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

Wolfgang Briglauer[1], Carlo Cambini[2], Klaus Gugler[3] and Volker Stocker[4]

This version: December 31st 2020

[1] Vienna University of Economics and Business (WU), Research Institute for Regulatory Economics, Vienna, School of Business, Economics & Information Systems, University of Passau, Passau, Germany. E-mail: wolfgang.briglauer@wu.ac.at

[2] Politecnico di Torino, Department of Management and Economics & EUI. E-mail: carlo.cambini@polito.it

[3] Vienna University of Economics and Business (WU), Research Institute for Regulatory Economics, Vienna, Austria. E-mail: klaus.gugler@wu.ac.at

[4] Weizenbaum Institute for the Networked Society, TU Berlin. E-mail: vstocker@inet.tu-berlin.de

JEL

L52; L96; L98

Keywords

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

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.

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 market failure 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). 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 and empirical evidence – 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 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.

While in some papers the impact of network neutrality regulations on incentives for network investment and content innovation varies, most analyses (in particular, Bourreau et al., 2015; Guo et al., 2017; see also the overview in Easley et al., 2018, Table A.1 at pp. 268-270) suggest that strict network neutrality regulation has a negative effect on social welfare. Against this background of the expected effects of network neutrality regulations, the theoretical literature certainly does not make a clear and compelling case for the introduction of such regulations on an a priori basis.

2.2 Empirical contributions

Table 1 provides a structured overview of the currently 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. telecommunications operators	Several dates in May 2010: 4th, 5th, 6th, 7th, and 8th	-	n.c.	n.c.
Lee and Kim (2014)	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)**)	Descriptive and OLS regression analysis	Industry-level data U.S. broadband network investments	1996–2014	-	n.c.	n.c.
Layton (2017)**)	Descriptive and OLS regression analysis	Micro-level data App downloads per day in Denmark (DK) and in the Netherlands (NL)	Days: 01.03.2011 (NL) 01.03.2012 (DK) 01.03.2016 (NL&DK)	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 (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.

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: *) Simulation model #6 examines the impact of net neutrality regulations; simulation-based models, however, do not classify as empirical analysis in a narrower sense. **) Authors do not provide an identification strategy.

Source: Own presentation.

3 Institutional background

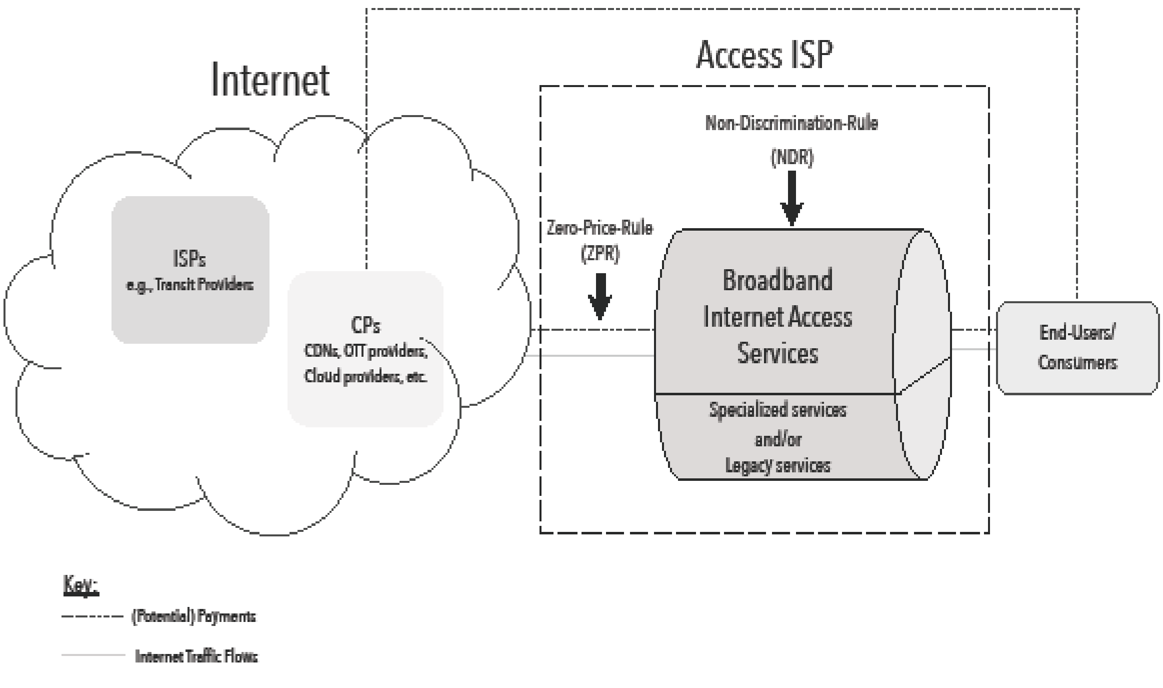
3.1 Scope of net neutrality regulations

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. As the delivery of corresponding services to end-users is thus rendered a 'private,' intra-ISP service, 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, is 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

