is structured as follows. Section 2 provides an overview of the related theoretical and empirical literature. Section 3 then discusses the relevant institutional background and provides a description of net neutrality regulations and historical developments, with a special focus on the EU and U.S. Section 4 provides a simple two-sided Hotelling model and derives testable propositions. Section 5 then outlines our empirical specification and identification strategy. Section 6 characterizes our OECD panel data set. Section 7 discusses our main estimation results, while the final section concludes with a review of our main findings and most relevant policy implications for the ongoing debate.

2 Review of the economic literature

Economists approached the topic of network neutrality regulations somewhat belatedly. Scholars from other fields, such as law and computer science, had recognized the relevance of the topic earlier (Faulhaber, 2011). In the meantime, however, a considerable body of theoretical economic literature has formed. Acknowledging the large amount of literature, which has been summarized in several surveys, we briefly review the main findings from related economic theory models based on two-sided market frameworks in Section 2.1. In contrast, the empirical literature is still very scant, and is reviewed comprehensively in Section 2.2. In summarizing, we identify the main research gaps in Section 2.3.

2.1 Theoretical contributions

A majority of the theoretical economic literature explores the impact of network neutrality regulations on market outcomes by applying game-theoretical analyses in the context of two-sided market frameworks. While typically investigating the effects of vertical control by ISPs, this literature conceptualizes network

neutrality regulations as strict forms of ex-ante market interventions—either imposing traffic regulations that instate an egalitarian regime in which ISPs are legally obliged to treat all traffic equally, or else banning ISPs from charging CPs termination fees (i.e., positive prices for the delivery of content and applications to end-users). The impact of network neutrality regulations is then assessed based on the comparison of two different scenarios. One presents a ‘neutral’ best effort scenario in which strict network neutrality is legally enforced and ISPs offer a single best-effort service to all CPs. Price and quality differentiations are excluded. This scenario is compared with a second one in which ISPs can deviate from the best-effort service model. In addition to a best-effort-type basic and free service class, ISPs offer CPs prioritized traffic delivery via a premium service class against a fee. In these model frameworks, ISPs can – absent network neutrality regulations – freely enter into contractual agreements with CPs.

Schuett (2010), Faulhaber (2011), Krämer et al. (2013), Greenstein et al. (2016), Easley et al. (2018), and Jamison (2019) provide excellent reviews of this strand of literature. The model approaches typically assume imperfect competition and market structures characterized by monopolistic or duopolistic ISPs, which act as gatekeepers between CPs on one market side and end-users on the other. While the models explore different trade-offs related to market outcomes like social welfare, network investment, (content) innovation, and consumer prices, they vary with regard to the underlying modelling assumptions (e.g., concerning revenue models or traffic architectures and whether or how congestion and traffic stochastics are taken into account) and the market structures on the CP market side and the market for ISPs. For example, Bourreau et al. (2015) analyze how the change from a strict network neutrality regime to a ‘discriminatory regime’ impacts social welfare, ISPs’ investments, and CPs’ innovation. Examining the case of two competing and horizontally differentiated ISPs and heterogeneous CPs, the authors find that removing a strict net neutrality regime would lead to higher ISP investments, more innovation by CPs, and increased social welfare. Choi and Kim (2010) examine investment under a strict network neutrality regime. The authors consider a monopolistic ISP and duopolistic CP market in a Hotelling framework and find that capacity expansion might decrease the sale price of the priority right under the discriminatory regime, leading to ambiguous effects on ISPs’ investment.

All in all, the existing theoretical literature presents ambiguous results. While in some papers the impact of network neutrality regulations on incentives for network investment and content innovation varies, in some

other analyses (see the overview in Easley et al., 2018, Table A.1 at pp. 268-270 show that network neutrality regulation might have a negative effect on social welfare depending on the overall relevance of ISPs and CPs on social welfare.

2.2 Empirical contributions

Table 1 provides an overview of the available empirical evidence. Most contributions are based on U.S. data and investigate the impact of net neutrality regulations on network investment. Existing evidence is mostly based on U.S. data using (too) broad measures (such as CAPEX) for investment, which are only indirectly impacted by net neutrality regulations. With the exception of Hooten (2019), who finds insignificant effects, all other contributions find a negative impact of such regulations on network investment, which is also broadly in line with the theoretical analysis.¹ Only Lee and Kim (2014), as well as Layton (2017), use non-U.S. based data – from South Korea and two EU countries (Denmark and the Netherlands), respectively – to examine the impact on content innovation and social welfare. Due to this limited number of investigations, however, there is no conclusive evidence with respect to these outcome variables.

2.3 Research gaps

Reliable empirical evidence on the various channels of net neutrality regulation is very limited, even more when focusing on empirical studies with a reliable identification strategy. The few empirical contributions concerning the impact of net neutrality regulations on investment point to a negative effect. There is no conclusive evidence so far regarding the impact on content innovation or on other relevant output measures such as subscriptions of high-speed broadband connections. None of the empirical contributions provides a treatment of the theoretical underpinnings of the net neutrality regime under research. Given the high direct costs of implementing, monitoring, and enforcing net neutrality regulations and the indirect costs related to potential market distortions, the current state of research raises serious concerns with respect to the related welfare effects of net neutrality regulations. Our paper aims to fill these research gaps in answering our research questions.

¹ This empirical result also corresponds well with the related empirical broadband literature, finding a negative effect of access regulation on the network investment of ISPs (Grajek & Röller, 2011; Briglauer, 2015; Briglauer et al. 2018).

Table 1: Empirical contributions concerning the impact of net neutrality regulations

Author(s)	Methodology	Data	Time dimension	INVEST	INNOV	WF
Ford et al. (2010)	Event studies, OLS regression analysis	Firm-level data Stock returns of U.S. ISP operators	Several dates in May 2010:	-	n.c.	n.c.
Nurski (2012)	Structural estimation modelling	UK household data on ISP and online content	2009	n.c.	n.c.	-
Lee and Kim (2014) ¹⁾	Demand estimation based on simulation models	Micro-level data Survey of 500 South Korean Internet users	2012	n.c.	n.c.	-
Hazlett and Wright (2017) ²⁾	Descriptive and OLS regression analysis	Industry-level data U.S. broadband network investments	1996–2014	-	n.c.	n.c.
Layton (2017) ²⁾	Descriptive and OLS regression analysis	Micro-level data App downloads per day in Denmark (DK) and in the Netherlands (NL)	Selected days in 2011, 2012, 2016	n.c.	-	n.c.
Ford (2018)	Difference-in-Difference regression analysis	Industry-level data Investment in the U.S. telecom sector and selected control industries	1980–2016	-	n.c.	n.c.
Hooten ³⁾ (2019)	Difference-in-Difference regression analysis	Firm-level data Investment in the U.S. telecom sector and selected control industries	2009–2018	~	n.c.	n.c.
Tudón (2019) ⁴⁾	Structural estimation modelling	State of Amazon's Twitch.tv each 10 minutes during 90 days of 2014	Several dates in 2014	-	+	-

Key: Outcome variables: (i) network investments (INVEST); (ii) content innovation (INNOV); (iii) total welfare (WF). Positive and negative impacts of net neutrality regulations on the outcome variables are presented as „+“ and „-“, respectively. Mainly positive and mainly negative impacts are presented as „+/-“ and „-/+“, respectively. „~“ symbolizes insignificant results in these contributions. „n.c.“ (no conclusions) means that the impact on the respective outcome variable is not examined. OLS: ordinary least squares.

Notes: ¹⁾ Simulation model #6 examines the impact of net neutrality regulations; simulation-based models, however, do not classify as empirical analysis in a narrower sense. ²⁾ Authors do not provide an identification strategy. ³⁾ Published contribution is currently subject to expression of editorial concern and under further revision. ⁴⁾ Author shows that a shift to neutrality lowers to net neutrality and ISP's incentive to invest. Net neutrality encourages content provision but also increases congestion and lowers consumer surplus.

Source: Own presentation.

3 Institutional background

3.1 Scope of net neutrality regulations

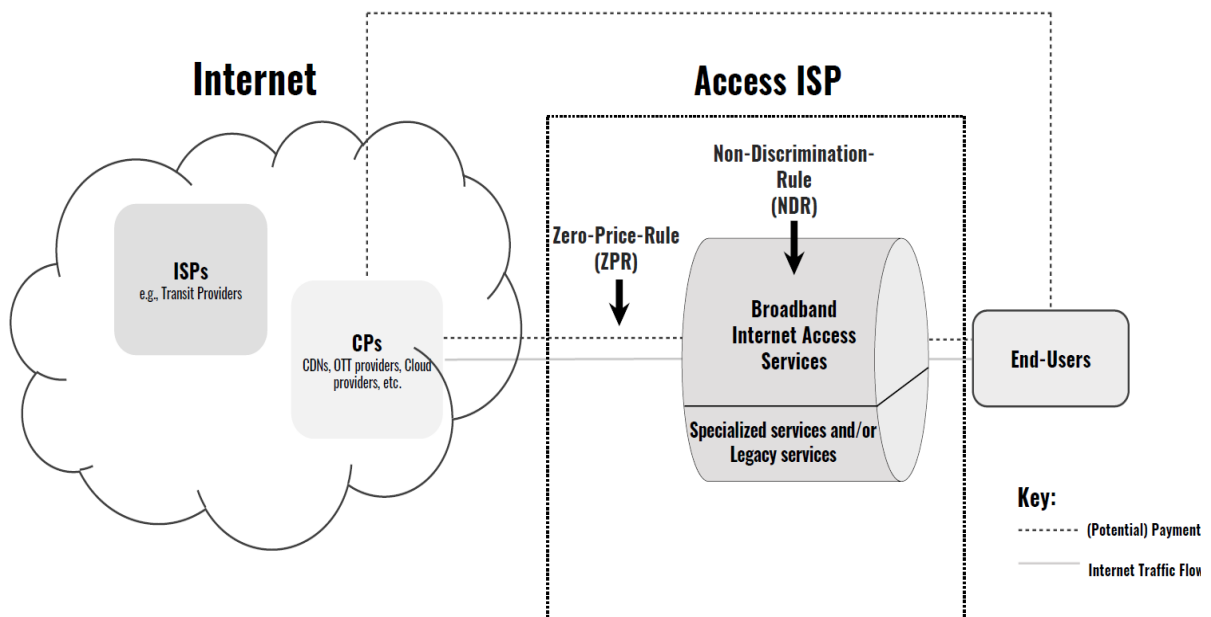
Beyond imposing transparency requirements, network neutrality regulations codify conduct rules for the Internet to safeguard non-discrimination in, and the openness of, the public Internet. For the sake of preventing access ISPs from discriminating against unaffiliated CPs (e.g., through the blocking of lawful content, throttling of traffic of unaffiliated CPs, or paid prioritization), these regulations introduce traffic rules that draw a dividing line between reasonable and unreasonable and thus prohibited forms of network management and pricing. Conceptually, such regulations have been understood to entail a ‘non-discrimination rule’ (NDR) and a ‘zero pricing rule’ (ZPR) (Schuett, 2010, pp. 1-2). The NDR implies an egalitarian traffic regime in which there is no traffic prioritization. It is intended to prevent network management practices by ISPs that could be used to discriminate against the content of specific CPs based on the selective treatment of affiliated CPs or the degradation of non-affiliated CPs. The ZPR implies that ISPs must not charge CPs a termination fee for the (prioritized) delivery of traffic.

Modern broadband platforms support the delivery of more than just access to the Internet. Relevant capacities are shared between different types of services. Broadly speaking, one can distinguish between three distinct service types (Stocker, 2020). First, there are (non-IP) legacy services like voice telephony or cable television service. These services are not IP-based and are not considered Internet services. They are not subject to network neutrality regulations. Second, there are broadband Internet access services. These services provide end-users (or consumers) with global Internet connectivity. They facilitate access to the global Internet population and the evolving range of content of the public Internet. This service category constitutes the focal point of the regulatory intervention of network neutrality rules, which restrict the entrepreneurial freedom of ISPs to negotiate on the basis of price and quality differentiation in contractual agreements with CPs regarding the delivery and/or pricing of content and application services. Third, there are specialized services. Although similar in many respects to broadband Internet access services, other IP-based services (i.e., specialized services) are exempt from the same rules. These services are ‘private’/‘closed’ and available only to a subset of the Internet population. Inherently application-specific, they often rely on the heavy use of network management so that their often-stringent delivery requirements in terms of

different application services or use cases (e.g., IPTV, VoIP, or machine-to-machine communications IoT use cases) can be met in a customized fashion. The emergence of 5G and the rise and evolution of clouds (e.g., content delivery networks, CDNs) further imply that growing numbers of servers – and thus content, applications, and computing resources – are being moved closer to end-users. Servers might even be deployed within the networks of access ISPs, thus rendering corresponding services private, intra-ISP services. As this shows, the line between what is considered public Internet or private networking, and the distinction between services that are subject to the rules and those that are not, are becoming increasingly blurred (Stocker et al., 2020).

Figure 1 below illustrates the main market players involved, traffic flows, as well as actual and potential payment streams subject to net neutrality regulations. ZPR and NDR rules apply only to access ISPs and more specifically to the ‘Broadband Internet Access Services’ they offer.

Figure 1: Network neutrality, market players, and payment streams — A stylized illustration



3.2 A concise history of net neutrality regulations in the EU and the U.S.

The first efforts to impose network neutrality in the U.S. can be traced back to a set of guiding principles for the conduct of ISPs that was presented in 2005 (FCC, 2005). In 2010 the FCC adopted its Open Internet Order (OIO), instating transparency regulations and a regulatory market split: broadband Internet access services were subject to strict conduct rules while other IP-based services (i.e., specialized services) were

exempt from these rules. A court decision found in 2014 that the FCC lacked the authority to implement such rules. This decision motivated subsequent efforts by the FCC – dominated by a Democratic majority – to reclassify relevant broadband services as a ‘telecommunications service’, thus assuming the authority to impose common carriage, utility-style regulation. In 2015, the FCC adopted the new Open Internet Order (FCC, 2015), which instated this reclassification as well as three net neutrality rules (no blocking, no throttling, no paid prioritization) and a general conduct rule to impose a non-discrimination standard. With President Trump taking office in 2017, and a shift in party majority within the FCC, the reclassification decision and strict network neutrality rules of the 2015 OIO were reversed in 2018 (FCC, 2018). The order is still active but has become the subject of debate once again under President-elect Biden.

Initially, the regulatory stance towards network neutrality was fundamentally different in the EU. The revised regulatory telecoms framework of 2009 contained a Declaration on Network Neutrality and introduced a set of comparatively soft regulations to deal with network neutrality issues via transparency rules (EC, 2009). After a series of member states began to consider the introduction of national network neutrality regulations, with Slovenia and the Netherlands introducing national legislation, the European Commission changed course. Arguably driven by the intent to prevent regulatory fragmentation within the Digital Single Market (Marcus 2016, pp. 265-270), in 2013, the EC issued a proposal for a regulation that subsumed network neutrality regulations, aiming to implement enhanced transparency rules and a regulatory market split that contained strict network neutrality regulations. In 2015, Regulation (EU) 2015/2120 (European Union, 2015) was adopted. It reinstated harmonization among net neutrality regimes within the EU member states. In the fall of 2016, BEREC, the Body of European Regulators for Electronic Communications, released their first guidelines for the implementation of the regulations (BEREC, 2016), which have been revised in the meantime (BEREC, 2020). The regulation is still in force, which marks a fundamental difference from the situation in U.S. for the years from 2017–2020.

In contrast to the U.S. and the EU, other developed countries, like New Zealand and Australia,² have never imposed strict network neutrality regulations.

² Information available at: <https://www.crowninfrastructure.govt.nz/ufb/what/> and <https://www.nbnco.com.au/corporate-information/about-nbn-co>.

4 A simplified theoretical model

In the following, we develop a simple two-sided market model to theoretically examine the impact of net neutrality regulations on ISPs' investment incentives and consumers' decision to subscribe to high-speed (fiber-based) broadband connections in order to benefit from innovative services. Our model builds on the model developed in Economides and Tåg (2012) and expands it to incorporate ISP investment to upgrade the network by further deploying fiber-optic cable infrastructure in the access network. Such network investments increase quality characteristics of broadband services and applications. They also allow CPs to offer better service experience and more content to end-users. A series of relevant papers on net neutrality (Choi and Kim, 2010; Hermalin and Katz, 2012; Bourreau et al., 2015) modelled ISP incentives to invest as an effort to reduce congestion. In these papers, investment that reduces congestion increases the perceived value of the service to end-users. We, however, model investment that directly enhances the quality of the service for end-users without modelling congestion. Our model however is only partial with respect to existing ones, since we do not specifically address the role of competition on CPs' side which is outside the scope of our empirical analyses. Moreover, we do not aim at developing a fully fledged welfare analysis on the impact of net neutrality regulation. Both these extensions have been already provided in the existing literature and we will thus reconcile our results with the existing ones at the end of this Section. . In sum, we simplified and tailored our model so that it is sufficient to evaluate the impact of net neutrality regulations on the ISPs' incentives to invest in new broadband capacities and on the consumers' decision to subscribe to fiber-based connections. Based on our model we formulate testable hypotheses on these impacts.

We first model a monopolistic ISP platform provider of a two-sided market. In a next step we model a duopolistic platform, which has become a more realistic market structure in several (but not all) countries since liberalization was initiated some two decades ago (the analysis is provided in Appendix A). The platform (in our setting, a monopolistic telecom incumbent operator/a duopoly formed by incumbent and another operator, e.g., cable TV operators) sells broadband access to consumers at a subscription price p and possibly collects a fee a from each CP. We can interpret a as the fee a CP must pay in order to secure a certain amount of capacity to spread its content over the Internet. By contrast, in the presence of a net

neutrality regime (under the terms of the ZPR),³ CPs do not pay any fee a and so they can use the network freely, while in absence of regulations the fee a is uniformly applied to all CPs.⁴ This setting corresponds to the most basic definition of net neutrality regulations in the economic literature presented in Section 2, according to which any kind of payments from CPs to ISPs are prohibited in the local access network (see Figure 1 and Greenstein et al., 2016, p. 128). Without loss of generality, we assume that the cost of providing the platform per consumer is normalized to 0.

We use a standard Hotelling model as extended to a two-sided framework by Armstrong (2006). On the consumers' side, each consumer i is located in x_i for accessing new broadband services through the ISP and interacting with the CPs. Consumers pay a transportation cost equal to $t = 1$ per unit of distance "traveled". Consumers' locations are uniformly distributed on the interval zero to one with the platform located at $x = 0$. Consumer i 's utility is given by:

$$U_{ci} = v + \varphi + \beta * n_{cp} - p - x_i \quad (1)$$

where v is an intrinsic value that a consumer receives from subscribing to a broadband connection provided by an ISP, irrespective of the amount of content.⁵ Broadband access, however, also provides access to numerous new services and applications offered by independent CPs. β is the marginal value that a consumer places on an additional CP and n_{cp} is the number of active CPs. The utility of consumers increases if the platform decides to invest in higher broadband access capacities, φ . More investment by the platform generates better connection quality or provides an improved capacity to be used to consume new or greater

³ Note that in our simplified setting CPs are not heterogeneous, i.e. they do not differ in terms of quality of contents provided or in their ability to match consumers' preference. Hence, in our approach discriminating CPs with paid prioritization is equivalent to applying an access fee a that fully extract all CP's profit.

⁴ This assumption – in line with Economides and Tåg (2012) – simplifies the analysis. For a more general model where the platform can price discriminate across CPs according to the degree of prioritization obtained and the impact of such net neutrality violations on the CPs' market, see Kourandi al. (2015). In this paper, we abstract from this case since our main focus is related to the platforms' incentives and not on CPs' decisions.

⁵ The parameter v can thus be interpreted as an option value for having a connection and thus being able to get access to a range of services and contents.

volumes of content, increasing the value of the connection. For example, switching from basic broadband to a high-speed (fiber-based) broadband connection may induce consumers to use new services like Netflix, Amazon Prime, or Disney+, or to consume other content requiring higher capacity levels, such as YouTube, Instagram, or Facebook.

CPs rely on advertising revenue per consumer, α , to generate revenue. As in Economides and Tåg (2012), we first assume that CPs are independent monopolists in their own market segment and are uniformly distributed on the unit interval with unit mass.⁶ Each CP thus obtains revenues equal to αn_c , where n_c is the number of consumers paying the platform for access to CPs. The parameter α can thus be interpreted as the value for a CP of having an additional consumer connected to the network. CPs are heterogeneous in terms of their cost to create new content. Assuming this cost to be equal to c , each provider indexed by j thus faces a cost equal to cy_j , where y_j is the index of the CP's location on the unit interval. As for consumers, the same normalization to 0 holds for the (marginal) cost incurred by each CP for serving advertisements to consumers. In presence of net neutrality regulations, CPs do not pay any fee for using the network. Conversely, if net neutrality regulations do not apply, each CP must pay the platform a uniform lump sum fee equal to a to gain access to users. Thus, a CP j 's profit is:

$$U_{CP_j} = \alpha * n_c - cy_j - a \quad (2)$$

Finally, the ISP profit function is given by:

$$\Pi_{ISP} = pn_c + an_{cp} - \frac{\varphi^2}{2} \quad (3)$$

In the case of net neutrality, $a = 0$, and thus there are no revenues from CPs. $\varphi^2/2$ is the quadratic investment cost for upgrading the access network from basic to high-speed broadband connections. This functional form means that investment cost is increasing and convex, implying that if an ISP decides to expand the fiber-based coverage in a country, the investment costs increase more than proportionally. Thus, we capture

⁶ In our simplified setting, since the focus of our empirical analysis is on ISPs' investment incentives, we assume that CPs do not compete with each other and for this reason, they do not, for example, set subscription fees for end-users. For a more general model with competitive CPs, see Bourreau et al. (2015).

the real difference in broadband deployment costs in case an ISP wants to expand its network from low-cost urban areas to more costly suburban and high-cost rural areas (Briglauer et al., 2018).

The structure of the game is as follows: first, the ISP decides how much to invest (φ) in increasing the quality of the existing network; then, the ISP sets the price p end-users must pay to subscribe to high-speed broadband connections, as well as the fixed fee a for CPs; lastly, end-users and CPs decide whether or not to access the upgraded ISP network.