Our model aims to point out the impact of net neutrality regulations on ISPs' investment incentives and on consumers' decision to subscribe to high-speed (fiber-based) broadband connections in order to benefit from innovative services. To this end, we build on the model of Economides and Tåg (2012) and expand it to incorporate ISP investment to upgrade the network by further deploying fiber-optic cable infrastructure in the access network, which substantially increases quality characteristics of broadband services and applications. Such network investments allow CPs to offer better quality of service and more content to end-users in a standard two-sided market environment. 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. Though simplified, our approach 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 to access new content.

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), 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.[3] This setting corresponds to

[3] 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'.

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:

$$U_{c_i} = v + \varphi + \beta * n_{cp} - p - x_i \tag{1}$$

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.[4] 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 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

[4] 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.

distributed on the unit interval with unit mass.[5] 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:

$$\mathrm{U}_{CP_j} = \alpha * n_c - cy_j - a \tag{2}$$

Finally, the ISP profit function is given by:

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

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 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.

[5] 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).

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:

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

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

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

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:[6]

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

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

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 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:

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

[6] 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.

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

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

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

In the second stage equilibrium, users' demand becomes:

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

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:[7]

$$\varphi_{NNR} = \frac{cv}{c-2\alpha\beta} \tag{11}$$

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.

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

$$n_{c\_NNR} = \frac{cv}{c-2\alpha\beta} \tag{12}$$

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:

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

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

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

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

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

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:[8]

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

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

[8] 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 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.

Note that CPs pay a positive fee $a^*(\varphi)$ 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:

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

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

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:

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

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.

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.[9] 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

[9] 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.

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:

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

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 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.

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 {intrinsic value of fiber-based subscription (v); content and service value for consumers (β); fiber investment (φ); advertising revenue per consumer (a); 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:

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

$$\ln(fiber\_sub_{it}) = \beta_0 + \beta_1 \ln(fiber\_sub_{it-1}) + \beta_2 \ln(fiber\_inv_{it}) + \boldsymbol{Z}_{it}\boldsymbol{\delta} + \beta_i + \beta_t + \mu_{it} \tag{23}$$

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 (Briglauer, 2015; Briglauer et al., 2018). Similarly, actual subscription on the demand side is subject to switching costs and inertia on part of consumers (Briglauer, 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_1, β_1 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 - α_1 and 1 - β_1 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 $\alpha_2/(1 - \alpha_1)$ in the investment equation and $\beta_2/(1 - \beta_1)$ in the subscription equation (Briglauer et al., 2018; Grajek and Röller, 2012). Equations (22) and (23) further contain vectors of covariates, $\boldsymbol{X}_{it}$ and $\boldsymbol{Z}_{it}$, which are specific to the investment and subscription equations, respectively. We add fixed effects (a_i and β_i) to capture time-invariant heterogeneity within countries and period effects (a_t and β_t). As will be discussed below, covariates in $\boldsymbol{Z}_{it}$, 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).[10]

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(fiber_inv)* and *ln(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

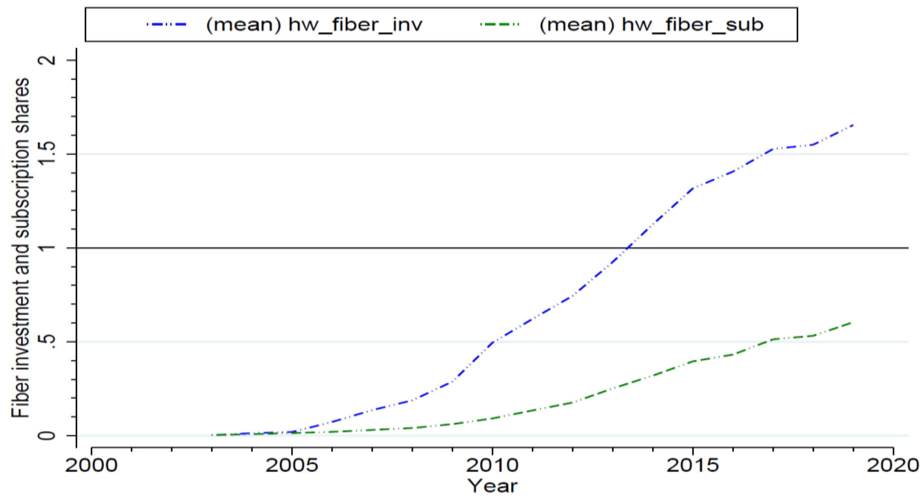
---

[10] 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.

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).

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.

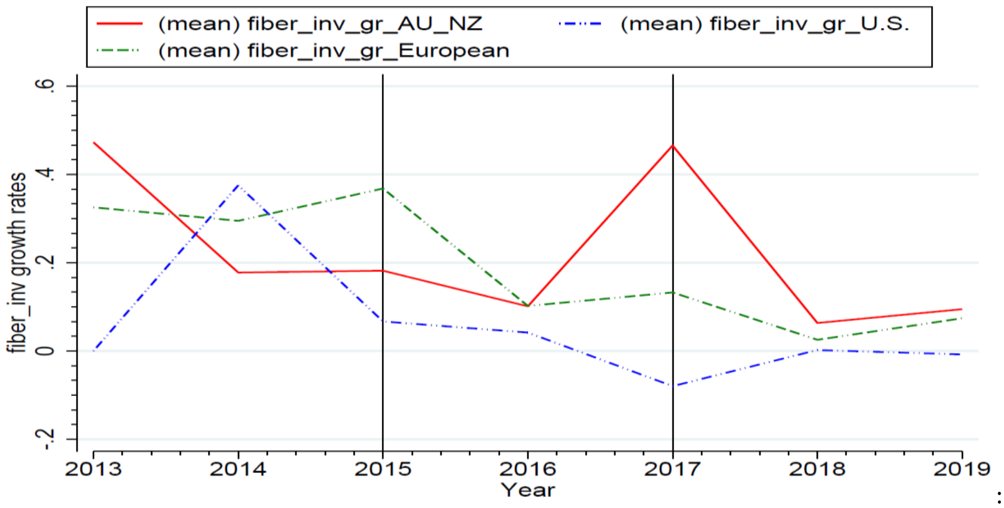
6.2 Main explanatory variables: net neutrality regulations

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.[11] 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 regulations in terms of NDR, ZPR, and transparency 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 (*L.NNR*) 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.

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

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, $\boldsymbol{X}_{it}$, 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, $\boldsymbol{Z}_{it}$, 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.[12]

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 $NNR_{j\neq I}$ ($NNR(expect)_{j\neq i}$).

[12] 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.[13] 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.[14]

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 (*L.NNR*) 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.

[13] Stata 16.1 was used to estimate the regressions.

[14] 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%.[15]

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 - β_1) which is substantially higher than the respective speed of investment adjustment (1 - a_1) as inferred from Table 2.[16] Taking the impact of *NNR* 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

[15] 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).

[16] 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.

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. 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)*).[17] 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

[17] 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.

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.

Table 2: Results for the fiber investment equation (*Dep. var.: ln(fiber_inv)*)

	(1) FE	(2) FE	(3) FE	(4) FE	(5) FEC	(6) OLS
Lagged dep. var.						
L.ln(fiber_inv))	0.562***	0.557***	0.567***	0.575***	0.673***	0.735***
	(11.17)	(11.27)	(11.32)	(11.79)	(17.82)	(23.11)
Net neutrality vars.						
NNR	-0.208	-0.201	-0.138	-0.569	-0.311	-0.319*
	(-0.93)	(-0.92)	(-0.64)	(-1.69)	(-0.59)	(-1.79)
L.NNR	-0.606***	-0.586***	-0.554***	-0.481**	-0.635	0.072
	(-3.16)	(-3.08)	(-3.11)	(-2.73)	(-1.21)	(0.47)
NNR(expect)	-0.533	-0.575	-0.590		-0.507	0.273
	(-1.01)	(-1.10)	(-1.16)		(-0.98)	(0.78)
Macroecono. vars.						
lt_ir	-0.119*	-0.119**	-0.135**	-0.130**	-0.122**	-0.132**
	(-2.03)	(-2.04)	(-2.21)	(-2.17)	(-2.03)	(-2.31)
free_invest	0.065***	0.064***	0.063***	0.063***	0.057***	0.005
	(3.22)	(3.21)	(3.19)	(3.29)	(2.58)	(0.46)
Market vars.						
telecom_prices	0.030**	0.031**	0.026**	0.026**	0.028**	0.026***
	(2.59)	(2.62)	(2.09)	(2.19)	(2.50)	(3.42)
cable_comp	-2.440	-1.447	-3.514	-3.889	-1.998	-1.867
	(-0.67)	(-1.01)	(-1.03)	(-1.15)	(-0.62)	(-1.23)
cable_comp_sq	1.334		2.436	2.835	0.795	1.925
	(0.35)		(0.68)	(0.81)	(0.23)	(0.71)
mobile_comp	-3.176*	-2.051**	-3.197**	-3.171**	-3.834***	-0.422
	(-2.02)	(-2.38)	(-2.38)	(-2.39)	(-2.71)	(-0.44)
mobile_comp_sq	0.506		0.478	0.493	0.841	0.056
	(1.18)		(1.43)	(1.46)	(1.45)	(0.12)
basic broadband	4.355**	4.228*	4.274**	4.291*	4.133**	0.903
	(2.06)	(1.93)	(2.05)	(2.03)	(2.52)	(1.29)
wages	0.000	0.000			0.000	-0.000
	(0.38)	(0.32)			(0.56)	(-0.42)
pop_dens	0.021	0.023			0.024	0.001
	(0.88)	(0.99)			(1.26)	(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	-3.872	1.335	0.900		1.743
	(-0.69)	(-0.84)	(0.39)	(0.28)		(1.09)
R^2(within)	0.871	0.870	0.870	0.870	0.817	
R^2(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(within). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Results for the fiber subscription equation (Dep. var.: *ln(fiber_sub)*)