4.1 Equilibrium in the case of net neutrality regulations (NNR)

Under net neutrality regulations, CPs do not pay any fee to the ISP platform. In this case, marginal consumer x_i , who is indifferent on the question of subscribing vs. not subscribing, is located at:

$$\bar{x}_i = n_c = v + \varphi + \beta * n_{cp}^e - p \quad (4)$$

The marginal CP, who is indifferent on the question of being active or leaving the market, is given by:

$$\bar{y}_j = n_{cp} = \frac{\alpha * n_c^e}{c} \quad (5)$$

where n_c^e and n_{cp}^e are the expected number of consumers and CPs, respectively. As in Economides and Tåg (2012), we look for fulfilled expectations equilibria where each side's expectations are fulfilled and thus $n_c^e = n_c$ and $n_{cp}^e = n_{cp}$. Simultaneously solving equations (4) and (5) yields:⁷

$$n_c(p, \varphi) = \frac{c(v + \varphi - p)}{c - \alpha\beta} \quad (6)$$

$$n_{cp}(p, \varphi) = \frac{\alpha(v + \varphi - p)}{c - \alpha\beta} \quad (7)$$

Note that the higher the platform investment φ , the higher the number of users who decide to connect to the network and the higher the number of CPs who are active in the market. Thus, ISP investment leads to

⁷ Positivity conditions dictate that $\alpha\beta < c$, implying that the cross-side externalities should not be too strong; and $v > p - \varphi$. For ensuring that the second order conditions hold, we further assume that $\alpha\beta < c/2$, again implying not too strong network externalities and/or relatively high fixed costs c for content creation.

an increase in users' demand and this, in turn, positively motivates CPs to enter the market, thereby leading to more content for users.

Moving to the profit of the ISP, we have:

$$\Pi_{ISP}(p, \varphi) = n_c(p, \varphi)p - \frac{\varphi^2}{2} = \frac{c(v + \varphi - p)}{c - \alpha\beta}p - \frac{\varphi^2}{2} \quad (8)$$

The ISP provider first sets the user price p that maximizes its profit:

$$\frac{\partial \Pi_{ISP}}{\partial p} = \frac{c(v + \varphi - 2p)}{c - \alpha\beta} = 0$$

$$p_{NNR}(\varphi) = \frac{v + \varphi}{2} \quad (9)$$

In the second stage equilibrium, users' demand becomes:

$$n_c(\varphi) = \frac{c(v + \varphi)}{2(c - \alpha\beta)} \quad (10)$$

Moving to the investment incentives, we have:

$$\Pi_{ISP}(\varphi) = \frac{c}{c - \alpha\beta} \frac{(v + \varphi)^2}{4} - \frac{\varphi^2}{2}$$

The optimal level of investment under the net neutrality rule is thus given by:⁸

$$\varphi_{NNR} = \frac{cv}{c - 2\alpha\beta} \quad (11)$$

Note that as the optimal investment level rises, there is a corresponding increase in users' willingness to pay for having the Internet connection. Moreover, as the investment increases, the value of an additional consumer for CPs, α , goes up, as does the value of an additional user for CPs, β .

⁸ The optimal condition applies when cross-side externalities among the two sides are not too strong, i.e., when $\alpha\beta < c/2$.

Finally, given (10) and (11), in equilibrium, the number of consumers subscribing to the platform is:

$$n_{c_NNR} = \frac{cv}{c - 2\alpha\beta} \quad (12)$$

4.2 Equilibrium in the absence of net neutrality regulation

Assume now that the ISP can charge a fixed fee a to CPs for being active in the market. Following the same steps shown in the previous paragraph, the users' and CPs' demands are given by:

$$n_c(p, a, \varphi) = \frac{c(v + \varphi - p) - \beta a}{c - \alpha\beta} \quad (13)$$

$$n_{cp}(p, a, \varphi) = \frac{\alpha(v + \varphi - p) - a}{c - \alpha\beta} \quad (14)$$

The profit function of the ISP is given by:

$$\Pi_{ISP}(p, a, \varphi) = n_c(p, a, \varphi) * p + n_{cp}(p, a, \varphi) * a - \frac{\varphi^2}{2}$$

or equivalently

$$\Pi_{ISP}(p, a, \varphi) = \frac{c(v + \varphi - p) - \beta a}{c - \alpha\beta} * p + \frac{\alpha(v + \varphi - p) - a}{c - \alpha\beta} * a - \frac{\varphi^2}{2} \quad (15)$$

Since p and a are set simultaneously, their optimal value is given by the following first order conditions:

$$p^* = \frac{c(v + \varphi) - a^*(\alpha + \beta)}{2c}$$

$$a = \frac{\alpha(v + \varphi) - p^*(\alpha + \beta)}{2}$$

The optimal monopolistic prices in the absence of net neutrality regulations are given by the following:⁹

⁹ Using assumptions similar to those used by Economides and Tåg (2012), we presuppose that $2c - (\alpha + \beta)^2 > 0$, implying that cross-group externalities are not too strong or, equivalently, that consumers and CPs are sufficiently

$$p^*(\varphi) = \frac{(v + \varphi)(2c - \alpha(\alpha + \beta))}{4c - (\alpha + \beta)^2} \quad (16)$$

$$\alpha^*(\varphi) = \frac{c(v + \varphi)(\alpha - \beta)}{4c - (\alpha + \beta)^2} \quad (17)$$

Note that CPs pay a positive fee $\alpha^*(\varphi)$ if and only if $\alpha > \beta$, that is when the value of an additional user for CPs is larger than the value of an additional CP for users. By contrast, in the case that $\alpha < \beta$, the ISP would subsidize the CPs for using its platform. In the sub-game equilibrium, the users' and CPs' demands become:

$$n_c(\varphi) = \frac{2c(v + \varphi)}{4c - (\alpha + \beta)^2} \quad (18)$$

$$n_{cp}(\varphi) = \frac{(\alpha + \beta)(v + \varphi)}{4c - (\alpha + \beta)^2} \quad (19)$$

Substituting the optimal conditions in (16) and (17) into (15), we obtain the ISP profit as function of the investment level φ :

$$\Pi_{ISP}(\varphi) = \frac{c(v + \varphi)^2}{4c - (\alpha + \beta)^2} - \frac{\varphi^2}{2}$$

Deriving the last condition with respect to φ , we obtain the following optimal level of investment in an unrestricted monopoly without net neutrality regulations:

$$\varphi^* = \frac{2cv}{2c - (\alpha + \beta)^2} \quad (20)$$

Again, note that the optimal investment level positively depends on users' willingness to pay v for subscribing to broadband connections, and also on the value of any additional CP or user, respectively α and β , for the other side of the market. Hence, the higher the cross-side effects between the two sides of the market, the larger the investment incentives of the ISP platform.

differentiated. This condition is more stringent than the one for ensuring a positive subscription price but it is necessary in order to guarantee that the second order conditions be satisfied.

By comparing the different investment levels under net neutrality regulations (11) and in the presence of an unrestricted monopoly (20), it is possible to verify that $\varphi_{NNR} < \varphi^*$ for any constellation of parameters c, α and β that satisfies the above conditions.¹⁰ Intuitively, by charging the CPs, the number of CPs in principle decreases. However, the ISP platform can lower its retail price for users and expand its user base by investing in higher quality infrastructure. In so doing, the ISP platform is able to attract more users that in turn, via the cross-side effects, positively affect the number of CPs entering the market. All in all, this implies that granting flexibility to the ISP in terms of providing paid access to its platform to CPs not only increases its revenue stream, but also attracts more users, thus increasing the number of CPs entering the market and incentivizing the ISP's network expansion.

Finally, the number of users subscribing to the platform is in equilibrium:

$$n_c^* = \frac{2cv}{2c - (\alpha + \beta)^2} \quad (21)$$

By comparing equation (21) with equation (12), again it comes out that $n_c^* > n_{c_NNR}$ always holds.

We can now recap the main results of our analysis of the case of a monopolistic platform ISP in the following Propositions 1 and 2:

Proposition 1: *For the ISP platform, being allowed to charge CPs for the use of the network unambiguously enhances its investment incentives. Moreover, the greater the willingness to pay among users, the higher the platform investments.*

Proposition 2: *The number of subscribers to the platform, i.e., the users' subscriptions to the high-speed broadband connection, is unambiguously higher when net neutrality regulations are not applied.*

In Appendix A, we further extend our baseline model to a duopolistic setting, i.e., to the presence of two competing ISP platforms. Users buy broadband access from one platform only (i.e., they single-home), while CPs are assumed to sell their contents through both platforms (i.e., they multi-home). The results show that if CPs value additional users more highly than end-users value additional CPs (i.e., $\alpha > \beta$), not

¹⁰ Indeed, we have to verify that $\frac{2cv}{2c - (\alpha + \beta)^2} > \frac{cv}{c - 2\alpha\beta}$. It results in $2(c - 2\alpha\beta) > 2c - (\alpha + \beta)^2$, implying $(\alpha + \beta)^2 - 4\alpha\beta = (\alpha - \beta)^2 > 0$ which is always true for any values of α and β .

only will the platforms charge CPs a positive price for accessing users, but the ISP platforms will unambiguously invest more in the absence of net neutrality regulations. Proposition 3 recaps these results:

Proposition 3: *In the presence of competing ISP platforms, if $\alpha > \beta$, being allowed to charge CPs for use of the network unambiguously enhances its investment incentives. However, when α is very low (i.e., $\alpha < \bar{\alpha} < \beta$), net neutrality regulations provide more incentive for ISP platforms to invest than in the absence of any restrictions.*

Intuitively, in the presence of unrestricted duopolistic competition, ISP platforms compete not only to attract users but also to attract CPs. In order to do so, investing in high-speed broadband infrastructure is fundamental to providing more capacity to both users and CPs, thus increasing market share. More intense competition attracts more users and this, in turn, attracts more CPs via cross-side externalities, especially when the value of an extra user for CPs is larger than the value of an extra CP for users ($\alpha > \beta$). Conversely, when α is very low (i.e., $\alpha < \bar{\alpha} < \beta$), competition between platforms becomes too intense because not only do they want to attract users, but they must also subsidize CPs to provide their services through their own platforms. Hence, revenues decrease considerably for ISPs and investing in better infrastructure becomes less beneficial because, although doing so attracts more users, the cross-side effect on CPs is quite limited.

Before concluding, it is worth mentioning that our focus – in line with our empirical goal – is to focus on ISPs’ incentives to invest. Of course, in absence of net neutrality regulation, CPs are asked to pay an access fee for accessing the network and in turn this policy may affect CPs’ profits and incentives to invest in content quality. As already shown in the literature (Bourreau et al., 2015) indeed while the absence of regulation may foster ISPs’ incentives, it may be detrimental for CPs’ ones diluting their incentives to improve their contents. Overall, the literature shows that clear cut results on the social preference of the presence or absence of net neutrality regulations depend on the comparison between these countervailing incentives and ambiguous results might emerge. Still, we do not aim to assess the overall welfare effect of such a policy, but only its main impact on ISPs’ investment incentives, as we will do in our empirical analysis in next Sections.

5 Regression framework

5.1 Empirical specification

In order to test Propositions 1 to 3 and answer our research questions, we estimate empirical models of investment in new (fiber-based) broadband access capacities (*fiber_inv*) and demand for new content in terms of consumers showing sufficient willingness to pay for these services and actually subscribing to fiber-based connections (*fiber_sub*) under a commercial contract. Note that the subscription decision depends on new content innovation as willingness to pay for the “fiber-premium” is determined by the incremental benefit consumers derive from innovative applications and services that can be delivered only via high-speed broadband Internet access. Considering the relationship between fiber investment and fiber subscription, the former is logically a pre-condition for the subscription decision. Whereas the consumer’s subscription decision does not depend directly on *NNR*, implementing *NNR* indirectly exerts an impact on fiber subscription by affecting ISP investment incentives (see equations (10) and (18)). Hence, in view of our theoretical model, the fiber subscription function f can be written in generic form as:

$$fiber_sub = f \{ \text{intrinsic value of fiber-based subscription } (\nu); \text{ content and service value for consumers } (\beta); \\ \text{fiber investment } (\varphi); \text{ advertising revenue per consumer } (a); \text{ cost to create new content } (c) \}$$

Our empirical estimation equations for fiber investment and fiber subscription for OECD country i in year t read as follows:

$$\ln(fiber_inv_{it}) = \alpha_0 + \alpha_1 \ln(fiber_inv_{it-1}) + \alpha_2 NNR_{it} \\ + \mathbf{X}_{it} \boldsymbol{\gamma} + \alpha_i + \alpha_t + \varepsilon_{it} \quad (22)$$

$$\ln(fiber_sub_{it}) = \beta_0 + \beta_1 \ln(fiber_sub_{it-1}) + \beta_2 \ln(fiber_inv_{it}) \\ + \mathbf{Z}_{it} \boldsymbol{\delta} + \beta_i + \beta_t + \mu_{it} \quad (23)$$

Since we use the logarithm of our dependent variables measuring fiber investment and subscription, the estimation results are interpreted as percentage changes, which facilitates cross-country comparisons. Also, residuals for fiber investment and subscription data in levels are positively skewed. The dependent variables are related in separate equations to different sets of regressors. The binary variable *NNR* is specific to the investment equation indicating whether or not net neutrality regulations (as described in Section 3) were introduced in a certain OECD country in a specific year; no neutrality regulation represents the base

category. Note that the presence of net neutrality regulations cannot be measured as a continuous variable, it rather represents a discretionary choice of legislators at the national or EU level. The coefficient on the net neutrality variable, α_2 , in equation (22) can be used to test Propositions 1 and 3 derived from our theoretical model. Including the contemporaneous fiber investment stock in equation (23) allows us to indirectly assess Proposition 2. Note that according to our theoretical model, net neutrality regulations exert only an indirect impact on fiber subscriptions via their influence on ISPs' investment incentives (equations (10) and (18)). As we do not have all the necessary data to estimate equilibrium conditions as outlined in Section 4, we can only test the shift effect of introducing net neutrality regulations. Identifying the direction of the overall effect is, however, sufficient in view of our research questions and allows us to derive essential policy implications.

We include a lagged dependent variable since large infrastructure projects, like fiber-based broadband deployment, can take years to complete in practice due to rigidities (Briglaue, 2015; Briglaue et al., 2018). Similarly, actual subscription on the demand side is subject to switching costs and inertia on part of consumers (Briglaue, 2014; Grajek and Kretschmer, 2012). We therefore include lagged dependent variables as a right-hand side regressor in equations (22) and (23) in order to capture real-world characteristics in terms of dynamic investment adjustment and demand adoption processes, respectively, even though our simplified theoretical model does not explicitly account for such dynamics. The dynamic specification of equations (22) and (23) can also be empirically tested. If α_i, β_i are equal to 0, then there are no dynamics or inertia, whereas coefficient estimates between 0 and 1 are consistent with a dynamic adjustment and adoption process that leads to a steady state. Note that $1 - \alpha_i$ and $1 - \beta_i$ measure the speed of investment adjustment and speed of adoption, respectively, and that the coefficients for the long-run (static) relationships can be derived from the dynamic model as $\alpha_2/(1 - \alpha_i)$ in the investment equation and $\beta_2/(1 - \beta_i)$ in the subscription equation (Briglaue et al., 2018; Grajek and Röller, 2012). Equations (22) and (23) further contain vectors of covariates, $\mathbf{X}_{it}$ and $\mathbf{Z}_{it}$, which are specific to the investment and subscription equations, respectively. We add fixed effects (α_i and β_i) to capture time-invariant heterogeneity within countries and period effects (α_t and β_t). As will be discussed below, covariates in $\mathbf{Z}_{it}$, as well as period effects, contain information on all structural parameters of our fiber subscription model f . Finally, ε_{it} and μ_{it} are additive error terms.

5.2 Identification strategy

First, in view of the potentially strong role of fixed effects as a determinant of broadband coverage and (albeit to a lesser extent) subscription, we start with an ordinary two-way fixed effects (FE) estimator. The fixed effects model ensures that individual country-level effects capture any time-invariant unobserved heterogeneity that is possibly correlated with the regressors. To obtain consistent estimates for the vector of coefficients, this specification requires strict exogeneity which represents a strong identifying assumption in general. However, major cost determinants of broadband investment, such as costs of civil engineering and network construction, are impacted by topographical factors such as ground conditions and stable regulations, including rights of way and provisions on network cooperation. These factors show either no or only very low variation over time and are therefore largely captured by the fixed effects (Briglauer et al., 2018). The latter also capture (rather) time-invariant factors of consumer preferences within a country such as determinants related to overall Information and Communications Technology (ICT) affinity among the population. For instance, in Northern European countries and East Asian OECD countries, consumers exhibit a comparatively high level of e-literacy and affinity for ICT and broadband content in particular, which has led to much earlier adoption of ICT and broadband services. Furthermore, broadband infrastructure upgrades and content innovation are subject to rather long investment horizons; hence, both represent a long-run decision that relies on the expectation of stable market conditions.

Period effects cover common shocks, such as macroeconomic business cycles, that are (to a large extent) common to all OECD countries, which already exhibit by their member status rather similar levels of economic development. Period effects also cover, to some extent, the cost of developing content (c) and content-related advertising revenues (α), both of which are determined at an international market level. CPs can often quickly deploy innovation that enhances the efficiency of content/service provision, thus reducing associated costs. Standards for the coding or compression of media content have enabled a more efficient use of network resources. Large CPs that own and operate their own private networks of servers and cables (e.g., Google, Facebook, and Amazon) can rapidly deploy such innovations across their networks or ‘on top’ of the public Internet. As these networks often have global footprints of servers and are present within thousands of ISP networks, the roll-out of innovations, along with the resulting effect on costs, can be pursued rapidly and on a global scale. For example, Netflix deployed its own content delivery network

(CDN) to distribute media content. This innovation enabled them to reduce the delivery cost of their content in all countries in which they offer their services (Böttger et al., 2018; Stocker et al., 2017). A similar effect can be observed with respect to advertising revenues. Advances in big data analytics and algorithmic decision-making have been spurred by innovations related to artificial intelligence and machine learning. Major CPs like Facebook or Google can thus harvest and analyse vast amounts of data. As a result of such innovations, large CPs can offer mass-customized, personalized, and more effective advertising on a global scale, which increases their advertising revenues across national borders (Bourreau et al., 2017, pp. 49-54).

Controlling for country fixed and period effects thus already provides strong support for the ‘selection on observables’ identifying assumption. In a similar vein, Akerman et al. (2015), examining basic broadband investment, summarize as follows: *“We find that 89% of the variation in broadband coverage can be attributed to time-invariant municipality and industry characteristics and common time effects, while less than 1% of the variation in broadband coverage can be attributed to a large set of time-varying variables.”*

Second, as shown in Section 3.2, net neutrality policy decisions have been subject to strong ideological and partisan views. An extreme case is the sequence of past net neutrality policy decisions in the U.S., where the nature of the debate surrounding net neutrality has been unusually partisan for an ICT issue (Jamison, 2019). Whereas the U.S. regulatory authority introduced strict net neutrality regulations in 2015 – the three Democratic commissioners voted for the 2015 decision and the two Republican commissioners voted against it – the decision was effectively vacated in 2017 when Republicans gained a 3:2 majority at the FCC. Similarly, in other OECD countries, and within EU member states in particular, the shift in net neutrality regulations can be seen as an outcome of a political decision-making process such as bureaucrats striving to maximize harmonization within the EU. This bureaucratic goal is apparently not driven by relevant market variables such as investment, innovation, or subscription choices. Also, politicians do not observe on a day-to-day basis relevant market outcome variables and therefore do not react to market shocks. In that sense, our binary indicator variable measuring net neutrality regulations represents a political economy variable, which is presumably exogenous with respect to decisions by the markets under consideration.

Third, to deal with remaining endogeneity concerns related to time-variant heterogeneity, we perform two-way fixed effects regressions with external instrumental variables: Whereas the partisan influence on net

neutrality regulations has likely not been as strong in all OECD countries, left-wing political parties tend to exhibit a stronger preference for regulations and equality concerns in general (“free Internet for all”), whereas right-wing parties tend to prefer deregulation and market-driven outcomes. Accordingly, a variable measuring right- and left-wing political majorities should be an informative predictor of whether or not net neutrality regulations are implemented in a certain country. Similarly, we employ measures of the overall degree of governmental intervention in a certain OECD country. The higher the degree of overall public intervention, the greater the extent of sector-specific intervention such as net neutrality. These variables represent political economy variables at the national level. Finally, the discussion in Section 3.2 identified international spillover effects of net neutrality regulations, which have affected most of the developed countries since the early 2000s. Although these spillover effects might not induce policy debates and decisions in all regions, they have certainly impacted policy debates and decisions within supranational regions and similar jurisdictions. Using several instrumental variables not only allows us to test the validity of instruments but also our presumption of net neutrality regulations being an exogenous policy variable.

Finally, the inclusion of a lagged dependent variable as a right-hand side regressor in equations (22) and (23) introduces another source of endogeneity. Estimating our baseline equations by means of an ordinary FE estimator would yield inconsistent and biased results, since the lagged dependent variable and the error terms would be correlated (Nickell, 1981). For this reason, we also employ a bias-corrected fixed-effects estimator (FEC), developed by Bruno (2005a,b) for dynamic unbalanced panel data, and a small number of cross-sectional units ($n = 32$).

6 Data

We investigate the effects of net neutrality regulations in 32 OECD countries using comprehensive panel data for the years from 2003–2018/2019. Whereas data for our dependent variables and main explanatory variables measuring net neutrality regulations are available for 2003–2019, the other data are only available for the years from 2003–2018. Note that our period of analysis covers almost the entire fiber-based broadband deployment period, which did not start before 2003 except for some early infrastructure projects in Japan and South Korea. The source for our dependent variables (Section 6.1) is the database of the FTTH Council Europe, which includes annual numbers of deployed and subscribed fiber-based broadband

connections for all OECD countries. Our main independent variable of interest, i.e., implemented net neutrality regulations in a particular OECD country, is constructed as a binary indicator based on our own research (Section 6.2). Finally, we use several other data sets for our control and instrumental variables (Sections 6.3 and 6.4). All sources and variable definitions are described in detail in Table A.1, while descriptive statistics are provided in Table A.2 in Appendix B. Because some values are missing, there are fewer than the maximum number of observations (512).¹¹

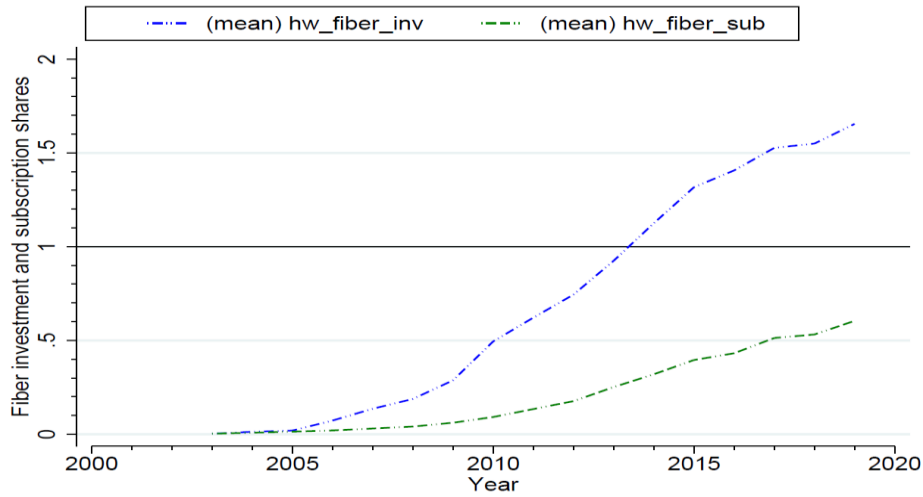
6.1 Dependent variables: fiber investment and subscription

Our dependent variables measure relevant fiber investments by local access ISPs and subscriptions to fiber connections by consumers in logarithmic form, denoted with $\ln(\text{fiber_inv})$ and $\ln(\text{fiber_sub})$, respectively. Fiber subscription measures the absolute number of subscribing consumers and businesses who show a willingness to pay for new high-speed broadband access and related content and services under a commercial contract. Fiber investment is measured in real terms as the absolute number of connections deployed, representing newly installed fiber-based broadband Internet access capacity in a given country.