	(1) FE	(2) FE	(3) FE	(4) FE	(5) FEC	(6) OLS
Lagged dep. var.						
L.ln(fiber_sub)	0.506***	0.100***	0.270**	0.250*	0.113***	0.171***
	(9.53)	(2.82)	(2.17)	(1.96)	(5.27)	(4.29)
Fiber investment (φ)						
ln(fiber_inv))		0.778***	0.806***	0.788***	0.771***	0.775***
		(26.32)	(22.78)	(20.33)	(36.24)	(23.02)
L.ln(fiber_inv))			-0.178	-0.159		
			(-1.34)	(-1.15)		
L2.ln(fiber_inv))				0.017		
				(1.06)		
Budget vars.						
comm_exp	0.708***	0.015	0.004	0.034	0.016	0.055
	(3.07)	(0.23)	(0.08)	(0.53)	(0.20)	(1.12)
hh_size	4.203**	1.456	1.127	1.294	1.429	0.405***
	(2.09)	(1.51)	(1.46)	(1.32)	(1.48)	(3.49)
ICT affinity vars. (ν)						
adr	-0.231**	-0.025	-0.022	-0.014	-0.023	-0.007
	(-2.55)	(-0.93)	(-1.01)	(-0.49)	(-0.87)	(-1.03)
ict_trade	0.032	0.000	-0.000	-0.005	0.000	0.008
	(1.28)	(0.03)	(-0.04)	(-0.55)	(0.03)	(1.41)
laptop	0.038	0.013	0.012	0.011	0.013	0.005
	(1.39)	(0.70)	(0.75)	(0.54)	(1.10)	(0.94)
tablet	0.026	0.014	0.012	0.016	0.014	0.003
	(0.99)	(1.13)	(1.23)	(1.56)	(1.33)	(0.53)
smphone	-0.011	-0.006	-0.004	-0.008	-0.006	0.002
	(-0.45)	(-0.48)	(-0.43)	(-0.76)	(-0.55)	(0.25)
internet_users	0.103***	0.027**	0.023**	0.030**	0.026**	0.013**
	(3.98)	(2.63)	(2.40)	(2.36)	(2.48)	(2.21)
Content vars. (β)						
servers	0.000**	0.000	0.000	0.000	0.000	0.000
	(2.12)	(0.79)	(0.62)	(0.52)	(0.43)	(0.16)
Netflix	0.341	0.086	0.107	0.104	0.083	0.094
	(0.85)	(0.74)	(1.04)	(1.01)	(0.48)	(0.90)
country FE (β_i)	YES	YES	YES	YES	YES	YES
year FE (β_t ; a, c)	YES	YES	YES	YES	YES	YES
constant (β_0)	-6.877	-3.936	-2.989	-4.229		-1.572***
	(-1.07)	(-1.38)	(-1.20)	(-1.31)		(-2.59)
R^2(within)	0.869	0.974	0.975	0.966	0.991	
R^2(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(within). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: IV results for the fiber investment equation (Dep. var.: *ln(fiber_inv)*)