We include all relevant fiber-based broadband technologies, which either deploy fiber-optic cables directly to the premises of consumers (homes or offices) or partly rely on old (“legacy”) copper wire and coaxial cable connections in the remaining segment of the access network (“hybrid fiber”) connecting the customer premises with the last distribution point. From that point on, all data transmission is fiber-based (see Table A.1 in Appendix B for further technical details). Note that, instead of using broad investment measures such as CAPEX, we have a physical measure of investment, i.e., new fiber-based lines and subscriptions related to ISP local access networks, which are also subject to net neutrality regulations (Section 3.1).

¹¹ Luxembourg and Iceland also had OECD membership status during our period of analysis; however, data are not available for some of our control variables (*laptop*, *smphone*, *tablet*, *telecom_prices*; see Table A.1 in Appendix B). Including these controls lowered the number of OECD countries with member status from 34 to 32. Missing values are related to some control variables but not in any systematic pattern with regard to fiber deployment or net neutrality regulations.

Figure 2: Fiber investment and subscription household shares (OECD mean values for 2003-2019)



Source: Own calculations based on FTTH Council Europe data.

Figure 2 depicts mean values of household weighted (*hw*) numbers of fiber investment and subscription in OECD countries for the years from 2003–2019. One can infer that both operator investment and consumer subscription follow a dynamic adjustment and adoption process. Whereas we observe overprovisioning of households on average due to multiple infrastructures in some (mostly urban) areas since 2013, consumer subscription is lagging behind persistently. Low fiber subscription shares represent a serious welfare concern, as only (output-oriented) subscription to fiber-based broadband connections and consumers actually utilizing related services and applications enables broadband as a general-purpose technology and generates the concomitant welfare effects (Bresnahan and Trajtenberg, 1995); the latter are expected to be much higher than direct investment-related multiplier effects.

6.2 Main explanatory variables: net neutrality regulations

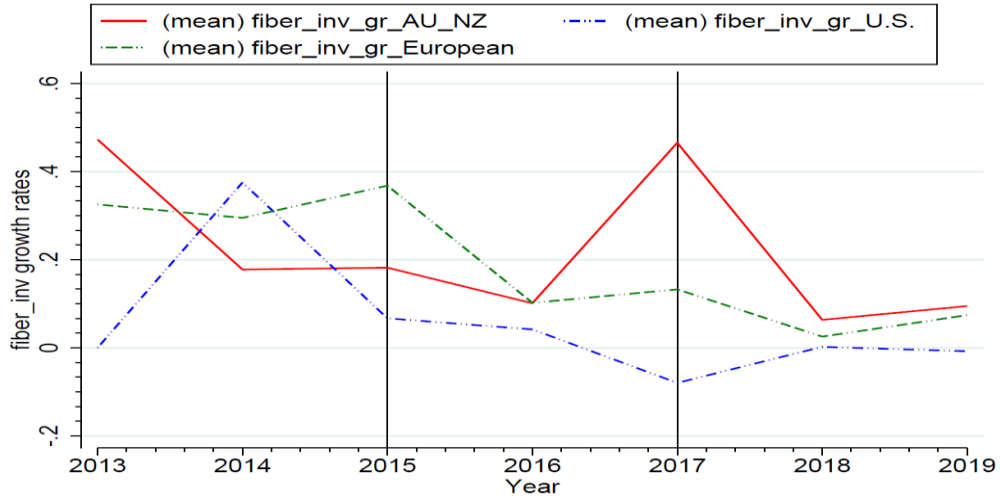
30 out of 32 selected OECD countries implemented net neutrality regulations as described in Section 3.1 during the period from 2003–2019. Only Australia and New Zealand opted not to implement any net neutrality regulations during this period.¹² In all other OECD countries, there have been some kind of net neutrality regulations imposed for at least one year during the period from 2003–2019. Note that strict net neutrality regulations in terms of ZPR and NDR also include soft regulations such as codes of conduct or transparency regulations. The dummy variable *NNR* hence takes on value 1 if legally binding net neutrality

¹² We do not drop these units in our regressions to identify period effects and effects of time-varying covariates.

regulations are implemented in country i in year t (and 0 otherwise). The date of the net neutrality regulations is based on the time of rulemaking via national or, in the case of EU member states, supranational legislation. As investment decisions are subject to strong rigidities, we also include lagged values of our net neutrality variable ($LNNR$) in estimating equation (22). Moreover, if firms correctly anticipated (and responded to) future implementation of net neutrality regulations, then the effects of currently implemented regulations would underestimate the true total effect of net neutrality regulations. For this reason, we also consider the impact of the first public announcement of proposed net neutrality regulations and related expectation effects ($NNR(expect)$). Table A.3 provides a detailed overview of net neutrality regulations in individual OECD countries with their respective year of rulemaking, date of first announcement, and sources.

Figure 3 shows fiber investment growth rates for selected (groups of) countries with different net neutrality regulations and policy reversals during the last few years, as discussed in Section 3.2. Although one can observe a general downward trend in growth rates since 2013, one also observes lower downward trends for European countries since the implementation of net neutrality regulations in 2015. In contrast, Australia and New Zealand exhibit a different pattern, with persistently higher growth rates since 2015, while the U.S. has experienced an increase in growth rates since net neutrality deregulation in 2017.

Figure 3: Fiber investment growth rates ($_gr_$) in selected (groups of) OECD countries for the years before and after major changes in rulemaking in the EU (in 2015) and the U.S. (in 2017)



Source: Own calculations based on FTTH Council Europe data.

6.3 Control variables

All control variables are described in detail in Table A.1 of Appendix B. The vector of investment covariates, $\mathbf{X}_{it}$, contains measures of macroeconomic conditions relevant for the investment decision, including the long-term interest rate, lt_ir , and the investment freedom, $free_invest$, of a country. Deployment costs are determined by population density, pop_dens , in view of the strong role of economies of density in broadband deployment, and average wages, $wages$, capturing the costs of civil engineering work as construction work represents by far the largest share of total deployment costs. Investment further depends on market structural characteristics, such as the degree of competition among wireline cable TV broadband infrastructures, $cable_comp$, and from wireless broadband (mobile) networks, $mobile_comp$, the average price level for telecommunications services, $telecom_prices$, as well as the potential market size proxied by basic broadband subscriptions, $basic_broadband$.

The vector of demand covariates, $\mathbf{Z}_{it}$, contains micro-founded determinants of demand measuring households' ICT budget, $comm_exp$, and average costs of fiber connections in terms of average household size, hh_size . Various measures of consumers' ICT preferences proxy the intrinsic value (v) of the fiber-based subscription (adr ; ict_trade ; $laptop$; $tablet$; $smartphone$; $internet_users$). Content (β) is measured in two ways. First, we consider the number of (secure) Internet servers, $servers$; and, second, we collect information on the market entrance of Netflix, $Netflix$. Video streaming services, meanwhile, represent more than 50% of global

Internet download traffic. As one of the most famous streaming services, Netflix represents about 15% of global Internet download traffic and in some developed countries, this share is even higher.¹³

6.4 Instrumental variables

In order to capture the outcome of political election processes at EU and national levels, we grouped political parties into two ideologically distinct groups of “(rather) left-wing” and “(rather) right-wing”. The variable *left_wing* measures the share of the population of country i in year t voting for (rather) left-wing parties (Grajek and Röller, 2012). For all EU member states, the share is determined by the share of elected representatives joining a certain faction of the European Parliament. The different factions are then classified as (rather) left- or (rather) right-wing and the respective shares are cumulated. For all other (non-EU) countries, the political parties elected in the national parliamentary elections are classified as (rather) left-wing or (rather) right-wing. Table A.4 provides an overview of country-specific sources. As another sort of political economy variable at the national level, we proxy governmental intervention in fiber deployment with the variables *exp_gdp* and *gov_spend*, which measure the overall degree of governmental spending and intervention in the economy (measured as percentage and portion of GDP). We expect that more left-leaning governments, as well as governments showing higher levels of public spending and market intervention, will tend to favour regulatory measures such as interventionist net neutrality regulations.

Finally, we construct Hausman-type spatial instruments as another sort of a political economy variable at the international level. As the discussion in Section 3.2 illustrated, net neutrality regulations and the corresponding debates were subject to strong regional spillover effects. In view of the historical development of net neutrality regulations, we distinguish the following regions into which we categorize OECD countries accordingly: Europe, Americas, Australia & New Zealand, and Asia. Spatial instruments are then defined as the ratio of implemented (announced/proposed) net neutrality regulations in all other countries within a certain region (i.e., other than the focal country i) to the total number of other (i.e., non-focal) countries in that region and denoted with $NNR_{j \neq i}$ ($NNR(expect)_{j \neq i}$).

¹³ Information available at: <https://variety.com/2018/digital/news/netflix-15-percent-internet-bandwidth-worldwide-study-1202963207/>.

7 Empirical results

Two-way fixed effects estimation results for the fiber investment and subscription equations are reported in Table 2 and Table 3, respectively.¹⁴ In all the specifications, the coefficient of the lagged dependent variable is positive, but smaller than one, and highly significant, which means that investment on the supply side and subscription on the demand side are indeed subject to significant adjustment costs and consumer inertia, respectively, as expected and suggested in Figure 2. As described in Section 5.2, an ordinary FE estimator would yield inconsistent and biased results, since the lagged dependent variable and the error terms would be correlated (Nickell, 1981). It can be shown that OLS and FE estimators are likely to be biased in opposite directions in autoregressive models (Bond, 2002). Whereas OLS leads to upward biased estimates of the coefficient of lagged dependent variables, since the values of the lagged dependent variable are positively correlated with the omitted country fixed effects, FE estimates are downward biased for small T . Hence, if the dynamic models in equations (22) and (23) are correctly specified, the true coefficient estimates are between OLS and FE estimates. Comparing the respective coefficient estimate in regression (1) to those in (5) to (6) in Table 2, and the coefficient estimate in regression (2) to those in (5) and (6) in Table 3, we can indeed infer that the bias corrected (FEC) estimates lie within the interval of FE and OLS estimates. Also, the ‘dynamic bias’ introduced by including a lagged dependent variable appears to be not too severe and can thus be neglected in the further analysis of the causal effect of net neutrality regulations.¹⁵

The coefficient estimates of our main variable of interest, i.e., net neutrality regulations (NNR), point to a negative impact on fiber investment in all regressions in Table 2, thus providing supportive evidence for our theoretical Propositions 1 and 3. Whereas the contemporaneous impact of implemented net neutrality regulations (NNR) and the coefficient of the variable reflecting expectations due to announcements of net neutrality regulations $NNR(expect)$ are insignificant, the coefficient estimate of the lagged net neutrality variable ($LNNR$) is significant at the 5% level in all FE regressions in regressions (1) to (4). As our net neutrality variables exhibit high collinearity, we also conducted joint hypotheses tests. According to F -statistics tests (not reported), the group of net neutrality variables is jointly significant at the 5% level.

¹⁴ Stata 16.1 was used to estimate the regressions.

¹⁵ For a similar line of reasoning, see Grajek and Röller (2012).

Individual significance tests indicate that the negative impact of net neutrality does not immediately manifest in current investment plans of ISPs but only with some delay due to considerable rigidities in broadband deployment. The extent of this effect is, however, substantial. The respective coefficient of the lagged net neutrality variable in regression (1) suggests that the introduction of *NNR* leads to a total decrease in new fiber investments by ISPs of about 45%.¹⁶

Table 3 reports the estimation results for the fiber subscription equation. The coefficient of the fiber investment variable ($\ln(fiber_inv)$) suggests that the current infrastructure stock is a very strong predictor for fiber subscription; increasing fiber investment by 1% increases fiber subscription by about 0.78-0.81% in regressions (1)-(4). As suggested by the evidence reported in Figure 2, subscription is somewhat lagging, however, behind fiber coverage. Coefficients of lagged variables of fiber investment are insignificant, which is to be expected as consumers' subscription decisions are only impacted by the currently available infrastructure stock and not by previous investment decisions. The latter impact current fiber subscriptions only via consumer inertia, albeit to a limited extent, as reflected in the low coefficient estimate of the lagged dependent variable in regressions (2) to (6). When controlling for installed fiber capacity, consumer inertia is comparatively low, giving rise to a rather high speed of adoption ($1 - \beta_I$) which is substantially higher than the respective speed of investment adjustment ($1 - a_I$) as inferred from Table 2.¹⁷ Taking the impact of *NNR*

¹⁶ We are aware that the magnitude of the estimated coefficients of our *NNR* variables may seem too large, but at the beginning of our sample, all the countries had virtually zero fiber connections (and towards the end of our sample, fiber coverage exceeded 100% of households in many countries). This implies that the increases we observed in (log) percentage terms tend to be very large. Note also that a change in the variable *NNR* from 0 to 1 is not a small change, so the coefficients do not approximate percentages. The large magnitude of this effect is also, to some extent, driven by the low base of fiber investment in the first years of our sample (for a similar reasoning see Briglauer et al., 2018).

¹⁷ This might seem at odds with the higher average coverage level as depicted in

Figure 2. Note, however, that high average household coverage due to several independent infrastructure operators in (sub-)urban areas does not imply ubiquitous household coverage. On contrary, most countries still exhibit low household coverage in rural areas (European Commission, 2020), where deployment costs are high and the speed of investment adjustment is low.

on fiber investment and the impact of the latter on fiber subscription, we find that *NNR* have not only exerted a negative impact on ISP network investment on the supply side, but also indirectly on the number of fiber-based connections subscribed to on the demand side. However, the indirect effect is lower, as both coefficients are lower than one for all regressions in Table 3. Multiplying the coefficient estimate of the variable *L.NNR* in regression (1) of Table 2 (-0.606) with the coefficient estimate of the variable $\ln(fiber_inv)$ in regression (2) of Table 3 (0.778) implies that introducing *NNR* has indirectly decreased fiber subscriptions by about 38%, thus providing supportive evidence for Proposition 2.

All control variables in the fiber investment and fiber subscription equations exhibit the expected signs when significant, which further reaffirms that our estimation equations are valid. Moreover, taking into account all controls, along with country fixed effects and period effects, our FE fiber investment and subscription estimation equations explain about 87% and 97%, respectively, of the total within variation. The very high explanatory power of our model specifications, which corresponds well with the previous literature (Akerman et al., 2015), is also reflected in the *F*-tests of overall model significance.

Regarding identification of causal effects in the fiber subscription equation, violation of strict exogeneity due to time-varying unobservable variables ('omitted variable bias') should be limited as almost 100% of the relevant within variation (about 97%) is explained by a large set of explanatory variables in our fiber subscription estimation equation. Including a lagged dependent variable as a right-hand side regressor further controls for unobserved time-variant heterogeneity. The more severe concern as regards endogeneity is the possibility of reciprocal causality ('simultaneity bias') potentially underlying fiber investment and fiber subscription; in particular, operators' current investment decisions might depend on past, current, or expected subscriptions of consumers. For this reason, we also conducted Granger causality tests. According to these tests, fiber investment Granger-causes fiber subscription (p -value = 0.000, $H_0: \ln(fiber_inv)$ does not Granger-cause $\ln(fiber_sub)$), but fiber subscriptions do not Granger-cause fiber investment (p -value =

0.7562, $H_0: \ln(fiber_sub)$ does not Granger-cause $\ln(fiber_inv)$).¹⁸ We are therefore confident that our coefficient estimates on fiber investment variables, as reported in Table 3, represent true causal effects.

Regarding the identification of causal effects of *NNR* variables in the fiber investment equation, we further deal with remaining endogeneity concerns related to time-variant heterogeneity due to omitted variables by employing several sources of exogenous variation from instrumental variables (IV), as described in Section 5.2. Table 4 below reports the corresponding results of FE-IV estimations for the fiber investment equation where regressions (1) to (4) vary with respect to included *NNR* variables and the resulting sets of instrumental variables. Importantly, one can infer that all coefficient estimates of the lagged variable, L_NNR , remain negative and significant, although the coefficient estimates are slightly higher than the respective FE estimates in Table 2. Likewise, coefficient estimates of all other independent variables appear to be robust with respect to the FE and FE-IV estimators, having the same signs and similar magnitude of coefficients.

Also, all postestimation analysis of residuals and regression diagnostics show that FE-IV estimation results represent reliable robustness analysis. According to Hansen *J* statistics of the overidentification test of all instruments, our respective instrument sets are jointly valid in all specifications in regressions (1) to (4). The Kleibergen-Paap (KP) test (LM statistic) of underidentification clearly rejects the null hypothesis that the estimation equation is underidentified for all regressions at the 5% significance level, implying that the excluded instruments are correlated with the endogenous regressors and thus relevant. Durbin-Wu-Hausman (DWH) endogeneity tests do not reject the null hypothesis of *NNR* variables being an exogenous variable in all regressions. Hence, DWH tests confirm our presumption that net neutrality regulations can, in fact, be considered exogenous policy decisions and the respective coefficient estimates of *NNR* variables as reported in Table 2 are thus consistent and more efficient, representing a reliable basis for our policy conclusions in the final section.

¹⁸ Tests are performed using the Stata command ‘xtgcause’, which implements a procedure proposed by Dumitrescu and Hurlin (2012) for testing Granger causality in panel data sets. We included a maximum number of two lags. *p*-values are reported for the Z-bar statistic.

Table 2: Results for the fiber investment equation (*Dep. var.: $\ln(\text{fiber_inv})$*)

	(1) FE	(2) FE	(3) FE	(4) FE	(5) FEC	(6) OLS
Lagged dep. var.						
$L.\ln(\text{fiber_inv})$	0.562*** (11.17)	0.557*** (11.27)	0.567*** (11.32)	0.575*** (11.79)	0.673*** (17.82)	0.735*** (23.11)
Net neutrality vars.						
NNR	-0.208 (-0.93)	-0.201 (-0.92)	-0.138 (-0.64)	-0.569 (-1.69)	-0.311 (-0.59)	-0.319* (-1.79)
$L.NNR$	-0.606*** (-3.16)	-0.586*** (-3.08)	-0.554*** (-3.11)	-0.481** (-2.73)	-0.635 (-1.21)	0.072 (0.47)
$NNR(\text{expect})$	-0.533 (-1.01)	-0.575 (-1.10)	-0.590 (-1.16)		-0.507 (-0.98)	0.273 (0.78)
Macroecono. vars.						
lt_ir	-0.119* (-2.03)	-0.119** (-2.04)	-0.135** (-2.21)	-0.130** (-2.17)	-0.122** (-2.03)	-0.132** (-2.31)
$free_invest$	0.065*** (3.22)	0.064*** (3.21)	0.063*** (3.19)	0.063*** (3.29)	0.057*** (2.58)	0.005 (0.46)
Market vars.						
$telecom_prices$	0.030** (2.59)	0.031** (2.62)	0.026** (2.09)	0.026** (2.19)	0.028** (2.50)	0.026*** (3.42)
$cable_comp$	-2.440 (-0.67)	-1.447 (-1.01)	-3.514 (-1.03)	-3.889 (-1.15)	-1.998 (-0.62)	-1.867 (-1.23)
$cable_comp_sq$	1.334 (0.35)		2.436 (0.68)	2.835 (0.81)	0.795 (0.23)	1.925 (0.71)
$mobile_comp$	-3.176* (-2.02)	-2.051** (-2.38)	-3.197** (-2.38)	-3.171** (-2.39)	-3.834*** (-2.71)	-0.422 (-0.44)
$mobile_comp_sq$	0.506 (1.18)		0.478 (1.43)	0.493 (1.46)	0.841 (1.45)	0.056 (0.12)
$basic\ broadband$	4.355** (2.06)	4.228* (1.93)	4.274** (2.05)	4.291* (2.03)	4.133** (2.52)	0.903 (1.29)
$wages$	0.000 (0.38)	0.000 (0.32)			0.000 (0.56)	-0.000 (-0.42)
pop_dens	0.021 (0.88)	0.023 (0.99)			0.024 (1.26)	0.001 (1.39)
$country\ FE\ (a_i)$	YES	YES	YES	YES	YES	YES
$year\ FE(a_t)$	YES	YES	YES	YES	YES	YES
$constant\ (a_0)$	-3.311 (-0.69)	-3.872 (-0.84)	1.335 (0.39)	0.900 (0.28)		1.743 (1.09)
$R^2(\text{within})$	0.871	0.870	0.870	0.870	0.817	
$R^2(\text{overall})$						0.858
$F\ statistic$	900.50	509.64	516.85	390.79		
# Countries	32	32	32	32	32	32
# Observations	497	497	497	497	497	497

Notes: t -statistics in parentheses are robust and allow for heteroscedasticity and correlation within countries; tests for the presence of cross-sectional dependence are based on the Stata command ‘xtcsd’ (DeHoyos and Sarafidis, 2006), which is suitable for cases where T is small. When controlling for year effects, the test does not reject the null hypothesis of cross-sectional independence. Note that we also include squared terms for competition variables ($_sq$), as competition might impact investment in a non-linear form (Sacco and Schmutzler, 2011). FEC standard errors in regression (5) are bootstrapped based on 100 iterations with bias correction initialized by the Arellano and Bond estimator. Note that there are no standard post-estimation tests available for the user-written ‘xtlsdvc’ Stata command (Bruno, 2005b), which also includes no constant; as a goodness-of-fit measure we report the correlation between actual and predicted values of the dependent variable in regression (5) as $R^2(\text{within})$. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Results for the fiber subscription equation (Dep. var.: $\ln(\text{fiber_sub})$)