	(1) FE-IV	(2) FE-IV	(3) FE-IV	(4) FE-IV
Lagged dep. var.				
L.ln(fiber_inv))	0.588***	0.578***	0.556***	0.585***
	(12.99)	(12.06)	(11.82)	(13.38)
Net neutrality vars.				
NNR	-0.783	-0.615		
	(-1.02)	(-0.91)		
L.NNR	-0.781*	-0.716*	-0.647*	-0.879*
	(-1.70)	(-1.94)	(-1.68)	(-1.89)
NNR(expect)	0.815		-0.705*	
	(0.98)		(-1.79)	
Macroecono. vars				
lt_ir	-0.141**	-0.154**	-0.119**	-0.148**
	(-2.27)	(-2.50)	(-2.13)	(-2.57)
free_invest	0.074***	0.076***	0.064***	0.075***
	(3.58)	(3.81)	(3.35)	(3.69)
Market vars				
telecom_prices	0.035***	0.034***	0.031***	0.034***
	(3.04)	(3.15)	(2.81)	(3.09)
cable_comp	-2.977**	-0.847	-1.455	-2.907**
	(-2.10)	(-0.55)	(-1.07)	(-2.01)
mobile_comp	-0.878*	-0.858*	-2.068**	-0.804*
	(-1.81)	(-1.88)	(-2.52)	(-1.94)
basic broadband	7.754***	8.363***	4.228**	7.992***
	(5.38)	(6.09)	(2.03)	(6.11)
wages	0.000	0.000	0.000	0.000
	(0.68)	(0.61)	(0.31)	(0.68)
pop_dens	0.030	0.043**	0.023	0.030
	(1.64)	(2.27)	(1.02)	(1.61)
country FE (β_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,[18] 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

[18] 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).[19]

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. Future research should also provide empirical evidence regarding relevant outcomes such as consumer prices for ISP access or content innovation. As available evidence on this hot policy issue is still very limited, and as the debate has been driven mainly by strongly ideological partisan views and bureaucrats' goals, reliable evidence will be very much needed for future debates and upcoming policy revisions.

Acknowledgments

Financial support from the WU anniversary foundation and a research fellowship provided by the Technical University of Berlin are gratefully acknowledged. Volker Stocker would like to acknowledge that this work has been funded by the Federal Ministry of Education and Research of Germany (BMBF) under grant no. 16DII111 ('Deutsches Internet-Institut'). Carlo Cambini graetfully acknowledges the fund from MIUR Award TESUN- 83486178370409 finanziamento dipartimenti di eccellenza CAP. 1694 TIT. 232 ART. 6. The views expressed in this article are those of the authors only.

[19] 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/).

References

Akerman, A., Gaarder, I. & Mogstad, M. (2015). The Skill Complementarity of Broadband Internet. *Quarterly Journal of Economics* 30, 1781-1824.

Armstrong, M. (2006). Competition in Two‐sided Markets. *The RAND Journal of Economics* 37(3), 668-691.

BEREC (2016). *BEREC guidelines on the implementation by national regulators of European net neutrality rules, BoR (16) 127.* https://berec.europa.eu/eng/document_register/subject_matter/berec/regulatory_best_-practices/guidelines/6160-berec-guidelines-on-the-implementation-by-national-regulators-of-european-net-neutrality-rules

BEREC (2020). *BEREC Guidelines on the Implementation of the Open Internet Regulation, BoR (20) 112*. https://berec.europa.eu/eng/document_register/subject_matter/berec/regulatory_best_practices/guidelines/9277-berec-guidelines-on-the-implementation-of-the-open-internet-regulation

Bond, S. (2002). Dynamic Panel Data Models: A Guide to Micro Data Methods and Practice. *CeMMAP working papers from Centre for Microdata Methods and Practice, No CWP09/02*, Institute for Fiscal Studies.

Bourreau, M., Kourandi, F. & Valletti, T. (2015). Net Neutrality with Competing Internet Platforms. *The Journal of Industrial Economics* 63(1), 30-73.

Bourreau, M., De Streel, A., & Graef, I. (2017). *Big Data and Competition Policy: Market power, Personalised Pricing and Advertising.* CERRE project report, Brussels.

Böttger, T., Cuadrado, F., Tyson G., Castro I. & Uhlig S. (2018). Open Connect Everywhere: A Glimpse at the Internet Ecosystem through the Lense of the Netflix CDN. *ACM SIGCOMM Computer Communication Review* 48(1), 28-34.

Bresnahan, T. & Trajtenberg, M. (1995). General Purpose Technologies 'Engines of Growth'? *Journal of Econometrics* 65, 83-108.

Briglauer, W., Cambini. C. & Grajek, M. (2018). Speeding Up the Internet: regulation and Investment in the European Fiber Optic Infrastructure. *International Journal of Industrial Organization* 61(C), 613-652.

Briglauer, W. (2015). How EU sector-specific regulations and competition affect migration from old to new communications infrastructure: recent evidence from EU27 member states. *Journal of Regulatory Economics* 48(2), 194-217.