	(1) FE	(2) FE	(3) FE	(4) FE	(5) FEC	(6) OLS
Lagged dep. var.						
$L.\ln(\text{fiber_sub})$	0.506*** (9.53)	0.100*** (2.82)	0.270** (2.17)	0.250* (1.96)	0.113*** (5.27)	0.171*** (4.29)
Fiber investment (φ)						
$\ln(\text{fiber_inv})$		0.778*** (26.32)	0.806*** (22.78)	0.788*** (20.33)	0.771*** (36.24)	0.775*** (23.02)
$L.\ln(\text{fiber_inv})$			-0.178 (-1.34)	-0.159 (-1.15)		
$L2.\ln(\text{fiber_inv})$				0.017 (1.06)		
Budget vars.						
comm_exp	0.708*** (3.07)	0.015 (0.23)	0.004 (0.08)	0.034 (0.53)	0.016 (0.20)	0.055 (1.12)
hh_size	4.203** (2.09)	1.456 (1.51)	1.127 (1.46)	1.294 (1.32)	1.429 (1.48)	0.405*** (3.49)
ICT affinity vars. (ν)						
adr	-0.231** (-2.55)	-0.025 (-0.93)	-0.022 (-1.01)	-0.014 (-0.49)	-0.023 (-0.87)	-0.007 (-1.03)
ict_trade	0.032 (1.28)	0.000 (0.03)	-0.000 (-0.04)	-0.005 (-0.55)	0.000 (0.03)	0.008 (1.41)
laptop	0.038 (1.39)	0.013 (0.70)	0.012 (0.75)	0.011 (0.54)	0.013 (1.10)	0.005 (0.94)
tablet	0.026 (0.99)	0.014 (1.13)	0.012 (1.23)	0.016 (1.56)	0.014 (1.33)	0.003 (0.53)
smphone	-0.011 (-0.45)	-0.006 (-0.48)	-0.004 (-0.43)	-0.008 (-0.76)	-0.006 (-0.55)	0.002 (0.25)
internet_users	0.103*** (3.98)	0.027** (2.63)	0.023** (2.40)	0.030** (2.36)	0.026** (2.48)	0.013** (2.21)
Content vars. (β)						
servers	0.000** (2.12)	0.000 (0.79)	0.000 (0.62)	0.000 (0.52)	0.000 (0.43)	0.000 (0.16)
Netflix	0.341 (0.85)	0.086 (0.74)	0.107 (1.04)	0.104 (1.01)	0.083 (0.48)	0.094 (0.90)
$\text{country FE } (\beta_i)$	YES	YES	YES	YES	YES	YES
$\text{year FE } (\beta_t; a, c)$	YES	YES	YES	YES	YES	YES
$\text{constant } (\beta_0)$	-6.877 (-1.07)	-3.936 (-1.38)	-2.989 (-1.20)	-4.229 (-1.31)		-1.572*** (-2.59)
$R^2(\text{within})$	0.869	0.974	0.975	0.966	0.991	
$R^2(\text{overall})$						0.973
F statistic	356.12	7681.89	15123.32	5690.64		2859.56
# Countries	32	32	32	32	32	32
# Observations	480	480	480	448	480	480

Notes: t -statistics in parentheses are robust and allow for heteroscedasticity and correlation within countries; tests for the presence of cross-sectional dependence are based on the Stata command ‘xtcsd’ (DeHoyos and Sarafidis, 2006), which is suitable for cases where T is small. When controlling for year effects, the test does not reject the null hypothesis of cross-sectional independence. FEC standard errors in regression (5) are bootstrapped based on 500 iterations with bias correction initialized by the Arellano and Bond estimator. Note that there are no standard post-estimation tests available for the user-written ‘xtlsdvc’ Stata command (Bruno, 2005b), which also includes no constant; as a goodness-of-fit measure, we report the correlation between actual and predicted values of the dependent variable in regression (5) as $R^2(\text{within})$. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: IV results for the fiber investment equation (Dep. var.: $\ln(\text{fiber_inv})$)

	(1) FE-IV	(2) FE-IV	(3) FE-IV	(4) FE-IV
Lagged dep. var.				
$L.\ln(\text{fiber_inv})$	0.588*** (12.99)	0.578*** (12.06)	0.556*** (11.82)	0.585*** (13.38)
Net neutrality vars.				
NNR	-0.783 (-1.02)	-0.615 (-0.91)		
$L.NNR$	-0.781* (-1.70)	-0.716* (-1.94)	-0.647* (-1.68)	-0.879* (-1.89)
$NNR(\text{expect})$	0.815 (0.98)		-0.705* (-1.79)	
Macroecono. vars				
lt_ir	-0.141** (-2.27)	-0.154** (-2.50)	-0.119** (-2.13)	-0.148** (-2.57)
$free_invest$	0.074*** (3.58)	0.076*** (3.81)	0.064*** (3.35)	0.075*** (3.69)
Market vars				
$telecom_prices$	0.035*** (3.04)	0.034*** (3.15)	0.031*** (2.81)	0.034*** (3.09)
$cable_comp$	-2.977** (-2.10)	-0.847 (-0.55)	-1.455 (-1.07)	-2.907** (-2.01)
$mobile_comp$	-0.878* (-1.81)	-0.858* (-1.88)	-2.068** (-2.52)	-0.804* (-1.94)
$basic_broadband$	7.754*** (5.38)	8.363*** (6.09)	4.228** (2.03)	7.992*** (6.11)
$wages$	0.000 (0.68)	0.000 (0.61)	0.000 (0.31)	0.000 (0.68)
pop_dens	0.030 (1.64)	0.043** (2.27)	0.023 (1.02)	0.030 (1.61)
$country\ FE\ (\beta_i)$	YES	YES	YES	YES
R^2 (uncentered)	0.853	0.855	0.870	0.854
F statistic	225.485	331.067	406.823	255.380
Hansen J (p -value)	0.193	0.320	0.132	0.104
KP (p -value)	0.013	0.019	0.000	0.007
DWH (p -value)	0.576	0.321	0.655	0.536
# Instruments	7	6	5	4
# Countries	32	32	32	32
# Observations	497	497	497	497

Notes: t -statistics in parentheses are robust and allow for heteroscedasticity and correlation within countries. Instruments in regressions (1) to (4) include contemporaneous and lagged values of the variables $left_wing$, exp_gdp , gov_spend , and Hausman-type instruments $NNR_{j \neq i}$, $L.NNR_{j \neq i}$ and $NNR(expect)_{j \neq i}$. Country fixed effects are included in all regressions. However, we had to exclude year period effects due to very high collinearity with the Hausman-type instrumental variables, which results as a logical consequence of the underlying construction of our spatial instruments. Note that the 'xtivreg2' Stata command includes no constant with a fixed effects model. As a goodness-of-fit measure, we report the uncentered R^2 (because there is no constant). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

8 Summary and policy implications

Network neutrality regulations have been subject to major controversies in the telecommunications arena over the last two decades and major policy changes in some OECD countries. Despite substantial direct and indirect costs related to net neutrality regimes, the theoretical literature does not make a clear and compelling case for the introduction of network neutrality regulations, nor is there any supportive evidence so far for the central claims of net neutrality proponents. We provide first results on the causal impact of net neutrality regulations on both (input-oriented) fiber-based network investment by ISPs and (output-oriented) consumer subscription to fiber-based connections. Our empirical analysis, based on theoretical underpinnings derived from a two-sided Hotelling model, finds that net neutrality regulations exert a direct negative impact on fiber investments and an indirect negative impact on fiber subscriptions. Employing various panel estimation techniques, including instrumental variables, underlines the exogeneity of our variables measuring net neutrality policies in OECD countries, pointing to true causal effects. Given the presumably high costs of implementing and enforcing net neutrality regimes,¹⁹ our results strongly suggest that policymakers should refrain from imposing strict net neutrality regulations. Relating our empirical results – which are in line with the theoretical literature – to high regulatory costs indicates that net neutrality regulations have been inefficient in the past and should thus be withdrawn.

Strict net neutrality regulations, as implemented in the EU and specified in the BEREC Guidelines, reveal a regulatory preference for network investments over the use of network management to avoid long-lasting or recurrent states of congestion (EU, 2015, Recital 15; BEREC, 2020, para. 93 at p. 29). This focus on ISP investments ignores the fact that large CPs, such as Google, Amazon, Facebook, Akamai, and Microsoft, have invested heavily in their own private networks of cables and strategically distributed servers. These providers can bypass the public and regulated Internet as they act as carriers of traffic via their private backbone networks; they can deliver content services from servers positioned close to the end-users. CDN

¹⁹ Although we do not have corresponding cost estimates, a closer look at consultation and legislation procedures, implementation guidelines, and monitoring reports issued by BEREC and national regulatory authorities clearly points to high regulatory costs. For detailed information, the reader is referred to BEREC's website on "Open Internet rules in the EU" (https://berec.europa.eu/eng/open_internet/).

providers like Akamai offer services via their platform to third-party companies. In effect, these providers can reduce or even eliminate their dependence on the public Internet. From a user experience perspective, these and other mechanisms can act as technological substitutes for network management or network investment by ISPs. They are typically deployed by entities other than ISPs and provide a means for bypassing network neutrality regulations (Stocker et al., 2017, 2020). The vast majority of Internet traffic is already delivered via CDNs, and CPs like Netflix deliver substantial amounts of traffic to end-users via CDN servers deployed within ISP networks (Labovitz, 2019, 2020).²⁰

Such developments raise questions regarding the scope and effectiveness of network neutrality regulations. Effective enforcement of network neutrality regulations requires a clear understanding of who the relevant players are, where the dividing lines between the (regulated) public Internet and (unregulated) specialized services are, and what types of network management practices are reasonable or not. Future research should not be based on an outdated model of the Internet ecosystem, but rather acknowledge its real-world characteristics. In order to have a more complete picture on the overall welfare effects, future research should also provide empirical evidence regarding relevant outcomes such as consumer prices for ISP access or content innovation.

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²⁰ The data volume of global content delivery network Internet traffic grew by more than 360%, from 54 exabytes per month in 2017 to 252 exabytes per month in 2020 (information available at: <https://www.statista.com/statistics/-267184/content-delivery-network-internet-traffic-worldwide/>).

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Appendix A

In this appendix, we extend our simplified baseline model to a duopolistic setting, i.e., to the presence of two ISPs on competing platforms. Users buy their Internet access from a single platform only (i.e., they single-home), while CPs are assumed to sell their contents through both platforms (i.e., they multi-home). The main assumptions regarding users' utility/content and ISP profits remain the same, as does the structure of the game.

The two platforms are located in $x = 0$ and $x = 1$ of our Hotelling model. The user x_i , indifferent on the question of buying from either platform 1 or platform 2, is given by the following condition:

$$v + \varphi_i + \beta * n_{cpi}^e - p_i - x_i = v + \varphi_j + \beta * n_{cpj}^e - p_j - (1 - x_i), \quad i, j = 1, 2$$

i.e.,

$$x_i = \frac{1}{2} + \frac{\varphi_i - \varphi_j + p_j - p_i + \beta * (n_{cpi}^e - n_{cpj}^e)}{2}, \quad i, j = 1, 2.$$

The CPs profit is given by:

$$U_{CPj} = \alpha * n_{ck}^e - cy_j - a_k, k = 1, 2$$

and the marginal CP is denoted by:

$$\bar{y}_{jk} = n_{cpk} = \frac{\alpha * n_c^e - a_k}{c}, k = 1, 2$$

As before, we assume fulfilled expectations equilibria where $n_{ci}^e = n_{ci}$, $i = 1, 2$ and $n_{cpk}^e = n_{cpk}$, $k = 1, 2$.

Given that $n_{c2} = 1 - n_{c1}$, the number of users and active CPs is:²¹

²¹ To guarantee a positivity condition, as before, we assume $c > \alpha\beta$. Moreover, to ensure the existence of an equilibrium, we further assume that $6c - \alpha^2 - 4\alpha\beta - \beta^2 > 0$. As in Economides and Tåg (2012), under these conditions, second order conditions are satisfied.

$$n_{c1} = \frac{1}{2} + \frac{c(\varphi_1 - \varphi_2 + p_2 - p_1) + \beta(a_2 - a_1)}{2(c - \alpha\beta)} \quad (A.1)$$

$$n_{c2} = \frac{1}{2} - \frac{c(\varphi_1 - \varphi_2 + p_2 - p_1) + \beta(a_2 - a_1)}{2(c - \alpha\beta)} \quad (A.2)$$

$$n_{cp1} = \frac{\alpha}{2c} + \frac{\alpha c(\varphi_1 - \varphi_2 + p_2 - p_1) + \alpha\beta(a_1 + a_2) - 2ca_1}{2c(c - \alpha\beta)} \quad (A.3)$$

$$n_{cp2} = \frac{\alpha}{2c} + \frac{\alpha c(\varphi_2 - \varphi_1 + p_1 - p_2) + \alpha\beta(a_1 + a_2) - 2ca_2}{2c(c - \alpha\beta)} \quad (A.4)$$

Under net neutrality regulations, $a_i = 0, i = 1, 2$, the ISPs' profit becomes:

$$\Pi_{ISP_i} = n_{ci}p_i - \frac{\varphi_i^2}{2}, i = 1, 2 \quad (A.5)$$

The equilibrium prices then are $p_i = \frac{c - \alpha\beta}{c} + \frac{\varphi_i - \varphi_j}{3}$, $i, j = 1, 2$. Substituting these results into (A.5) and maximizing with respect to φ_i , we obtain the following symmetric investment level equilibrium ($\varphi_i = \varphi_j = \varphi_{NNR}^D$) under net neutrality regulations:

$$\varphi_{NNR}^D = \frac{1}{3} \quad (A.6)$$

In an unrestricted duopoly setting, the ISPs' profit is given by:

$$\Pi_{ISP_i}(p_i, p_j, a_i, a_j) = n_{ci}p_i + n_{cpi}a_i - \frac{\varphi_i^2}{2}, i = 1, 2 \quad (A.7)$$

Maximizing (A.7) with respect to the four prices p_i and $a_i, i = 1, 2$, we obtain the following optimal conditions:

$$p_1 = \frac{4c - \alpha^2 - 3\alpha\beta}{4c} + \frac{\varphi_1 - \varphi_2}{2(6c - \alpha^2 - 4\alpha\beta - \beta^2)} \quad (A.8)$$

$$p_2 = \frac{4c - \alpha^2 - 3\alpha\beta}{4c} - \frac{\varphi_1 - \varphi_2}{2(6c - \alpha^2 - 4\alpha\beta - \beta^2)} \quad (A.9)$$

$$a_1 = \frac{(\alpha - \beta)}{4} + \frac{c(\alpha - \beta)(\varphi_1 - \varphi_2)}{2(6c - \alpha^2 - 4\alpha\beta - \beta^2)} \quad (A.10)$$

$$a_2 = \frac{(\alpha - \beta)}{4} - \frac{c(\alpha - \beta)(\varphi_1 - \varphi_2)}{2(6c - \alpha^2 - 4\alpha\beta - \beta^2)} \quad (\text{A.11})$$

Substituting (A.8), (A.9), (A.10) and (A.11) into (A.7), and maximizing with respect to $\boldsymbol{\varphi}_i$, $i = 1, 2$, we obtain the following optimal symmetric investment level in an unrestricted duopoly:

$$\varphi^{*D} = \frac{1}{3} + \frac{(\alpha - \beta)(2c(4\alpha - \beta) - 5\alpha^2\beta - \alpha\beta^2)}{24(c - \alpha\beta)(6c - \alpha^2 - 4\alpha\beta - \beta^2)} \quad (\text{A.12})$$

Comparing (A.12) with (A.6), we have:

$$\varphi^{*D} - \varphi_{NNR}^D = \frac{(\alpha - \beta)(2c(4\alpha - \beta) - 5\alpha^2\beta - \alpha\beta^2)}{24(c - \alpha\beta)(6c - \alpha^2 - 4\alpha\beta - \beta^2)}$$

that can be rewritten as:

$$\varphi^{*D} - \varphi_{NNR}^D = \frac{(2c + \alpha^2)(\alpha - \beta) + \alpha(6c - \alpha^2 - 4\alpha\beta - \beta^2)}{24(c - \alpha\beta)(6c - \alpha^2 - 4\alpha\beta - \beta^2)}$$

It is easy to note that, since $c > \alpha\beta$ and $6c - \alpha^2 - 4\alpha\beta - \beta^2 > 0$ for the existence of an equilibrium, then as long as $\alpha > \beta$, i.e., the value of additional users is valued more by CPs than the value of additional content by users, which seems plausible for asking CPs to pay for prioritized traffic (see equations A.10 and A.11), is a sufficient condition to have $\varphi^{*D} > \varphi_{NNR}^D$. Hence, when $\alpha > \beta$, the investment by duopolistic platforms is higher in an unrestricted scenario than under net neutrality regulations.

For completeness, in the case that $\alpha = \beta$, the investment levels under NNR and unrestricted duopoly are the same, while for $\alpha < \beta$, investments are still larger in an unrestricted duopoly if and only if the following condition holds:

$$\alpha - \beta < -\frac{\alpha(6c - \alpha^2 - 4\alpha\beta - \beta^2)}{2c + \alpha^2} \text{ i.e. } \alpha < \bar{\alpha} = \beta - \frac{\alpha(6c - \alpha^2 - 4\alpha\beta - \beta^2)}{2c + \alpha^2}$$

i.e., when α is very low ($\alpha < \bar{\alpha} < \beta$). Note, however, that when this condition holds, it implies that, from (A.10) and (A.11), the CPs receive a subsidy from platforms for using their networks.

Appendix B

Tables A.1 to A.4

Table A.1: Variable descriptions and sources

Variable name	Description	Source*
Dependent variables: Fiber-based broadband		
<i>fiber_inv</i>	Fiber investment refers to a family of FTTx roll-out scenarios which include the following fiber investment arrangements in terms of total number of homes passed (connected but not necessarily subscribed): fiber-to-the home (FTTH) and fiber-to-the building (FTTB), as well as the hybrid fiber technologies fiber-to-the cabinet (FTTC) and fiber-to-the last amplifier (FTTLA). One refers to FTTC when VDSL technologies are run on a hybrid fiber-based network, which extends to street cabinets, and copper lines, which typically cover around several hundred meters from street cabinet to the customers' premises. FTTLA refers to broadband access enabled by the DOCSIS 3.0 technology on hybrid fiber-coaxial cables. "Homes passed" is the total number of premises. Premises are a home or place of business.	FTTH Council Europe*
<i>fiber_sub</i>	Number of actual subscriptions of installed FTTx connections. Subscribers can be households or businesses.	FTTH Council Europe*
Net neutrality variables (see Table A.3)		
Market variables: basic broadband		
<i>basic_broadband</i>	Basic broadband infrastructure and subscriptions rely entirely on existing copper- or coaxial cable and DSL or cable modem technologies in the access network. Total broadband subscriptions refer to fixed-line subscriptions that enable access to the public Internet at downstream speeds ≥ 256 kbit/s.	ITU
<i>cable_comp</i>	Share of cable subscriptions relative to total basic broadband subscriptions. Cable modem Internet subscriptions refers to the number of Internet subscriptions using a cable modem service to access the Internet at downstream speeds ≥ 256 kbit/s. Cable modem is a modem attached to a cable television network.	OECD
<i>wages</i>	Average annual wages per capita in USD.	©MarketLine
<i>pop_dens</i>	Population density of a country in persons per square kilometer.	WorldBank
<i>telecom_prices</i>	Index (2010=100) putting in relation the prices of telecommunications services in different years.	©Euromonitor
<i>mobile_comp</i>	Total number of wireless broadband subscriptions in thousands.	©Euromonitor
Macroeconomic variables		
<i>lt_ir</i>	Long-term interest rate for debt security issued at 10 years maturity in local currency unit.	OECD
<i>free_invest</i>	Investment freedom as part of Heritage Index of Economic Freedom. Maximum value of 100 would be taken on if there were unlimited flow of investment capital.	Heritage

Table A.1 (continued)

Budget variables		
<i>comm_exp</i>	Consumer expenditure on communications; the amount (in USD) spent on communications by an average household in the respective year.	©Euromonitor
<i>hh_size</i>	Average number of persons living in a household.	©MarketLine
ICT affinity and content variables		
<i>adr</i>	Ratio of dependents (people younger than 15 or older than 65) per 100 working-age individuals.	WorldBank
<i>internet_users</i>	Number of individuals who have made use of the internet within the last 12 months per 100 persons.	ITU
<i>servers</i>	Secure Internet servers using encryption technology in Internet transactions per 1 million people.	WorldBank
<i>Netflix</i>	Dummy variable that takes on a value of 1 if Netflix streaming services were available, and 0 otherwise.	Own research
<i>laptop</i>	Percentage of households possessing a laptop.	©Euromonitor
<i>smartphone</i>	Percentage of households possessing a smartphone.	©Euromonitor
<i>tablet</i>	Percentage of households possessing a tablet.	©Euromonitor
<i>ict_trade</i>	Sum of ICT goods imports and ICT goods exports, both expressed as percentage of total goods imports/exports (including computers and peripheral equipment, communication equipment, consumer electronic equipment, electronic components, and other information and technology goods).	WorldBank
Instrumental variables		
<i>left_wing</i>	Share of the population of country i in year t voting for (rather) left-wing parties.	Table A.4
<i>exp_gdp</i>	Total governmental expenditure as percentage of GDP.	©MarketLine
<i>gov_spend</i>	$GE_i = 100 - a(\text{Expenditures}_i)^2$ where GE_i represents the government expenditure score in country i ; Expenditures represents the total amount of government spending at all levels as a portion of GDP (between 0 and 100), and a is a coefficient to control for variation among scores (set at 0.03).	Heritage
$NNR_{j \neq i}$, $NNR(\text{expect})_{j \neq i}$	Average number of implemented (announced) net neutrality regulations in all other countries within a certain OECD region (other than country i) in year t . It is defined as the ratio of net neutrality regulations implemented (announced) in all other regional OECD countries (i.e., other than focal country i) to the total number of other countries within an OECD region.	Own calculation

Notes: *Some of the data are commercially available only (©) whereas the other data are publicly available. *Data from FTTH Council Europe were available via membership status and own research.

Table A.2: Summary statistics

	#Obs	Mean	St.Dev	Min	Max
Fiber vars.					
<i>fiber_inv</i>	576	1.01e+07	2.67e+07	0	2.24e+08
<i>ln(fiber_inv)</i>	576	11.594	6.226	0	19.227
<i>L.ln(fiber_inv)</i>	544	11.323	6.296	0	19.227
<i>L2.ln(fiber_inv)</i>	512	11.023	6.364	0	19.227
<i>fiber_sub</i>	576	3380000	1.08e+07	0	1.08e+08
<i>ln(fiber_sub)</i>	576	10.398	5.796	0	18.495
<i>L.ln(fiber_sub)</i>	544	10.119	5.836	0	18.296
Net neutrality vars.					
<i>NNR</i>	576	.38	.486	0	1
<i>L.NNR</i>	544	.347	.477	0	1
<i>NNR(expect)</i>	576	.432	.496	0	1
Control vars.					
<i>lt_ir</i>	525	4.043	2.745	-.362	26
<i>telecom_prices</i>	544	99.183	15.789	43.5	250.8
<i>cable_comp</i>	512	.252	.16	0	1
<i>mobile_comp</i>	544	.483	.445	0	2.169
<i>basic_broadband</i>	512	.564	.258	0	1
<i>free_invest</i>	576	74.913	11.85	50	95
<i>wages</i>	543	36178.97	19692.79	4724.26	95514.62
<i>pop_dens</i>	544	142.815	136.037	2.558	529.652
<i>adr</i>	543	50.146	5.574	36.323	67.548
<i>comm_exp</i>	512	2.899	.8	0	5.29
<i>hh_size</i>	544	2.608	.457	2	4.17
<i>ict_trade</i>	512	17.139	10.702	4.445	64.126
<i>laptop</i>	544	42.719	25.613	.3	91.8
<i>tablet</i>	544	12.944	17.833	0	68.4
<i>smartphone</i>	544	30.33	28.169	.2	93.1
<i>Internet_users</i>	543	67.768	20.611	11.38	97.644
<i>servers</i>	512	4241.342	11462.11	3.575	123000
<i>Netflix</i>	576	.34	.474	0	1
Instrumental vars.					
<i>NNR_{j≠i}</i>	576	.372	.381	0	.97
<i>NNR(expect)_{j≠i}</i>	576	.425	.406	0	.97
<i>left_wing</i>	576	37.965	13.655	0	66.667
<i>exp_gdp</i>	544	40.898	12.699	0	65.26
<i>gov_spend</i>	576	42.568	21.053	0	90.1

Notes: Summary statistics refer to 32 OECD countries; listed variables are available for the periods 2002–2019, 2003–2019, or 2003–2018, implying different maximum numbers of observations (576, 544, and 512, respectively). Note also that some variables exhibit missing values. *L* and *L2* stand for values lagged by one and two periods, respectively.

Table A.3: Overview of net neutrality regulations in OECD countries from 2002-2019

CC*	Net Neutrality Regulations⁺	Source (last accessed on 16 December 2020)
EU+	Year of rulemaking: 2015 Year of first notification: 2013	Regulation (EU) 2015/2120 [‡] Proposal for Regulation EC (2013)627 ^α
CA	Year of rulemaking: 2010 Year of first notification: 2009	http://www.crtc.gc.ca/eng/archive/2009/2009-657.htm OECD (2013)
CL	Year of rulemaking: 2010 Year of first notification: 2007	https://www.leychile.cl/Navegar?idNorma1016570 http://www.leychile.cl/Navegar/-scripts/obtienearchivo?id=recursoslegales/10221.3/22975/2/HL20453.pdf
FI	Year of rulemaking: 2015 Year of first notification: 2014	https://www.finlex.fi/fi/laki/ajantasa/2014/20140917 https://www.finlex.fi/sv/laki/ajantasa/2014/20140917
IS	Year of rulemaking: 2016 Year of first notification: 2016	https://www.accessnow.org/iceland-path-net-neutrality/ https://www.accessnow.org/cms/assets/uploads/2016/03/Access-Nows-written-opinion-on-the-TSM-2.pdf
IL	Year of rulemaking: 2013 Year of first notification: 2013	http://law.co.il/media/computer-law/net_neutrality_tazkir.pdf
JP	Year of rulemaking: 2010 Year of first notification: 2007	http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/Telecommunications/pdf/news071023_2_ap.pdf https://www.researchgate.net/publication/228295273_A_Comparison_of_Network_Neutrality_Approaches_In_The_US_Japan_and_the_European_Union
KR	Year of rulemaking: 2011 Year of first notification: 2011	https://www.medianama.com/2020/08/223-net-neutrality-south-korea/
MX	Year of rulemaking: 2014 Year of first notification: 2014	http://www.lexology.com/library/detail.aspx?g=7a7e43f0-ef5a-4a60-a7f1-807e7180f1c6 https://www.natlawreview.com/article/general-overview-mexico-s-new-federal-telecommunications-and-broadcasting-law
NL	Year of rulemaking: 2012 Year of first notification: 2011	OECD (2013); https://www.theguardian.com/technology/-/2011/jun/23/netherlands-enshrines-net-neutrality-law
SL	Year of rulemaking: 2012 Year of first notification: 2011	https://www.uradni-list.si/_pdf/2012/Ur/u2012109.pdf
TR	Year of rulemaking: 2012 Year of first notification: 2012	http://www.btk.gov.tr/en-US/Laws
CH	Year of rulemaking: 2014 Year of first notification: 2014	https://www.bakom.admin.ch/bakom/en/homepage/digital-switzerland-and-internet/internet/net-neutrality.html
AU; NZ	No net neutrality regulations in 2002–2019 period	

Table A.3 (continued)

CC*	Net Neutrality Regulations⁺	Source (last accessed on 16 December 2020)
U.S.	Year of rulemaking: 2010 Year of first notification: 2009	https://docs.fcc.gov/public/attachments/FCC-10-201A1.pdf http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-09-93A1.doc
	Year of rulemaking: 2015	http://transition.fcc.gov/Daily_Releases/Daily_Business/2015/db0312/FCC-15-24A1.pdf
	Year of first notification: 2014	https://transition.fcc.gov/Daily_Releases/Daily_Business/2014/db0515/FCC-14-61A1.pdf
	Year of withdrawal of rule: 2017	https://www.fcc.gov/document/fcc-releases-restoring-internet-freedom-order
	Year of first notification: 2017	

Notes: * We refer to OECD countries with two-digit country codes in column 1 of Table A.3 (and A.4); EU+ refers to Norway and the following group of EU member states: EU: AT, BE, CZ; DK; EE; FR; DE; GR; HU; IE; IT; NL; NO; PL; PT; SK; ES; SE; UK. The year of rulemaking refers to the date of Regulation (EU) 2015/2120 (European Union, 2015); the year of first notification refers to a proposal for a regulation of the European Parliament and of the Council (European Commission, 2013). + Binding net neutrality regulations are mandated and use a formal policy instrument such as legislation, administrative order, etc. and come with punishments in case of deviation.

Table A.4: Election results in all OECD countries (2002–2019)

CC	Source (last accessed on 16 December 2020)
EU	https://www.election-results.eu/
NO	http://eed.nsd.uib.no/webview/ ; https://valgresultat.no/?type=ko&year=2019
IS	http://eed.nsd.uib.no/webview/index.jsp?study=http://129.177.90.166:80/obj/fStudy/-ISPA1999_Display&mode=cube&v=2&cube=http://129.177.90.166:80/obj/-fCube/ISPA1999_Display_C1&top=yes
CH	https://en.wikipedia.org/wiki/2019_Swiss_federal_election ; https://www.bfs.admin.ch/bfs/en/home.html
TR	https://en.wikipedia.org/wiki/2018_Turkish_parliamentary_election ; http://www.ysk.gov.tr/tr/ysk-logo/1609
CA	https://www.elections.ca/content.aspx?section=ele&lang=e
U.S.	https://www.britannica.com/topic/United-States-Presidential-Election-Results-1788863
CL	https://en.wikipedia.org/wiki/2017_Chilean_general_election https://web.archive.org/web/20161025162111/http://www.serveelecciones.cl
MX	https://web.archive.org/web/20170817034702/
IL	https://en.wikipedia.org/wiki/September_2019_Israeli_legislative_election https://votes22.bechirov.gov.il/nationalresults
JP	https://en.wikipedia.org/wiki/Next_Japanese_general_election http://www.shugiin.go.jp/internet/itdb_english.nsf/html/statics/english/strength.htm
KR	https://en.wikipedia.org/wiki/2016_South_Korean_legislative_election ; http://info.nec.go.kr/
AU	https://www.aec.gov.au
NZ	https://en.wikipedia.org/wiki/Next_New_Zealand_general_election ; https://elections.nz

U.S. broadband networks rise to the challenge of surging traffic during the pandemic

Anna-Maria Kovacs, Ph.D., MBA

June 2020

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U.S. broadband networks rise to the challenge of surging traffic during the pandemic

Anna-Maria Kovacs

Since the Covid-19 shelter-in-place and lockdowns began, internet traffic has surged and networks in various parts of the world have responded at different levels. Data from Ookla show that the U.S. broadband networks have performed very well, particularly when compared to those of the European Union (EU) and the OECD. Three factors that may account for that are the high level of investment in telecommunications by U.S. carriers, the prevalence of high-speed fixed-broadband networks in the U.S., and a light-touch regulatory environment.

Global internet traffic has exploded

It is not unusual, of course, for internet traffic to grow. Cisco VNI predicted that global internet traffic would grow at an annual compounded growth rate of 30% between 2017 and 2022.¹ What is unusual in the Covid-19 environment is the suddenness of the traffic growth. Rather than growing 30% in a year, traffic grew about that much in a month. Sandvine reports a “staggering increase in volume for network operators to cope with and absorb.”² During March, according to Sandvine, global traffic grew 28.69% with an additional 9.28% during April, for a total of 38% over the two months. Upstream traffic growth was even more stunning, up 123.18% in March before leveling off.

Methodology

Ookla gathers data from millions of internet users every day about the speeds at which their networks operate and then aggregates that data.³ It has provided a weekly report on global internet network performance during the pandemic by country.⁴ Ookla’s report dated June 8th for the period ending June 7th provides, for each week, both the mean and median performance for many countries’ fixed-broadband and mobile-broadband networks.⁵

Our goal is to compare the performance of the U.S. networks to those of some of its peers, i.e. entities that have relatively similar scale and population density. Specifically, we analyzed data for the U.S., for the OECD⁶ countries excluding the U.S, for the EU, and for the combined-total of the four largest countries in the EU (Germany, France, Italy, and Spain).

The U.S. houses roughly 328 million people in about 3.7 million square miles, for a population density of 93 people per square mile. Within the U.S., there is tremendous variety, with population density ranging from Alaska’s 1.2 people per square mile to the District of Columbia’s 9,857 people per square mile.⁷ The EU houses roughly 446 million people in 1.54 million square miles, for a population density of 289 people per square mile, but again with great variations among its member states.⁸ The OECD includes many of

the EU countries, but adds some countries like Canada and Australia that, like the U.S., include very large areas with low population density.

The period covered was determined by Ookla, which treated the week of March 2^d to March 8th as the base week, i.e. the week before the pandemic effect began. Unless otherwise stated, our analysis covers the fourteen weeks that begin with Ookla's base week, from March 2^d through June 7th.

We analyzed Ookla's data for both fixed and mobile networks to determine the average⁹ performance for each of these entities during the pandemic. In each case, we took the mean of the weekly rates provided by Ookla for each country for the given period. For the U.S. and the global average¹⁰ that is the rate we report. For the EU, EU-4, and OECD we weighted the mean by the percentage of that entity's broadband-subscriptions that each country contributes to the total, based on the most recent subscription numbers provided by the OECD.

U.S. networks generally outperformed their peers

As can be seen from Figure 1, the U.S.' fixed-broadband download speeds far exceeded those of its EU and OECD peers. Of course, that reflects the performance of the networks during normal times as well as during the pandemic. Figure 1 shows the range of weekly speeds during the pandemic (as do Figures 2-4). It is worth noting that on average, the U.S. mean download speed during the pandemic period was 138 megabits per second (mbps) while the weighted mean download speeds of the EU, EU-4, and OECD were 102 mbps, 106 mbps, and 89 mbps, respectively. The global mean download speed was 75 mbps. In other words, the U.S. fixed-broadband download speed exceeded the global speed by 83%, and those of the EU, EU-4, and OECD by 35%, 30%, and 55% respectively.

While Figure 1 is based on the mean download rates for each entity, Figure 2 is based on the median. Again, the U.S. greatly outperformed its peers. It outperformed the global average by 150%, the EU by 83%, and both the EU-4 and the OECD by 95%.

Figures 1 and 2 also shows that the U.S. networks' fixed-broadband speed bottomed out within three weeks, as did the global index, while the speeds of the EU, EU-4, and OECD continued to decline for another three weeks.

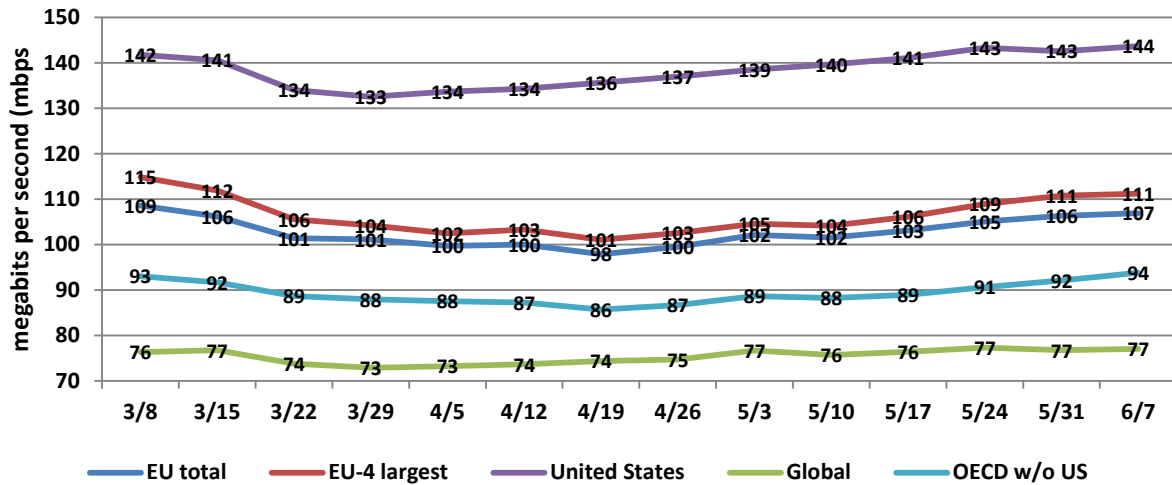
As Figures 3 and 4 show, the U.S. mobile-broadband download speed also exceeded that of its peers, though not nearly as dramatically. The U.S. mobile average (mean) download speed was 37% higher than the global rate, and 9%, 15%, and 16% higher than those of the EU, EU-4, and OECD. When median rates are considered, the U.S. outperformed the global average by 70%. It also outperformed the EU, EU-4, and OECD by 6%, 18%, and 11% respectively.

Figures 3 and 4 show that the mobile networks of all the entities reached bottom during the third week, recovered at somewhat different rates, but all have reached or exceeded their pre-Covid levels as of June 7th.

Figure 1

Fixed Broadband: Weighted Average Download Speed

during the pandemic: 3/2/20-6/7/20

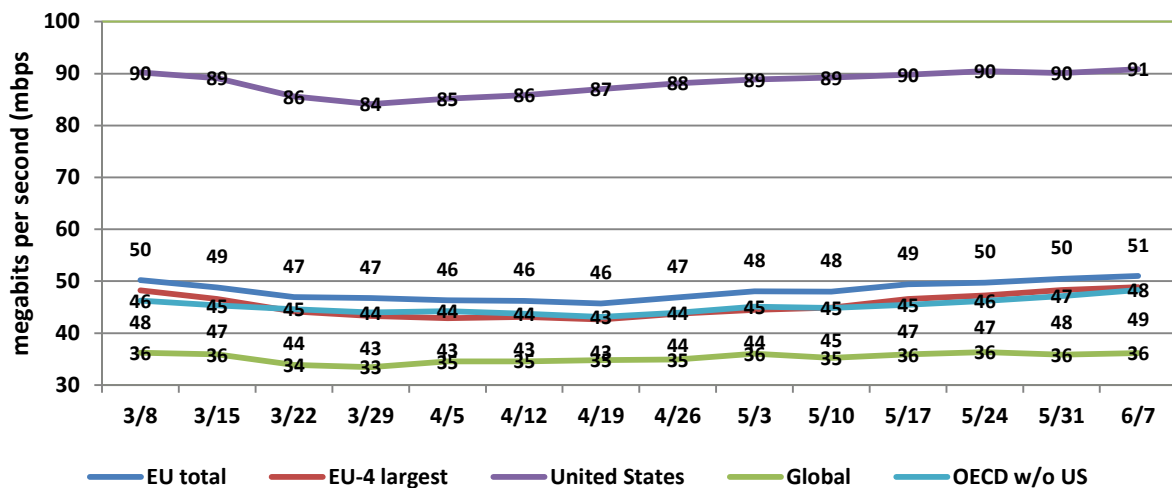


Source: Ookla Speedtest (speed), OECD (weighting)

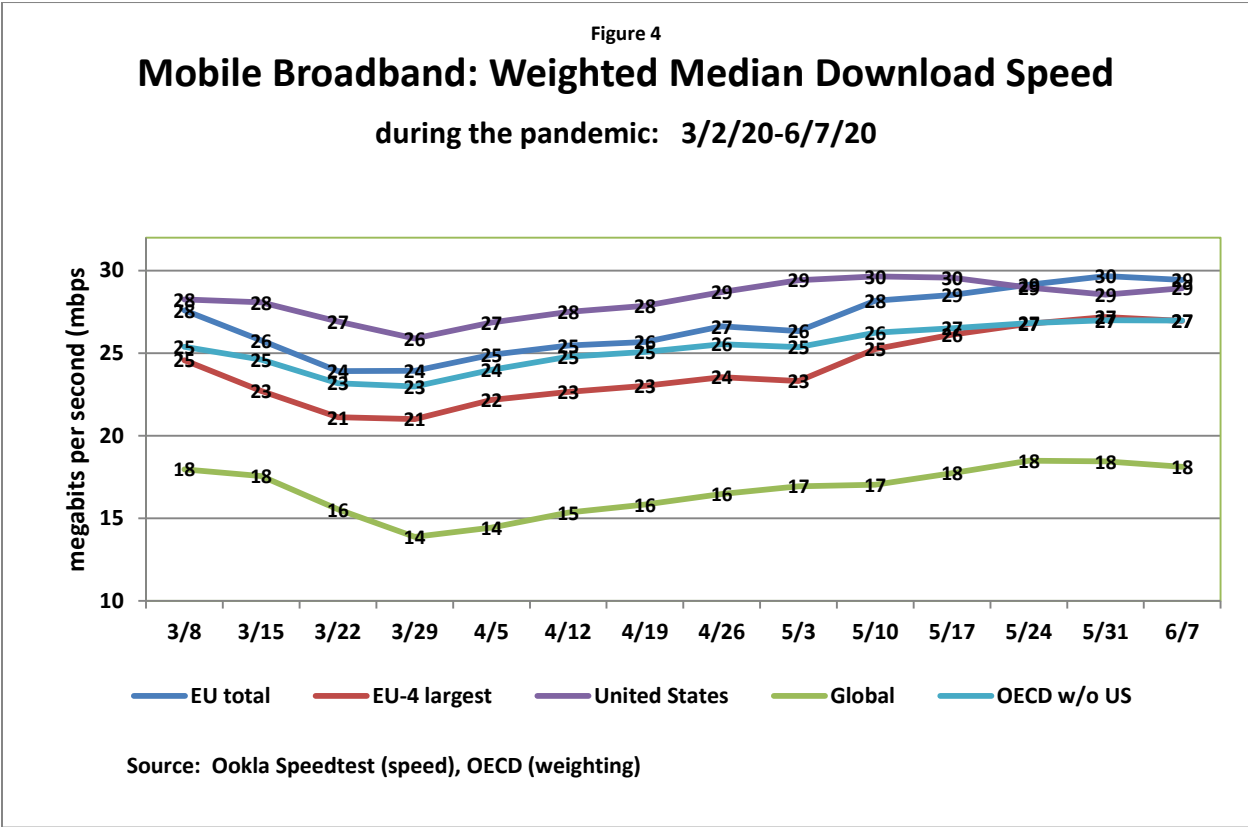
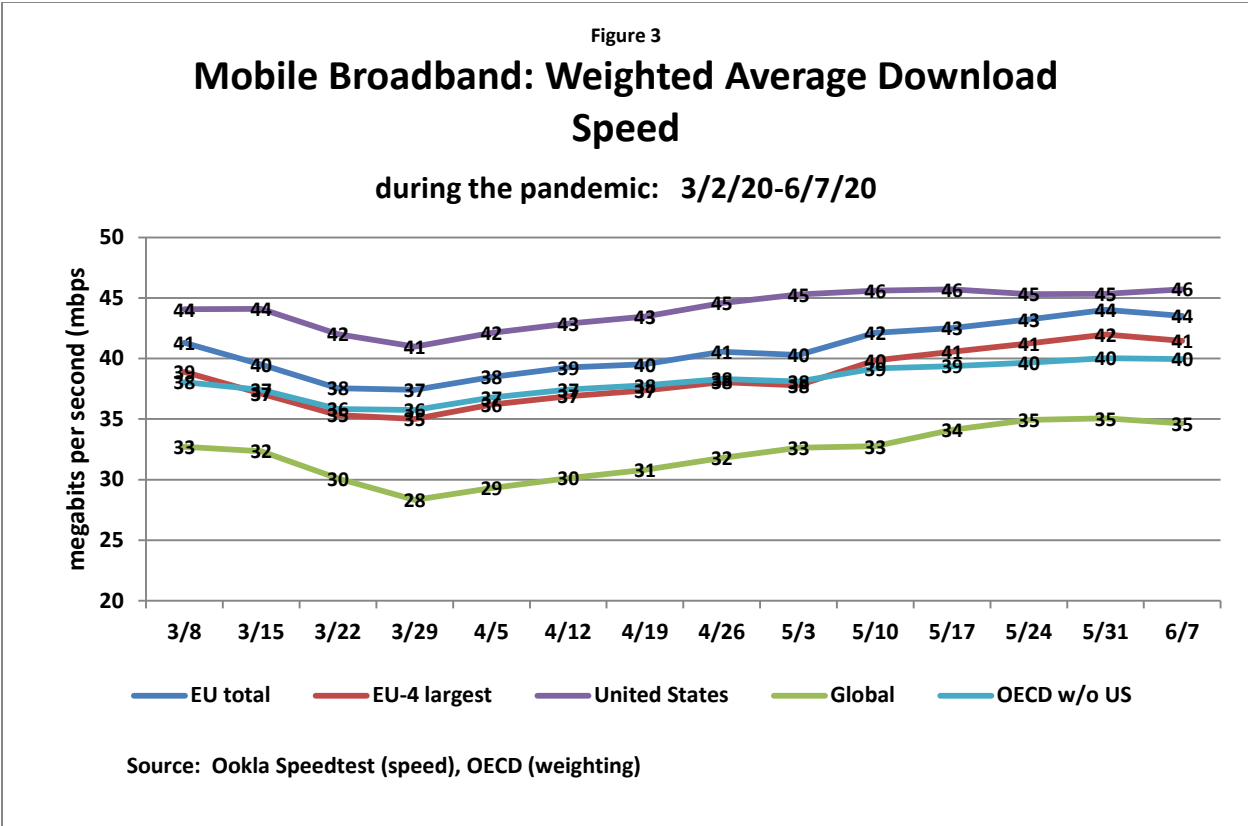
Figure 2