Briglauer, W. (2014). The Impact of Regulation and Competition on the Adoption of Fiber-based Broadband Services: Recent Evidence from the European Union Member States. *Journal of Regulatory Economics* 46(1), 51-79.

Bruno, G. (2005a). Approximating the Bias of the LSDV Estimator for Dynamic Unbalanced Panel Data Models. *Economics Letters* 87, 361-366.

Bruno, G. (2005b). Estimation and Inference in Dynamic Unbalanced Panel-Data Models with a Small Number of Individuals. *The Stata Journal* 5, 473-500.

Choi, J. P. & Kim, B.C. (2010). Net Neutrality and Investment Incentives. *The RAND Journal of Economics* 41(3), 446-471.

De Hoyos, R.E., & Sarafides, V. (2006). Testing for cross-sectional dependence in panel-data models. *The Stata Journal* 6(4), 482-496.

Dumitrescu, E.I. & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic Modelling* 29, 1450-1460.

Economides, N. & Tåg, J. (2012). Network Neutrality on the Internet: A Two-Sided Market Analysis. *Information Economics and Policy* 24(2), 91-104.

Easley, R. F., Guo, H. & Krämer, J. (2018). Research commentary – From Net Neutrality to Data Neutrality: A Techno-Economic Framework and Research Agenda. *Information Systems Research* 29(2), 253-272.

EC (European Commission) (2009). Directive 2009/136/EC of the European Parliament and of the Council of 25 November 2009 Amending Directive 2002/22/EC on Universal Service and Users'

Rights Relating to Electronic Communications Networks and Services, Directive 2002/58/EC, Official Journal of the European Union, L 337, 11-36, 18 December, Brussels, Belgium.

EC (European Commission) (2013). Proposal for a Regulation of the European Parliament and of the Council Laying Down Measures Concerning the European Single Market for Electronic Communications and to Achieve a Connected Continent, and Amending Directives 2002/20/EC, 2002/21/EC and 2002/22/EC and Regulations (EC) No 1211/2009 and (EU) No 531/2012, COM(2013) 627 final, 11 September, Brussels, Belgium.

European Commission (2020). *Digital Economy and Society Index (DESI) 2020 Connectivity*. https://ec.europa.eu/digital-single-market/en/connectivity, Brussels, Belgium.

EU (European Union) (2015). Regulation (EU) 2015/2120 of the European Parliament and of the Council of 25 November 2015 Laying Down Measures Concerning Open Internet Access and Amending Directive 2002/22/EC on Universal Service and Users' Rights Relating to Electronic Communications Networks and Services and Regulation (EU) No 531/2012 on Roaming on Public Mobile Communications Networks within the Union, *Official Journal of the European Union*, L 310, 1-18, 26 November, Brussels, Belgium.

Faulhaber, G.R. (2011). Economics of Net Neutrality: A Review. *Communications & Convergence Review* 3(1), 7-25.

FCC (Federal Communications Commission) (2005a). In the Matters of Appropriate Framework for Broadband Access to the Internet over Wireline Facilities et al., Policy Statement, CC Docket No. 02-33 et al. (FCC 05-151), Washington, D.C.: Federal Communications Commission.

FCC (Federal Communications Commission) (2005b). In the Matter of Madison River Communications, LLC and Affiliated Companies, Order, File No. EB-05-IH-0110 (DA 05-543), adopted: 3 March, released: 3 March, Washington, D.C.: Federal Communications Commission.

FCC (Federal Communications Commission) (2010). In the Matter of Preserving the Open Internet; Broadband Industry Practices, Report and Order, GN Docket No. 09-191, WC Docket No. 07-52 (FCC 10-201), adopted: 21 December, released: 23 December, Washington, D.C.: Federal Communications Commission.

FCC (Federal Communications Commission) (2015). In the Matter of Protecting and Promoting the Open Internet, Report and Order on Remand, Declaratory Ruling, and Order, GN Docket No. 14-28 (FCC 15-24), adopted: 26 February, released: 12 March, Washington, D.C.: Federal Communications Commission.

FCC (Federal Communications Commission) (2018). In the Matter of Restoring Internet Freedom, Declaratory Ruling, Report and Order, and Order, WC Docket No. 17-108 (FCC 17-166), adopted: 14 December, released: 4 January, Washington, D.C.: Federal Communications Commission.

Ford, G. S. (2018). Regulation and Investment in the US Telecommunications Industry. *Applied Economics* 50(56), 6073-6084.

Ford, G.S., Spiwak, L.J., & Stern, M.L. (2010). The Broadband Credibility Gap. *CommLaw Conspectus* 19, 75.

Grajek, M. & L.H. Röller (2012). Regulation and Investment in Network Industries: Evidence from European Telecoms. *Journal of Law and Economics* 55, 189-216.