Fixed Broadband: Weighted Median Download Speed

during the pandemic: 3/2/20-6/7/20



Source: Ookla Speedtest (speed), OECD (weighting)

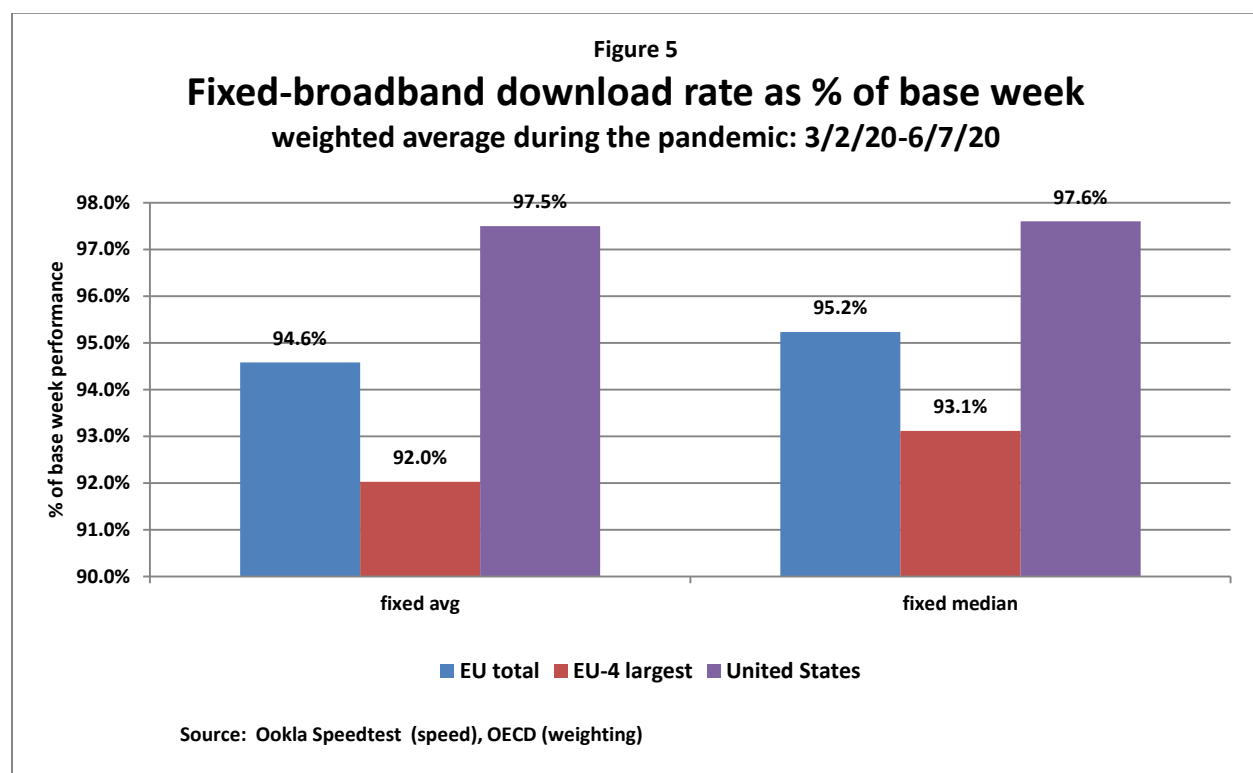


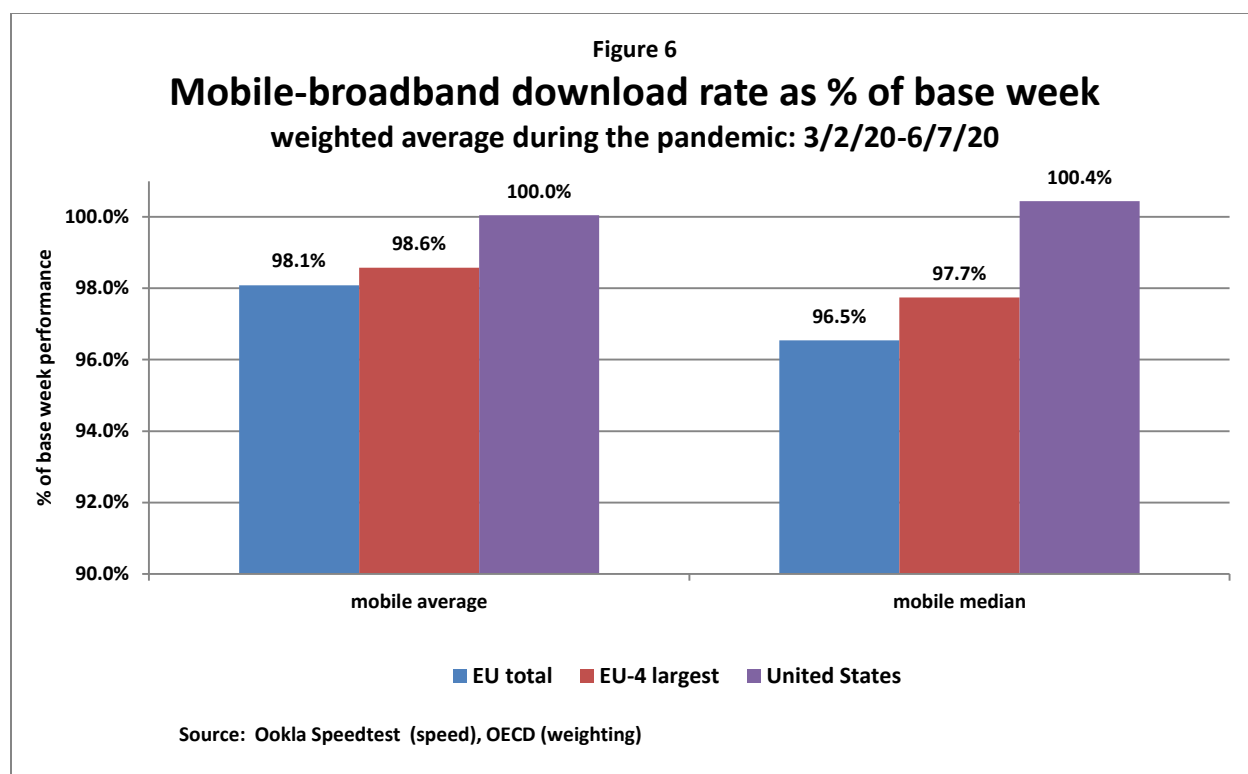
Investment and technology-mix affect performance

According to Sandvine, the two biggest contributors to internet traffic are YouTube and Netflix. Together, they comprise a total of 27% of global traffic and 24% of U.S. traffic.¹¹ EU Commissioner Thierry Breton was concerned that European networks would not be able to handle the rapid traffic increases during the pandemic. Via Twitter, on March 18th, he asked European consumers to shift their video streaming from high-definition (HD) to standard-definition (SD). He also asked the video-streaming companies directly.¹² Netflix responded by reducing its streaming speeds in Europe by 25%,¹³ while YouTube shifted to SD globally.

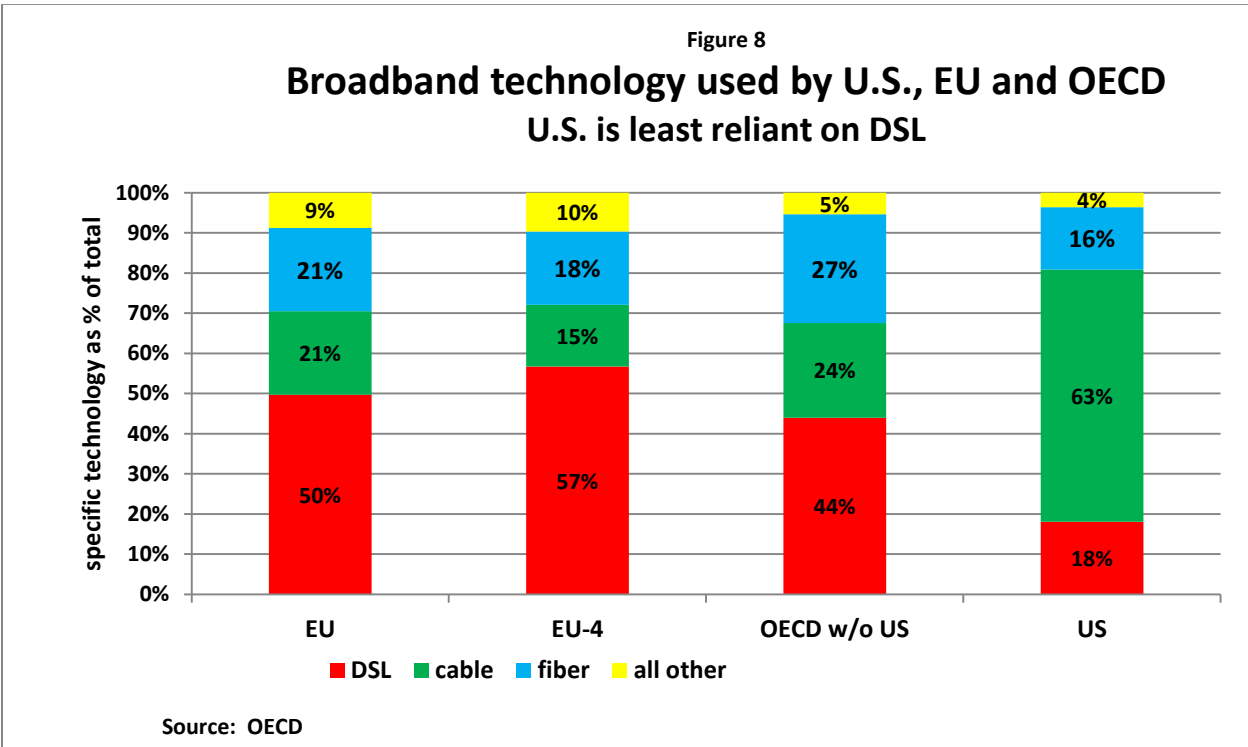
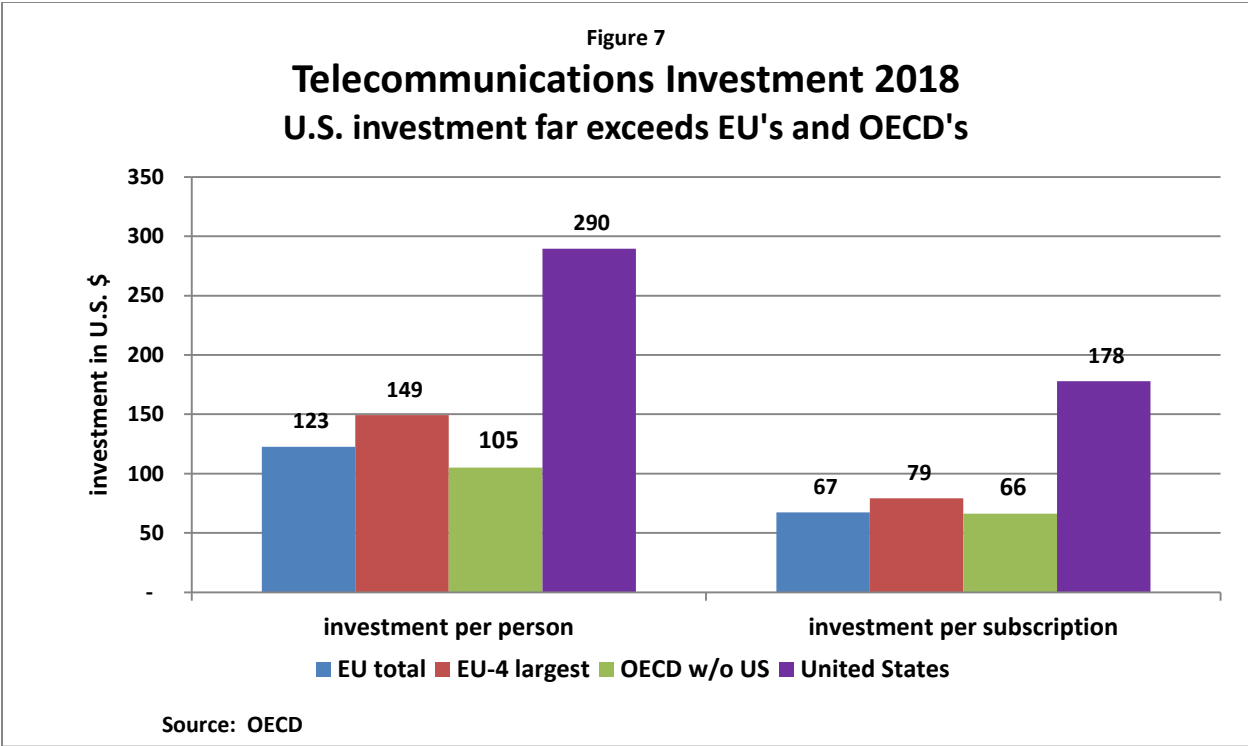
Commissioner Breton's concern is understandable if one examines the data for the individual EU countries during the week he made his request. The performance of the EU's networks deteriorated significantly, with the EU's fixed-broadband networks operating an average of 7% below their base-week level and their mobile-broadband networks operating roughly 10% below. Ten EU countries had fixed-broadband performance deteriorate by more than 10%. For perspective, the performance of U.S. fixed-broadband and mobile-broadband networks remained within 5% of the base-week level.

The longer-term effect of the deeper descent and more gradual recovery of the EU and EU-4 networks can be seen in Figures 5 and 6, which compare the weighted-average and weighted-median performance of the fixed-broadband and mobile-broadband networks of the EU, EU-4, and the U.S. from March 2^d through May 7th.¹⁴





One obvious question is why the EU needed such help from the video-streaming companies and the U.S. did not. Three factors may help explain the difference in performance between the U.S. and its peers. First is the far higher level of investment in telecommunications by the U.S. than by the EU and, for that matter, the OECD. Figure 7 shows that U.S. carriers invest in telecommunications 136% more per person than do those of the EU, 94% more than those of the EU-4, and 176% more than those of the OECD.¹⁵ On a per-subscription basis, including both fixed-broadband and mobile-broadband subscriptions,¹⁶ the U.S. carriers spend 163%, 125%, and 169% more than their counterparts in the EU, EU-4, and OECD respectively. An article by Roger Entner shows that this is not a recent phenomenon. Rather, the U.S. telecom carriers have out-invested their peers for decades.¹⁷



Second, the U.S. also employs a different mix of technologies than do its peers. In particular, the U.S. is much less DSL-reliant than the EU, instead relying more heavily on cable and fiber networks, both of which provide high-speed fixed-broadband. Figure 8 shows the fixed-broadband technologies used by the U.S., EU, EU-4, and OECD. It is striking how little the U.S. relies on DSL compared to its peers. DSL constitutes only 18% of U.S. fixed-broadband subscriptions v. 50% for the EU, 57% for the EU-4, and 44% for the OECD. On the other hand, the U.S. employs cable—which is now capable of gigabit speed—much more heavily. Of U.S. subscribers, 79% use either cable or fiber, v. 42% in the EU, 33% in the EU-4, and 51% in the OECD. As the Ookla results show, the U.S. mix of technologies results in performance that is far superior to that of its peers.

Third, relative to a more heavy-handed regulatory approach in Europe, the U.S. has enjoyed a broadband policy environment dating back to the turn of the century that has encouraged private sector investment in networks. While among the complex of countries that constitute the EU or OECD there is a range of regulatory policies, on the whole it is fair to say that the U.S. has enjoyed a lighter-touch regulatory environment.¹⁸ While this lighter-touch regulatory approach cannot be said to always be superior to alternative governance mechanisms, the lighter-touch approach toward the broadband industry has proven to be consistent with a “Results-Based” regulatory approach that looks at tangible economic metrics to guide policy. Price, output, investment and network innovation have proven themselves to be responsive to the policy environment in the U.S.¹⁹ The result is that U.S. networks are better positioned to perform at higher levels and could respond more rapidly to the Covid-driven demand surge than those in Europe.

¹ Cisco Visual Networking Index: Forecast and Trends, 2017-2022, Figure 5.

² Sandvine, *Global Internet Phenomena Report Covid-19 Spotlight*, May 2020, p. 5.

³ Ookla explains its methodology in: *Ookla SPEEDTEST Methodology, the definitive source for network performance metrics, 2006-2020*. On page 3 of this document, Ookla explains why its tests often show higher speeds than those that use other methodologies.

⁴ We used data from Ookla Speedtest Covid-19 spreadsheet updated for the week ending June 7, 2020.

⁵ It is worth noting that Ookla tends to show speeds higher than those shown by other testing methodologies, but it is consistent within itself, as Ookla explains in its document about its methodology. In other words, a comparison of U.S. speeds shown by Ookla v. speeds shown by Cisco VNI could (and does) vary significantly, so that a comparison of a U.S. speed measured by Ookla v. another country’s speed measured by Cisco would not be valid. However, a comparison of a U.S. speed measure by Ookla v. that of another country’s speed measured by Ookla is valid because the methodology is consistent.

⁶ Unless otherwise specified, in this paper OECD refers to the OECD excluding the U.S.

⁷ U.S. Census 2010.

⁸ Website of the European Union, Living in the EU.

⁹ OECD iLibrary, National Accounts of OECD Countries, Volume 2019, Detailed Tables, OECD Publishing, Paris 2019. OECD website tables: 1.1, 1.2, 2.1, 9a, 9b. For the OECD, for the EU, and for the combined four largest EU countries (EU-4, Germany, France, Italy, Spain) we weighted the averages by the fixed and mobile subscriber numbers provided by the OECD for 2018, the most recent year available. Our totals for the OECD do not include Korea and Iceland, because Ookla did not provide data for those. Our totals for the EU do not include Bulgaria, Croatia, Cyprus, and Romania, because the OECD did not provide data for those.

¹⁰ Ookla presents the data for the U.S. and the global index as single entities so we did not have the necessary data to weight the components.

¹¹ Sandvine, *Global Internet Phenomena Report Covid-19 Spotlight*, May 2020, p. 7.

¹² Twitter stream by Thierry Breton, on March 18th stating that he had an “Important phone conversation with @Reed Hastings, CEO of Netflix” and requesting “To secure Internet access for all let’s #SwitchToStandard definition when HD is not necessary.” Follow up on March 19th: “I welcome the very proper action that #Netflix has taken to preserve the smooth functioning of the Internet during the #COVID19 crisis while maintaining a good experience for users” and on March 20th: “I warmly 👍 the initiative that @Google takes to preserve the smooth functioning of the Internet during the #COVID19 crisis by having #YouTube switch all 🇪🇺 traffic to SD by default.”

¹³ Netflix blog, March 21, 2020.

¹⁴ Ookla provides data on the relative performance of each country’s fixed and mobile broadband as measured against the base week. For each week, it provides the percentage by which the performance is higher or lower than that of the base week, and it does so for both the average and median. Figures 5 and 6 show the weighted average of that performance for the period of 3/2-20-6/7/20.

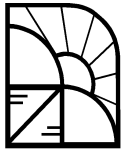
¹⁵ Figure 7 also looks at investment per broadband subscription, using OECD data, with the telecommunications investment divided by the total fixed broadband plus mobile broadband subscriptions.

¹⁶ There are more subscriptions than people because some people subscribe to both fixed and mobile broadband while some subscribe to only one or to neither. The OECD data on subscriptions includes subscriptions that can serve voice as well as data, as does the data on telecommunications investment.

¹⁷ Roger Entner, Industry Voices – Entner: A tale of two continents and the internet during COVID-19, in *FierceTelecom*, April 29, 2020.

¹⁸ Anna-Maria Kovacs, The Effect of Title II Classification on Wireless Investment, July 2017, posted by the Georgetown Center for Business and Public Policy.

¹⁹ John W. Mayo, “Results-Based Regulation: 20th Century Lessons and 21st Century Opportunities,” Economic Policy Vignette, Georgetown Center for Business and Public Policy, September 2015.



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PHOENIX CENTER POLICY BULLETIN NO. 49

George S. Ford, PhD

May 2020

COVID-19 AND BROADBAND SPEEDS: A MULTI-COUNTRY ANALYSIS

Abstract: COVID-19 has forced the residents of many nations to shelter-in-place, either by choice or by mandate. As a result, Internet use has skyrocketed, putting stress on both fixed and mobile broadband networks. In this BULLETIN, I take an early look at the performance of broadband networks with respect to download speeds. Using weekly speed data for fixed and mobile networks for months preceding and following March-2020, I find sizable reductions in speed for several countries, but also some increases in speed. Larger negative effects appear more often for lower-income countries and those with slower networks, with a few exceptions including France. Significantly, fixed networks in the United States were resilient to the traffic surges; there were no statistically-significant changes in download speeds. Mobile networks in the United States, alternately, were found to have a statistically-significant increase in download speeds.

I. Background

Deadly to both people and economies, the COVID-19 pandemic has wreaked havoc across the globe.¹ With much of the world forced to shelter-in-place, Internet use skyrocketed as

¹ See, e.g., R. Berman, *The Economic Devastation is Going to be Worse than You Think*, THE ATLANTIC (March 21, 2020) (available at: <https://www.theatlantic.com/politics/archive/2020/03/covid-19s-devastating-effects-jobs-and-businesses/608461>); N. Paumgarten, *The Price of the Coronavirus Epidemic*, THE NEW YORKER (April 20, 2020) (available at: <https://www.newyorker.com/magazine/2020/04/20/the-price-of-the-coronavirus-pandemic>).