Grajek, M. & Kretschmer, T. (2012). Identifying Critical Mass in the Global Cellular Telephony Market. *International Journal of Industrial Organization* 30(6), 496-507.

Greenstein, S., Peitz, M. & Valletti, T. (2016). Net Neutrality: A Fast Lane to Understanding the Trade-Offs. *Journal of Economic Perspectives* 30(2), 127-150.

Guo, H., Bandyopadhyay, S., Lim, A., Yang, Y. & Cheng, H.K. (2017). Effects of Competition among Internet Service Providers and Content Providers on the Net Neutrality Debate. *MIS Quarterly* 41(2), 353-370.

Hazlett, T. W. & Wright, J. D. (2017). The Effect of Regulation on Broadband Markets: Evaluating the Empirical Evidence in the FCC's 2015 "Open Internet" order. *Review of Industrial Organization* 50(4), 487-507.

Hermalin, B. E. & Katz, M. L. (2007). The Economics of Product-Line Restrictions with an Application to the Network Neutrality Debate. *Information Economics and Policy* 19(2), 215-248.

Hooten, C.A. (2019). Testing the economics of the net neutrality debate. *Telecommunications Policy* 44(5), Article 101869.

Jamison, M. (2019). Net Neutrality Policies and Regulation in the United States. *Review of Network Economics* 17(3), 151-174.

Krämer, J., Wiewiorra, L. & Weinhardt, C. (2013). Net Neutrality: A Progress Report. *Telecommunications Policy* 37(9), 794-813.

Kourandi, F., Krämer, J. and Valletti, T. (2015). Net Neutrality, Exclusivity Contracts and Internet Fragmentation. *Information Systems Research* 26(2), 320-338.

Labovitz, C. (2019). *Internet Traffic 2009–2019*. Presentation at NANOG 76, 9–12 June. Washington, DC. https://pc.nanog.org/static/published/meetings/NANOG76/1972/20190610_Labovitz_Internet_Traffic_2009-2019_v1.pdf

Labovitz, C. (2020). *Effects of COVID-19 lockdowns on service provider networks*. Presentation at NANOG 79, 1–3 June [Online Event]. https://storage.googleapis.com/site-media-prod/meetings/NANOG79/2208/20200601_Labovitz_Effects_Of_Covid-19_v1.pdf.

Layton, R. (2017). *Which Open Internet Framework is Best for Mobile App innovation? An empirical inquiry of net neutrality rules around the world*. Aalborg Universitetsforlag. Ph.d.-serien for Det Tekniske Fakultet for IT og Design, Aalborg Universitet https://doi.org/10.5278/vbn.phd.engsci.00181

Lee, D. & Kim, Y.H. (2014). Empirical Evidence of Network Neutrality: The Incentives for Discrimination. *Information Economics and Policy* 29, 1-9.

Marcus, J. S. (2016). New Network Neutrality Rules in Europe: Comparisons to those in the U.S.. *Colorado Technology Law Journal* 14(2), 259-280.

Nickell, S. (1981). Biases in dynamic models with fixed effects. *Econometrica* 49, 1417-1426.

Sacco, D. & Schmutzler, A. (2011). Is there a U-shaped relation between competition and investment? *International Journal of Industrial Organization* 29 (1), 65-73.

Schuett, F. (2010). Network Neutrality: A Survey of the Economic Literature. *Review of Network Economics* 9(2), 1-15.

Stocker, V., Smaragdakis, G., Lehr, W.H. & Bauer, S. (2017). The Growing Complexity of Content Delivery Networks: Challenges and Implications for the Internet Ecosystem. *Telecommunications Policy* 41(10), 1003-1016.

Stocker, V. (2020). *Innovative Capacity Allocations for All-IP Networks: A Network Economic Analysis of Evolution and Competition in the Internet Ecosystem*. Nomos Baden-Baden.

Stocker, V., Smaragdakis, G. & Lehr, W.H. (2020). The State of Network Neutrality Regulation. *ACM SIGCOMM Computer Communication Review* 50(1), 45-59.

Wu, T. (2002). *A Proposal for Network Neutrality*. http://www.timwu.org/OriginalNNProposal.pdf.

Wu, T. (2003). Network Neutrality, Broadband Discrimination. *Journal on Telecommunication and High Technology Law* 2, 141-179.