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people turned to the Internet for work and entertainment.² The sharp and unexpected increase in traffic has stressed some Internet networks, causing shutdowns and slower download speeds. In the United States, for instance, traffic is up about 40%, while in Italy, an early hotbed of the virus, traffic has more than doubled.³

In this BULLETIN, I use data from Ookla, a popular Internet speed test tool, to quantify the effect of COVID-19 on download speeds for fixed and mobile connections. Changes in average download are calculated for the periods before-and-after the initiation of shelter-in-place policies, most of which were implemented in March-2020.⁴ Peer group analysis, where countries are grouped by average speeds, is also performed. Statistically significant changes in speeds are found for many countries in the sample, though not all are reductions in speed. Speed reductions are found more frequently in lower-income countries and countries with slower average download speeds, but I demonstrate that speed and income are highly correlated. Significantly, fixed networks in the United States were resilient to the traffic surges; there were no statistically-significant changes in download speeds. Mobile networks in the United States, alternately, were found to have a statistically-significant increase in download speeds.

II. Data

Weekly data on average download speeds for fixed and mobile connections covering 116 countries for the weeks beginning December 16, 2019 through May 11, 2020 are obtained from Ookla.⁵ Data on per-capita Gross Domestic Product (“GDP”, constant US\$) for each country are obtained from the World Bank Development Indicators database.⁶ Syria is dropped from the

² D. Holtz-Eakin, *Who Needs Net Neutrality? Internet Providers are Handling Coronavirus Demand Just Fine*, USA TODAY (May 11, 2020) (available at: <https://www.usatoday.com/story/opinion/2020/05/11/coronavirus-streaming-demand-light-regulation-works-column/3105366001>); R. Bennett, *The Internet Works Fine for Those Who Have It*, HighTech Forum (May 11, 2020) (available at: <https://hightechforum.org/the-internet-works-fine-for-those-who-have-it>); S. Flemming, *Will the Coronavirus Break the Internet*, World Economic Forum (March 23, 2020) (available at: <https://www.weforum.org/agenda/2020/03/will-coronavirus-break-the-internet>); M. Beech, *COVID-19 Pushes Up Internet Use 70% and Streaming More than 12%, First Figures Reveal*, FORBES (March 25, 2020) (available at: <https://www.forbes.com/sites/markbeech/2020/03/25/covid-19-pushes-up-internet-use-70-streaming-more-than-12-first-figures-reveal/#5e56e97c3104>); E. Koeze and N. Popper, *The Virus Changed the Way We Internet*, NEW YORK TIMES (April 7, 2020) (available at: <https://nyti.ms/2XePBWp>).

³ See, e.g., A. Bergman and J. Iyengar, *How COVID-19 is Affecting Internet Performance*, FASTLY.COM (April 8, 2020) (available at: <https://www.fastly.com/blog/how-covid-19-is-affecting-internet-performance>).

⁴ https://en.wikipedia.org/wiki/COVID-19_pandemic_lockdowns.

⁵ Data is obtained from: <https://ookla.d.pr/FtTnM>.

⁶ Data is obtained from: <http://wdi.worldbank.org/tables>.

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sample due to a lack of recent GDP data. I also exclude China and its territories from the sample because these economies initiated shut down protocols well before March-2020 (leaving few observations prior to shelter-in-place policies), though the effects on their networks are apparent in the data. In all, analysis is performed on 108 countries with 20 weekly observations each.

III. Statistical Analysis

Ookla's speed data is obtained from voluntary speed tests. It is a convenience sample, so there may be sampling bias in the data. Also, bias may derive from the dramatic increase in the number of speed tests occurring (in many countries) in March-2020. Also, the type of user and, for mobile services, the typical location of users, may have changed, perhaps dramatically, in response to shelter-in-place orders. Such bias is unavoidable and a caveat to this analysis.

As the data is a sample of users, the average weekly speed data have sampling variation. Statistical testing is required to determine whether the observed changes in average download speeds before-and-after the COVID shelter-in-place policies are out of the ordinary or else consistent with random variation in the data. The statistical procedure is a means-difference test implemented for each country by Least-Squares regression:

$$y_t = \beta + \Delta POST + \varepsilon_t, \quad (1)$$

where y_t is the speed (either fixed or mobile) in period t , $POST$ is a dummy variable equal to 1.0 after shelter-in-place policies were implemented, and ε_t is the econometric disturbance term. The estimated coefficient β measure the average speed in the pre-COVID period and Δ measures the change in average speed during the COVID period. Thus, the average speed during the COVID period is $\beta + \Delta$. A t-statistic on Δ is a direct test of the null hypothesis that speeds did not change (that is, $\Delta = 0$). Ideally, the magnitude of traffic changes on speeds could be evaluated, but I do not have data on traffic changes for individual countries. I leave that analysis to future research.

Equation (1) requires that the $POST$ variable be defined. Most countries implemented shelter-in-place policies in March-2020. Thus, I define the pre-COVID period as all weeks in the sample through February-2020. The COVID period is then defined as all weeks in April-2020, thereby excluding March-2020 from the sample as a transition period. Since the number of observations for each country is 16 weeks for country-specific analysis, I use the t-statistic for hypothesis tests.

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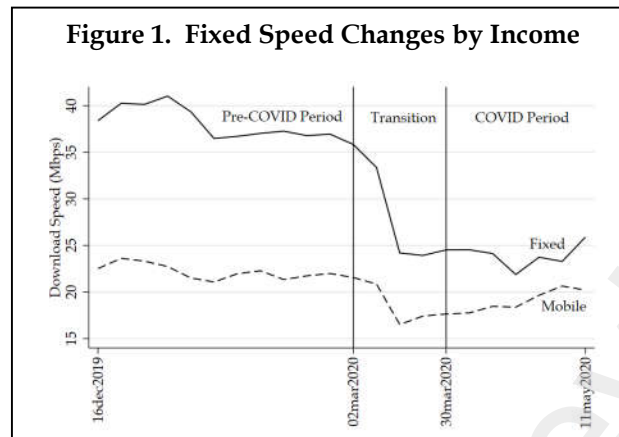


Figure 1 illustrates the weekly data for Peru, with vertical lines bounding the month of March. The speed changes in Peru for fixed services are particularly pronounced, though there is also a material decline in speed for mobile services. The shift in speed occurs during the transition window (as is the case for nearly all counties), which is excluded from the estimation sample. Equation (1) compares means in the Pre-COVID period and the COVID period. By excluding the transition period (March-2020), the analysis may miss sharp but temporary declines during the transition window. As such, the effects quantified by Equation (1) are sustained through the week beginning May 11, 2020.

In a separate analysis, I include the March-2020 data and estimate the following regression,

$$y_t = \beta + \sum_{t=12}^{20} \lambda_t^{POST} + \varepsilon_t, \quad (2)$$

where λ_t are weekly fixed effects for all weeks after February-2020. There are 11 weeks before March-2020 and 11 weeks after February-2020. The λ_t coefficients are the means differences for each week relative to the pre-COVID period, and the pattern in these coefficients (and their significance levels) can be used to look for statistically significant means differences during the transition month March and then through the remainder of the sample period.

A. Results for Fixed Broadband

Table A-1 in the Appendix summarizes the results for Equation (1) estimated individually for each country. For fixed connections, 54 of 108 countries experienced a speed reduction, and 33 of these changes are statistically different from zero at the 10% level or better. The average speed reduction is 9.2% while the average speed increase is 6.6%, so there is an asymmetry in the responses. Despite the claim that the Coronavirus “is breaking the Internet,” fixed download speeds in the United States were stable with no statistically-significant changes in

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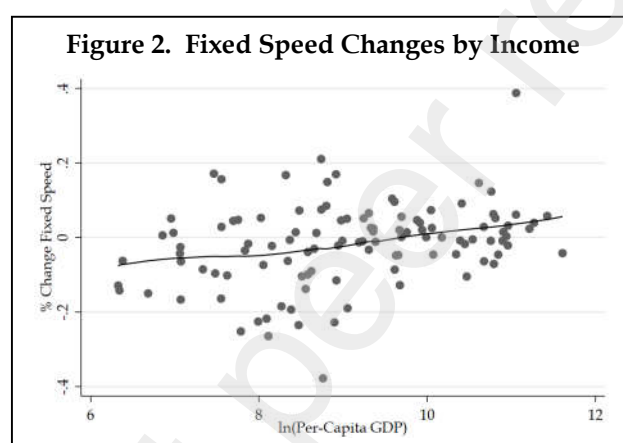
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speed.⁷ Reductions in speed of more than 5% are found for 32 countries including, in order of size, Peru, Morocco, Nigeria, Algeria, Libya, Philippines, Jordan, Tunisia, Venezuela, Sri Lanka, Pakistan, Sudan, Nepal, Afghanistan, Ecuador, Ethiopia, Oman, Lebanon, Dominican Republic, Italy, Albania, India, North Macedonia, Ghana, Iraq, Turkey, Myanmar, Guatemala, Japan, Kenya, France, Indonesia, and Mozambique. Of these countries, the reduction in speed is not statistically different from zero for either Ethiopia or Mozambique. Statistically significant speed reductions of an amount less than 5% are observed for Bangladesh, Canada, Croatia, Luxembourg, Portugal, Singapore and Trinidad and Tobago. Statistically significant *increases* in fixed broadband speeds are found for Austria, Belarus, Brazil, Chile, the Czech Republic, Denmark, Estonia, Finland, Germany, Jamaica, Kuwait, Lao PDR, Mexico, Mongolia, Norway, Panama, Qatar, the Russian Federation, Serbia, Slovak Republic, South Africa, Sweden, Switzerland, Thailand, Ukraine, the United Arab Emirates, Uruguay, and Vietnam.



Most of the countries experiencing large reductions (5% or more) have relatively low per-capita GDP. Among these countries, only France, Italy and Japan have a per-capita GDP exceeding \$20,000. Figure 2 provides a scatter plot and a Lowess smoother for the estimated percentage changes in speed (Qatar is the positive outlier and Peru is the negative outlier). A linear fit of the percent change in speed on the natural log of per-capita GDP has a constant term of 0.253 and a slope coefficient of 0.026 ($R^2 = 0.098$), though the figure reveals substantial variation in the speed change across income.

⁷ See, e.g., S. Meinrath, *The Coronavirus Pandemic is Breaking the Internet*, THE HILL (May 2, 2020) (available at: <https://thehill.com/opinion/technology/495806-the-coronavirus-pandemic-is-breaking-the-internet-and-what-to-do-about-it>).

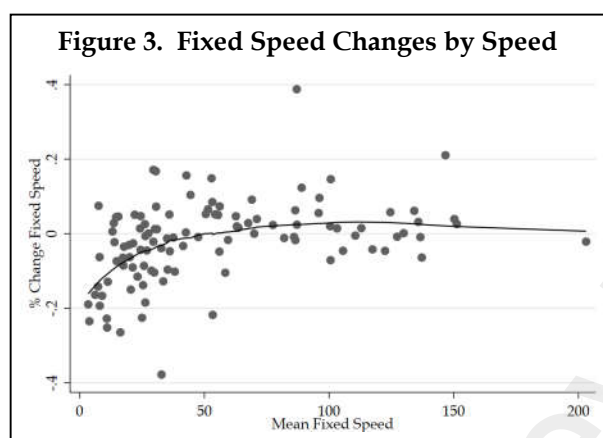


Figure 3 illustrates the relationship between the percent change in fixed speed and mean fixed speed. Larger reductions in speed are observed for countries with slower fixed broadband networks. The Lowess curve flattens at around 50 Mbps. Note that the correlation coefficient between per-capita GDP and mean fixed speed is 0.70, so Figures 2 and 3 offer related descriptions of the data.

B. Results for Mobile Broadband

Table A-2 summarizes the estimates of Equation (1) for mobile broadband speeds, of which 77 experienced speed reductions of some size; 66 countries had statistically significant reductions in speed. Mobile networks appear to have suffered more under the weight of increased usage. The average speed reduction is 9.9% while the average speed increase is 8.9%, so the changes are more symmetric than for fixed networks. In the United States, however, download speeds for mobile networks rose by 2.54% (a relatively small but still statistically significant rise in speed). Fifty countries experienced reductions in mobile download speeds more than 5%, and for all but one the change was statistically different from zero (Maldives): Sri Lanka, Ghana, Dominican Republic, Venezuela, the Philippines, Mozambique, Libya, Malaysia, Ethiopia, Tanzania, Kuwait, Peru, Sudan, Georgia, India, Chile, South Africa, Croatia, Cyprus, Oman, Lao PDR, Israel, Ireland, Italy, Spain, Uruguay, Honduras, Turkey, Czech Republic, Afghanistan, Morocco, the United Arab Emirates, Portugal, Finland, Belarus, Maldives, Poland, New Zealand, Bangladesh, Greece, Tunisia, the Russian Federation, Kazakhstan, France, Nigeria, Luxembourg, Moldova, Switzerland, Kenya, and Slovenia. Other countries with statistically significant reductions in speed smaller than 5% include Australia, Austria, Belgium, Hungary, Indonesia, Latvia, Myanmar, Saudi Arabia, Serbia, Singapore, and Thailand.

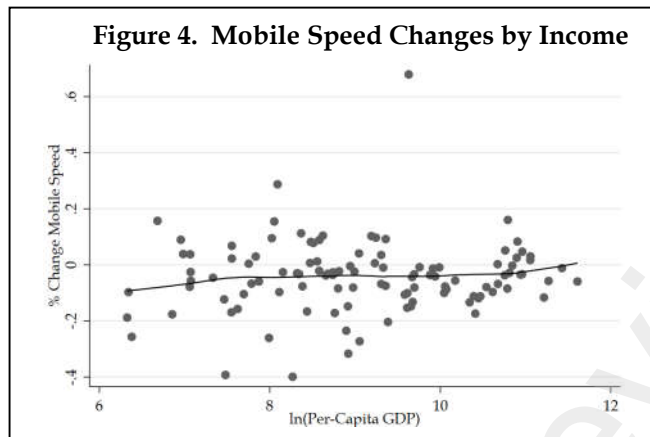
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While many of the countries in this list have relatively low per-capita GDP, income is less relevant in this group (see Figure 4). The slope of a linear fit of the change in speed on the natural log of per-capita GDP is not statistically different from zero. Higher income countries experienced a sizable decline in speed include Cyprus, the Czech Republic, Finland, France, Greece, Ireland, Israel, Italy, Kuwait, Luxembourg, New Zealand, Portugal, Slovenia, Spain, Switzerland, and the United Arab Emirates. Countries with statistically-significant increases in speed include Albania, Armenia, Brazil, Bulgaria, Costa Rica, Germany, Guatemala, Iraq, Jamaica, Japan, Jordan, Mexico, Nepal, Netherlands, Panama, Paraguay, Sweden, Trinidad and Tobago (the positive outlier), Ukraine, the United States, and Vietnam, most of which have per-capita GDP of less than \$20,000. There is no linear relationship between the change in mobile speed and log per-capita GDP.

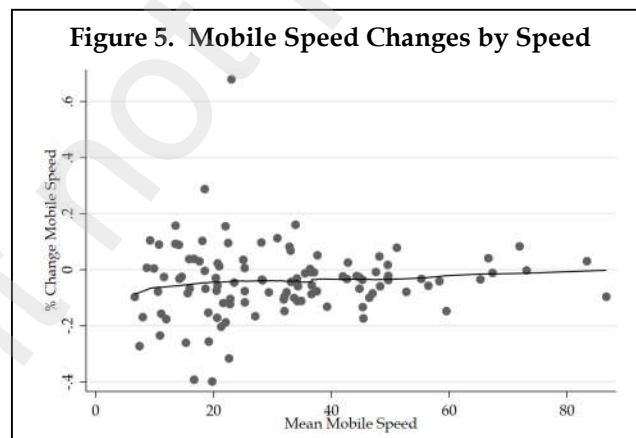


Figure 5 shows that the changes in mobile speed are related to mean network speed, but not as strongly as for income. There is no linear relationship between the two. The variance in the

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changes is plainly larger at lower speeds. Between Figures 3 and 5, faster networks appear to be more resilient to sizable traffic increases, though more so for fixed networks.

C. Weekly Changes

Equation (2) permits the estimation of weekly-specific differences in speed after February-2020. Results are summarized in Table A-3. For expositional purposes, the results are presented as patterns in the coefficients where “0” indicates no statistically significant change in speed, “-” indicates a statistically-significant reduction in speed, “+” indicates a statistically significance increase in speed, and “/” indicates the transition from March to April. Statistical significance is measured at the 10% level. For instance, fixed networks in Peru have the pattern “0---/-----” indicating statistically-significant reductions in download speeds starting the second week of March-2020 and persisting throughout the sample period, as is illustrated in Figure 1. For the United States, the pattern for fixed download speed is “0000/00000” indicating no statistically significant changes in download speeds in any period. As the patterns are unique to each country, I do not discuss these results in detail.

IV. Peer Performance

The analysis above calculates the mean difference for each country individually. Here, I compute the mean difference for each country relative to its peers, where its peers are based on broadband speed. A Finite Mixture Model (“FMM”) is used to classify each country into one of two groups based on average download speed.⁸ For each country, I then estimate the following regression but include in the sample all countries in its peer group,

$$\ln(y_{i,t}) = \delta D_i \cdot POST + \lambda_t + \mu_i + \varepsilon_{i,t}, \quad (3)$$

where D_i is a dummy variable indicating the country of interest, λ_t is a time fixed effect, and μ_i is a country fixed effect. The coefficient δ measures the difference in the percent change in log speed for country i relative to its peers.

A. Fixed Network Speed

The FMM divides the sample into two groups.⁹ The “slower” speed group contains 60 countries with an average speed of 23.1 Mbps. The “faster” speed group contains 50 countries

⁸ G. J. McLachlan and D. Peel, FINITE MIXTURE MODELS (2000).

⁹ The procedure assigns a probability for group membership, and I divide the sample into groups with a cutoff of 0.50.

with an average speed of 91.7 Mbps. Estimating Equation (1) for each peer group (adding in country fixed effects), the slower-speed group has an average decline in speed of 6.4% while the faster-speed group has an average increase in speed of 2.8%. Both changes are statistically different from zero at better than the 1% level. It appears that lower speed fixed networks (and, by correlation, networks in lower-income countries) are more vulnerable to increases in traffic.

Table A-4 summarizes the changes in fixed speeds for each country relative to its peers. Forty-eight countries have disparate performance among their peers of which 23 are reductions in speed. For fixed broadband, speeds in the United States are consistent with the peer groups (the δ coefficient is not statistically different from zero). Countries with statistically-significant *declines* in relative speeds include Afghanistan, Algeria, Canada, Ecuador, France, Italy, Japan, Jordan, Libya, Luxembourg, Morocco, Nepal, Nigeria, Pakistan, Peru, the Philippines, Portugal, Singapore, Sri Lanka, Sudan, Trinidad and Tobago, Tunisia, and Venezuela. Countries with statistically-significant *increases* in speed relative to their peer group include Belarus, Bosnia and Herzegovina, Chile, Georgia, Germany, Greece, Honduras, Jamaica, Kuwait, the Kyrgyz Republic, Lao PDR, Lebanon, Maldives, Mexico, Mongolia, Nicaragua, Qatar, Serbia, South Africa, Tajikistan, Thailand, the United Arab Emirates, Uruguay, Uzbekistan, and Vietnam.

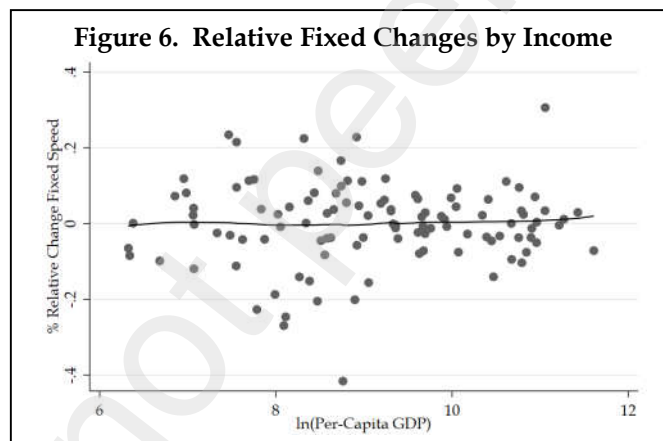


Figure 6 shows the relationship between the changes relative to peer-group and log per-capita GDP. Once the sample is divided into groups, the positive relationship between speed changes is no longer present. Due to the positive correlation of fixed speed and income, dividing the countries into speed-based peer groups appears to fully account for the effect of income. The means of fixed speed and per-capita GDP for the “Slower” and “Faster” peer groups are 23.4 Mbps and \$6,604 and 91.7 Mbps and \$32,880.

B. Mobile Network Speed

For mobile speeds, the FMM divides the sample into a “slower” speed group with 47 countries (average speed 16.6 Mbps) and a “faster” speed with 63 countries (average speed

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43.2 Mbps). Estimating Equation (1) for each peer group (adding in country fixed effects), the slower-speed group has an average decline in speed of 6.7% while the high-speed group has an average reduction in speed of 3.8%. Both changes are statistically different from zero at better than the 1% level. While both peer groups saw a reduction in download speeds for mobile networks, the slower speed networks were affected more by the increases in traffic.

Table A-4 summarizes the changes in mobile speeds for each country relative to its peers. Fifty-eight countries are found to have disparate performance among peers. The United States has a positive and statistically significant increase in relative speed among its peers. Countries with statistically-significant *declines* among peers include Chile, Croatia, Cyprus, the Czech Republic, Dominican Republic, Ethiopia, Finland, Georgia, Ghana, India, Ireland, Italy, Kuwait, Libya, Malaysia, Morocco, Mozambique, Oman, Peru, Philippines, Poland, Portugal, South Africa, Spain, Sri Lanka, Sudan, Tanzania, Turkey, the United Arab Emirates, Uruguay, and Venezuela. Countries with statistically-significant *increases* in relative speed among peers include Albania, Armenia, Bolivia, Brazil, Bulgaria, Cambodia, Costa Rica, Denmark, Germany, Guatemala, Iraq, Jamaica, Japan, Jordan, Kyrgyz Republic, Mexico, Nepal, Netherlands, Panama, Paraguay, Qatar, Sweden, Tajikistan, Trinidad and Tobago, Ukraine, the United States, and Vietnam. The pattern of speed changes and per-capita GDP is almost identical Figure 6, so I do not reproduce that figure here.

V. Conclusion

Using Ookla download speed data, I provide estimates of the effect of rising Internet use following the COVID pandemic on fixed and mobile download speeds for a large sample of countries. Download speeds for fixed and mobile networks have fallen by a statistically-significant amount for about half the countries in the sample (109 total). In several countries, speeds have increased. Slower networks appear to suffer the most under the burden of increased traffic, and, saying almost the same thing, countries with relatively low per-capita GDP are more likely to see their network speeds decline. For the U.S., fixed networks proved resilient to traffic surges as there were no statistically-significant changes in download speeds during the COVID period. Download speeds for U.S. mobile networks have increased (by a statistically-significant amount) since March-2020.

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Table A-1. Changes in Fixed Broadband Speeds

Country	Pre	Post	Diff	Country	Pre	Post	Diff
Afghanistan	7.8	6.7	-14.19%**	Libya	11.9	9.2	-22.77%***
Albania	31.3	28.0	-10.41%***	Lithuania	101.9	103.4	1.44%
Algeria	4.2	3.2	-23.5%***	Luxembourg	118.2	113.2	-4.2%**
Argentina	37.3	36.9	-1.02%	Malaysia	82.3	81.3	-1.15%
Armenia	26.2	26.0	-0.64%	Maldives	15.0	15.7	4.6%
Australia	42.2	42.4	0.33%	Mexico	35.0	36.8	5.16%**
Austria	53.3	56.1	5.21%**	Moldova	58.3	57.4	-1.68%
Azerbaijan	20.1	19.5	-3.02%	Mongolia	28.9	33.7	16.76%***
Bahrain	27.6	27.7	0.08%	Montenegro	48.1	47.7	-0.89%
Bangladesh	24.5	23.5	-4.3%***	Morocco	17.9	13.2	-26.47%***
Belarus	50.9	55.2	8.5%***	Mozambique	8.2	7.7	-6.26%
Belgium	86.0	85.3	-0.88%	Myanmar	17.8	16.3	-8.54%***
Bolivia	17.6	17.0	-3.49%	Nepal	21.3	18.1	-14.99%***
Bosnia and Herzegovina	30.8	31.2	1.23%	Netherlands	111.8	113.5	1.5%
Brazil	50.0	53.2	6.55%***	New Zealand	110.0	109.4	-0.5%
Bulgaria	54.9	57.6	5.03%	Nicaragua	13.4	13.8	2.85%
Cambodia	21.6	21.0	-2.56%	Nigeria	12.0	9.0	-25.2%***
Canada	124.0	118.3	-4.59%***	North Macedonia	29.6	26.7	-9.93%***
Chile	93.3	102.2	9.6%***	Norway	121.7	128.8	5.78%***
Colombia	29.6	29.0	-2.14%	Oman	36.4	31.7	-12.79%***
Costa Rica	35.3	34.8	-1.28%	Pakistan	9.5	7.9	-16.66%***
Croatia	36.6	34.8	-4.7%**	Panama	86.9	89.0	2.42%**
Cyprus	27.2	25.9	-4.49%	Paraguay	33.2	31.9	-3.87%
Czech Republic	54.6	58.6	7.34%***	Peru	38.2	23.8	-37.8%***
Denmark	130.9	138.9	6.14%**	Philippines	27.1	21.0	-22.55%***
Dominican Republic	24.0	21.2	-11.5%***	Poland	93.4	98.6	5.56%
Ecuador	26.9	23.2	-13.8%***	Portugal	105.5	100.7	-4.58%**
El Salvador	14.0	13.7	-2.26%	Qatar	76.4	106.0	38.77%***
Estonia	61.3	64.2	4.69%**	Romania	149.2	153.1	2.59%
Ethiopia	11.7	10.2	-12.88%	Russian Federation	63.1	64.1	1.59%**
Finland	84.3	89.6	6.28%***	Saudi Arabia	62.6	63.8	2.0%
France	138.7	129.9	-6.38%***	Serbia	49.5	56.9	14.87%***
Georgia	23.8	24.2	1.42%	Singapore	204.9	200.5	-2.12%**
Germany	83.4	93.6	12.35%**	Slovak Republic	69.5	72.3	3.95%**
Ghana	37.3	33.7	-9.63%**	Slovenia	69.6	69.7	.01%
Greece	26.1	26.8	2.57%	South Africa	28.5	33.4	16.97%***
Guatemala	15.1	14.0	-7.36%**	Spain	127.1	126.1	-0.8%
Honduras	14.3	14.9	4.47%	Sri Lanka	28.2	23.0	-18.48%***
Hungary	129.9	130.0	0.15%	Sudan	6.7	5.6	-16.4%**
India	39.8	35.7	-10.18%***	Sweden	134.5	138.7	3.17%**
Indonesia	20.4	19.1	-6.28%***	Switzerland	148.0	153.8	3.95%**
Iraq	22.5	20.5	-9.04%**	Tajikistan	21.5	22.6	5.1%
Ireland	76.6	78.4	2.34%	Tanzania	13.2	13.3	0.59%
Israel	87.4	85.9	-1.73%	Thailand	135.9	164.5	21.05%***
Italy	60.9	54.5	-10.47%***	Trinidad and Tobago	56.5	53.8	-4.8%***
Jamaica	29.6	31.8	7.25%**	Tunisia	8.8	7.1	-19.34%***
Japan	102.9	95.6	-7.09%***	Turkey	26.8	24.5	-8.62%**
Jordan	57.8	45.2	-21.78%***	Ukraine	49.5	52.1	5.27%***
Kazakhstan	41.9	40.5	-3.28%	UAE	95.5	109.5	14.64%***
Kenya	17.8	16.6	-6.42%**	United Kingdom	66.8	68.7	2.86%
Kuwait	69.0	75.4	9.13%**	United States	136.9	135.7	-0.9%
Kyrgyz Republic	30.3	30.7	1.27%	Uruguay	42.4	46.9	10.41%***
Lao PDR	27.4	32.1	17.13%**	Uzbekistan	23.8	24.9	4.74%
Latvia	99.8	101.9	2.01%	Venezuela	3.7	3.0	-18.96%***
Lebanon	7.7	8.2	7.51%	Vietnam	41.0	47.5	15.64%***

Statistical Significance: *** 1% ** 5% * 10%.

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Table A-2. Changes in Mobile Broadband Speeds

Country	Pre	Post	Diff	Country	Pre	Post	Diff
Afghanistan	6.9	6.2	-9.71%**	Libya	11.9	9.1	-23.49%***
Albania	49.9	53.8	7.82%***	Lithuania	48.0	47.7	-0.83%
Algeria	8.8	8.9	0.67%	Luxembourg	49.8	46.8	-5.93%***
Argentina	25.4	25.5	0.59%	Malaysia	23.2	18.5	-20.37%***
Armenia	30.1	33.5	11.24%***	Maldives	29.9	27.5	-8.09%*
Australia	65.8	63.5	-3.47%*	Mexico	27.6	30.3	9.7%***
Austria	50.6	49.1	-2.84%**	Moldova	34.9	32.8	-5.91%*
Azerbaijan	28.9	27.8	-3.78%	Mongolia	20.7	20.1	-3.01%
Bahrain	36.6	36.3	-0.89%	Montenegro	42.1	41.1	-2.38%
Bangladesh	11.0	10.1	-7.83%**	Morocco	33.7	30.4	-9.69%***
Belarus	16.2	14.9	-8.4%***	Mozambique	21.2	15.7	-25.65%***
Belgium	50.6	48.7	-3.71%***	Myanmar	23.8	22.7	-4.6%
Bolivia	17.7	18.2	2.98%*	Nepal	12.6	14.6	15.71%***
Bosnia and Herzegovina	34.6	33.5	-3.12%*	Netherlands	70.0	75.8	8.33%***
Brazil	24.9	25.8	3.52%***	New Zealand	53.3	49.1	-7.91%***
Bulgaria	66.0	68.7	4.08%***	Nicaragua	20.6	21.1	2.26%
Cambodia	15.8	16.4	3.78%	Nigeria	16.3	15.2	-6.69%**
Canada	73.2	73.0	-0.26%	North Macedonia	50.1	49.0	-2.17%
Chile	20.4	17.3	-15.31%***	Norway	67.0	66.2	-1.16%
Colombia	18.7	18.7	-0.43%	Oman	41.4	35.9	-13.21%***
Costa Rica	18.3	20.2	10.28%*	Pakistan	15.0	14.6	-2.54%
Croatia	63.0	53.7	-14.77%***	Panama	13.4	14.7	9.2%**
Cyprus	48.2	41.7	-13.36%***	Paraguay	14.0	15.3	8.89%*
Czech Republic	48.2	43.4	-10.01%***	Peru	22.2	18.4	-17.17%***
Denmark	49.5	50.4	1.72%	Philippines	16.7	12.4	-26.04%***
Dominican Republic	25.7	17.5	-31.67%***	Poland	33.8	31.0	-8.05%***
Ecuador	21.1	21.4	1.23%	Portugal	37.9	34.6	-8.71%***
El Salvador	11.8	11.5	-2.61%	Qatar	83.3	85.8	3.02%
Estonia	46.2	44.5	-3.61%	Romania	37.4	37.0	-0.97%
Ethiopia	23.2	18.9	-18.79%***	Russian Federation	20.9	19.4	-7.49%***
Finland	48.6	44.5	-8.43%***	Saudi Arabia	59.7	57.2	-4.14%
France	46.2	43.1	-6.79%***	Serbia	44.7	43.7	-2.26%*
Georgia	28.6	23.9	-16.61%***	Singapore	55.9	54.1	-3.31%*
Germany	37.0	38.9	5.14%***	Slovak Republic	35.5	35.0	-1.29%
Ghana	19.2	11.7	-39.24%***	Slovenia	38.0	35.9	-5.6%***
Greece	38.9	35.9	-7.7%***	South Africa	33.5	28.5	-14.78%***
Guatemala	21.3	24.5	15.48%***	Spain	36.6	32.5	-11.16%***
Honduras	24.0	21.5	-10.43%***	Sri Lanka	22.6	13.6	-39.91%***
Hungary	43.2	41.8	-3.34%**	Sudan	8.6	7.2	-16.92%***
India	11.8	10.0	-15.72%***	Sweden	47.7	49.9	4.72%*
Indonesia	14.4	13.9	-3.24%	Switzerland	58.4	55.0	-5.74%***
Iraq	9.5	10.4	10.43%*	Tajikistan	10.3	11.2	8.96%
Ireland	26.7	23.6	-11.64%***	Tanzania	13.2	10.9	-17.63%***
Israel	23.0	20.3	-11.91%***	Thailand	28.4	27.4	-3.56%**
Italy	36.4	32.3	-11.2%***	Trinidad and Tobago	19.8	33.2	67.91%***
Jamaica	32.2	34.9	8.18%***	Tunisia	26.6	24.6	-7.64%
Japan	32.1	37.3	16.02%***	Turkey	35.1	31.6	-10.08%***
Jordan	17.4	22.4	28.73%***	Ukraine	22.0	24.1	9.51%***
Kazakhstan	19.2	17.9	-6.8%**	UAE	89.3	80.7	-9.65%***
Kenya	20.9	19.7	-5.68%**	United Kingdom	36.4	36.4	.25%
Kuwait	50.1	41.4	-17.38%***	United States	42.5	43.6	2.54%*
Kyrgyz Republic	16.5	17.1	3.87%	Uruguay	33.4	29.8	-10.62%***
Lao PDR	23.6	20.7	-12.29%***	Uzbekistan	9.8	9.9	0.42%
Latvia	34.2	32.7	-4.36%**	Venezuela	8.4	6.1	-27.26%
Lebanon	46.0	44.7	-2.66%	Vietnam	32.3	34.4	6.8%**

Statistical Significance: *** 1% ** 5% * 10%.

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Table A-3. Patterns in Means Differences

Country	Fixed	Mobile	Country	Fixed	Mobile
Afghanistan	0000/0000-	0000/00000	Libya	-0--/-----	00--/----0
Albania	0---/-----	0000/00+++	Lithuania	0000/00000	+0--/-0-++
Algeria	000-/-----	00--/-0++	Luxembourg	+000/000-0	0000/00000
Argentina	0000/00000	000-/00000	Malaysia	0000/00000	00--/-----
Armenia	0+00/00000	0000/0+++0+	Maldives	0000/0+000	0000/00000
Australia	0000/00000	0+0/-0000	Mexico	++00/00000	0000/+++++
Austria	0000/0000+	+---/-00-	Moldova	++00/00000	++0/-000
Azerbaijan	0000/00000	0000/00000	Mongolia	00++/+++++	0000/00000
Bahrain	0000/00000	000-/00000	Montenegro	000-/00000	00+0/-0000
Bangladesh	0000/00-0-	00--/----0	Morocco	00--/-----	00--/----0
Belarus	0+++ /++++0	00--/-0-00	Mozambique	0000/-0000	00--/-----
Belgium	0000/000-0	00-0/00-0-	Myanmar	000-/0-00	0000/---00
Bolivia	0000/00000	--0+/00000	Nepal	000-/-----	++++/+++++
Bosnia and Herzegovina	0000/00000	000-/00000	Netherlands	0+00/00000	00++/+++++
Brazil	++00/000++	000-/00+++	New Zealand	0000/00000	+0+0/0-00
Bulgaria	0000/000++	0000/000++	Nicaragua	++00/00000	0000/00000
Cambodia	0000/00000	+0--/00000	Nigeria	00--/-----	0000/00000
Canada	000-/---00	0000/00000	North Macedonia	000-/----0	00--/00000
Chile	++00/+++++	00--/-----	Norway	0+++ /+++++	++00/00000
Colombia	0000/00000	00--/-00+0	Oman	---/-000	00--/-----
Costa Rica	+0--/-0000	0---/000++	Pakistan	00--/-----	-0--/---++
Croatia	0000/-0-00	00--/-----	Panama	00--/0++00	000-/00+++
Cyprus	0000/00000	00--/-0-0	Paraguay	0000/000-0	00-0/000++
Czech Republic	0000/0000+	000-/----0	Peru	0--/-----	00--/-----
Denmark	0000/00000	00-0/0++0	Philippines	0000/-0000	00--/-----
Dominican Republic	0000/-----	00--/-----	Poland	0000/00000	0--/---00
Ecuador	00-0/-----	0-0-/000+0	Portugal	++00/00-00	00--/---00
El Salvador	0000/00000	0000/00000	Qatar	0+++ /+++++	0000/0000+
Estonia	0000/000+0	00-0/00000	Romania	0000/00000	000-/00000
Ethiopia	0000/00000	0000/00000	Russian Federation	0+++ /+++++	000-/-----
Finland	++0+ /+++++	00--/---00	Saudi Arabia	0000/0000+	00--/---00
France	0000/00-00	00--/-----	Serbia	++++ /+++++	000-/0000
Georgia	0++0/00000	000-/----0	Singapore	00--/---00	0000/00000
Germany	++00/00000	0000/0+++0	Slovak Republic	0+00/0000+	++0-/00000
Ghana	0000/00000	0000/---00	Slovenia	0+00/00000	0---/-00-0
Greece	0000/0000+	00--/---00	South Africa	0000/0++++	000-/-----
Guatemala	0000/00000	+00-/+++++	Spain	0000/00000	00--/----0
Honduras	0000/00000	0---/-00-	Sri Lanka	00--/-----	00--/-----
Hungary	0000/00000	000-/00000	Sudan	0000/-0000	00--/---00
India	00--/-----	00--/-----	Sweden	0000/+000+	0000/000+0
Indonesia	000-/000-	000-/0000	Switzerland	+000/0000+	00--/00000
Iraq	---0/---0+	---0/000++	Tajikistan	0000/00000	0000/00000
Ireland	0000/0000+	00--/---0-	Tanzania	0000/00000	---/-0-00
Israel	00-0/00000	0--/----0	Thailand	++++ /+++++	0000/00000
Italy	0--/-----	0--/-----	Trinidad and Tobago	0000/0-00	0000/+++++
Jamaica	000+/00000	00-0/000+0	Tunisia	0--/-----	-0--/---00
Japan	0000/00---	0+++ /+++++	Turkey	000-/0000	00--/----0
Jordan	0000/00000	00-0/+++++	Ukraine	0000/++00+	0000/00+++
Kazakhstan	0000/00-00	000-/---00	UAE	0+++ /+++++	000-/---00
Kenya	0+--/---0-	0000/00000	United Kingdom	0000/0000+	0000/0000-
Kuwait	0-00/00000	---/-----	United States	0000/00000	++0-/000++
Kyrgyz Republic	000-/00000	0000/00000	Uruguay	0000/000+0	0---/-0-00
Lao PDR	0+00/+0000	0000/-----	Uzbekistan	0000/00000	0000/0000+
Latvia	0000/00000	0--/-0-00	Venezuela	00--/----0	0---/-----
Lebanon	0---/---0+	0--/-0000	Vietnam	0000/+++++	0000/+0000

Note: 0 No Stat. Sig. Change; - Stat. Sig. Reduction; + Stat. Sig. Increase; / March-April transition.

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Table A-4. Peer Comparison, Fixed & Mobile Broadband

Country	Fixed	Mobile	Country	Fixed	Mobile
Afghanistan [S, S]	-8.1%*	-3.06%	Libya [S, S]	-18.22%***	-18.81%***
Albania [S, F]	-4.4%	12.25%***	Lithuania [F, F]	-1.23%	2.97%
Algeria [S, S]	-18.51%***	6.94%	Luxembourg [F, F]	-6.89%**	-2.11%
Argentina [S, F]	6.47%	4.63%	Malaysia [F, S]	-3.87%	-14.89%***
Armenia [S, F]	6.24%	15.8%***	Maldives [S, F]	11.78%**	-3.97%
Australia [S, F]	7.32%	0.29%	Mexico [S, F]	12.61%**	14.29%***
Austria [F, F]	2.46%	0.96%	Moldova [F, F]	-4.05%	-2.44%
Azerbaijan [S, F]	3.8%	0.19%	Mongolia [S, S]	25.22%***	4.39%
Bahrain [S, F]	7.05%	3.06%	Montenegro [F, F]	-3.6%	1.34%
Bangladesh [S, S]	2.26%	-1.46%	Morocco [S, F]	-21.82%***	-6.35%**
Belarus [F, S]	5.7%*	-1.83%	Mozambique [S, S]	0.12%	-20.8%***
Belgium [F, F]	-3.63%	0.07%	Myanmar [S, S]	-2.43%	2.18%
Bolivia [S, S]	3.9%	10.63%*	Nepal [S, S]	-9.37%**	24.57%***
Bosnia and Herzegovina [S, F]	8.32%*	0.72%	Netherlands [F, F]	-1.25%	12.81%***
Brazil [F, F]	3.81%	7.7%***	New Zealand [F, F]	-3.22%	-4.37%
Bulgaria [F, F]	2.14%	8.28%***	Nicaragua [S, S]	10.04%**	9.9%
Cambodia [S, S]	4.17%	11.54%*	Nigeria [S, S]	-20.3%***	0.14%
Canada [F, F]	-7.29%***	3.74%	North Macedonia [S, F]	-3.79%	1.72%
Chile [F, S]	6.75%**	-9.48%*	Norway [F, F]	3.00%	2.81%
Colombia [S, S]	4.83%	6.78%	Oman [S, F]	-6.9%	-9.95%***
Costa Rica [S, S]	5.47%	18.65%***	Pakistan [S, S]	-11.24%**	4.11%
Croatia [S, F]	1.82%	-11.7%***	Panama [F, S]	-0.38%	17.2%***
Cyprus [S, F]	2.24%	-10.07%***	Paraguay [S, S]	2.75%	16.86%***
Czech Republic [F, F]	4.57%	-6.49%**	Peru [S, S]	-34.03%***	-11.5%**
Denmark [F, F]	3.47%	5.68%*	Philippines [S, S]	-17.05%***	-21.2%***
Dominican Republic [S, S]	-5.55%	-27.23%***	Poland [F, F]	2.95%	-4.6%*
Ecuador [S, S]	-7.93%*	8.61%	Portugal [F, F]	-7.26%***	-5.22%*
El Salvador [S, S]	4.48%	4.12%	Qatar [F, F]	35.86%***	7.14%**
Estonia [F, F]	1.96%	0.16%	Romania [F, F]	-0.06%	2.98%
Ethiopia [S, S]	-6.3%	-12.24%**	Russian Federation [F, S]	-1.17%	-0.95%
Finland [F, F]	3.45%	-4.95%*	Saudi Arabia [F, F]	-0.77%	-0.55%
France [F, F]	-9.01%***	-3.19%	Serbia [F, F]	11.98%***	1.59%
Georgia [S, F]	8.48%*	-13.59%***	Singapore [F, F]	-4.89%*	0.49%
Germany [F, F]	10.%***	9.42%***	Slovak Republic [F, F]	1.16%	2.61%
Ghana [S, S]	-3.02%	-35.43%***	Slovenia [F, F]	-2.71%	-1.94%
Greece [S, F]	9.71%**	-4.17%	South Africa [S, F]	25.66%***	-11.6%***
Guatemala [S, S]	-0.84%	24.17%***	Spain [F, F]	-3.47%	-7.77%***
Honduras [S, S]	11.99%**	-4.13%	Sri Lanka [S, S]	-13.13%***	-36.26%***
Hungary [F, F]	-2.6%	0.5%	Sudan [S, S]	-10.58%**	-11.13%**
India [S, S]	-4.11%	-10.03%*	Sweden [F, F]	0.41%	8.99%***
Indonesia [S, S]	0.15%	3.73%	Switzerland [F, F]	1.18%	-2.08%
Iraq [S, S]	-3.63%	18.75%***	Tajikistan [S, S]	12.61%**	17.45%***
Ireland [F, F]	-0.41%	-8.41%***	Tanzania [S, S]	7.53%	-11.63%**
Israel [F, S]	-4.47%	-5.75%	Thailand [F, F]	18.11%***	0.27%
Italy [F, F]	-13.1%***	-7.87%***	Trinidad and Tobago [F, S]	-7.61%***	82.13%***
Jamaica [S, F]	14.95%***	12.76%***	Tunisia [S, F]	-14.08%***	-4.49%
Japan [F, F]	-9.82%***	20.94%***	Turkey [S, F]	-2.29%	-6.64%**
Jordan [F, S]	-23.61%***	38.3%***	Ukraine [F, S]	2.5%	17.86%***
Kazakhstan [S, S]	3.37%	-0.2%	UAE [F, F]	11.77%***	-6.32%**
Kenya [S, S]	-0.21%	1.23%	United Kingdom [F, F]	0.04%	4.23%
Kuwait [F, F]	6.61%**	-14.67%***	United States [F, F]	-3.62%	6.64%**
Kyrgyz Republic [S, S]	8.46%*	11.71%*	Uruguay [F, F]	7.78%***	-7.2%***
Lao PDR [S, S]	26.43%***	-6.11%	Uzbekistan [S, S]	12.37%**	7.5%
Latvia [F, F]	-0.74%	-0.65%	Venezuela [S, S]	-14.43%***	-22.46%***
Lebanon [S, F]	10.41%**	1.14%	Vietnam [S, F]	24.02%***	11.29%***

Statistical Significance: *** 1% ** 5% * 10%.

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