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:

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

i.e.,

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

The CPs profit is given by:

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

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:[20]

[20] 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:

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

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

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

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

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:

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

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

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

that can be rewritten as:

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

It is easy to note that, since $c > \boldsymbol{\alpha\beta}$ and $\boldsymbol{6c-\alpha^2-4\alpha\beta-\beta^2>0}$ for the existence of an equilibrium, then as long as $\boldsymbol{\alpha} > \boldsymbol{\beta}$, 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 $\boldsymbol{\varphi^{*D} > \varphi^D_{NNR}}$. Hence, when $\boldsymbol{\alpha} > \boldsymbol{\beta}$, the investment by duopolistic platforms is higher in an unrestricted scenario than under net neutrality regulations.

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

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

i.e., when $\boldsymbol{\alpha}$ is very low ($\boldsymbol{\alpha < \bar{\alpha} < \beta}$). 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	
fiber_inv	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*
fiber_sub	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	
basic_broad-band	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
cable_comp	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
wages	Average annual wages per capita in USD.	©MarketLine
pop_dens	Population density of a country in persons per square kilometer.	WorldBank
telecom_prices	Index (2010=100) putting in relation the prices of telecommunications services in different years.	©Euromonitor
mobile_comp	Total number of wireless broadband subscriptions in thousands.	©Euromonitor
	Macroeconomic variables	
lt_ir	Long-term interest rate for debt security issued at 10 years maturity : local currency unit.	OECD
free_invest	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	
comm_exp	Consumer expenditure on communications; the amount (in USD) spent on communications by an average household in the respective year.	©Euromonitor
hh_size	Average number of persons living in a household.	©MarketLine
	ICT affinity and content variables	
adr	Ratio of dependents (people younger than 15 or older than 65) per 100 working-age individuals.	WorldBank
internet_users	Number of individuals who have made use of the internet within the last 12 months per 100 persons.	ITU
servers	Secure Internet servers using encryption technology in Internet transactions per 1 million people.	WorldBank
Netflix	Dummy variable that takes on a value of 1 if Netflix streaming services were available, and 0 otherwise.	Own research
laptop	Percentage of households possessing a laptop.	©Euromonitor
smartphone	Percentage of households possessing a smartphone.	©Euromonitor
tablet	Percentage of households possessing a tablet.	©Euromonitor
ict_trade	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	
left_wing	Share of the population of country *i* in year *t* voting for (rather) left-wing parties.	Table A.4
exp_gdp	Total governmental expenditure as percentage of GDP.	©MarketLine
gov_spend	$GE_i = 100 - a(\text{Expenditures}_i)^2$ 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
$NNR_{j\neq i}$, $NNR(expect)_{j\neq i}$	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.					
fiber_inv	576	1.01e+07	2.67e+07	0	2.24e+08
ln(fiber_inv))	576	11.594	6.226	0	19.227
L.ln(fiber_inv)	544	11.323	6.296	0	19.227
L2.ln(fiber_inv)	512	11.023	6.364	0	19.227
fiber_sub	576	3380000	1.08e+07	0	1.08e+08
ln(fiber_sub)	576	10.398	5.796	0	18.495
L.ln(fiber_sub)	544	10.119	5.836	0	18.296
Net neutrality vars.					
NNR	576	.38	.486	0	1
L.NNR	544	.347	.477	0	1
NNR(expect)	576	.432	.496	0	1
Control vars.					
lt_ir	525	4.043	2.745	-.362	26
telecom_prices	544	99.183	15.789	43.5	250.8
cable_comp	512	.252	.16	0	1
mobile comp	544	.483	.445	0	2.169
basic_broadband	512	.564	.258	0	1
free_invest	576	74.913	11.85	50	95
wages	543	36178.97	19692.79	4724.26	95514.62
pop_dens	544	142.815	136.037	2.558	529.652
adr	543	50.146	5.574	36.323	67.548
comm_exp	512	2.899	.8	0	5.29
hh_size	544	2.608	.457	2	4.17
ict_trade	512	17.139	10.702	4.445	64.126
laptop	544	42.719	25.613	.3	91.8
tablet	544	12.944	17.833	0	68.4
smartphone	544	30.33	28.169	.2	93.1
Internet_users	543	67.768	20.611	11.38	97.644
servers	512	4241.342	11462.11	3.575	123000
Netflix	576	.34	.474	0	1
Instrumental vars.					
$NNR_{j \neq i}$	576	.372	.381	0	.97
$NNR(expect)_{j \neq i}$	576	.425	.406	0	.97
left_wing	576	37.965	13.655	0	66.667
exp_gdp	544	40.898	12.699	0	65.26
gov_spend	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¤
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	https://docs.fcc.gov/public/attachments/FCC-10-201A1.pdf
	Year of first notification: 2009	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 Commission, 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.servelelecciones.cl
MX	https://web.archive.org/web/20170817034702/
IL	https://en.wikipedia.org/wiki/September_2019_Israeli_legislative_election
	https://votes22.bechirot.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