ISSN 1866-3494

August 17, 2021

ESMT Working Paper 21-01

Effectiveness and efficiency of state aid for new broadband networks: Evidence from OECD member states

Wolfgang Briglauer, Vienna University of Economics and Business (WU)

Michał Grajek, ESMT Berlin

Effectiveness and Efficiency of State Aid for New Broadband Networks: Evidence from OECD Member States[1]

Wolfgang Briglauer* and Michał Grajek**

This version: August 17, 2021

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

** (corresponding author) ESMT Berlin, Schlossplatz 1, 10178 Berlin, Germany. E-mail: michal.grajek@esmt.org

[1] Wolfgang Briglauer gratefully acknowledges financial support from the WU anniversary foundation. Apart from that, our research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors declare that no conflict of interest that could bias the work on this manuscript or the results presented in it exist.

Abstract

The deployment of new broadband networks (NBNs) based on fiber-optic transmission technologies promises high gains in terms of productivity and economic growth, and has attracted subsidies worth billions from governments around the world in the form of various state aid programs. Yet, the effectiveness and the efficiency of such programs remains largely unstudied. We employ panel data from 32 OECD countries during 2002-2019 to provide robust empirical evidence of both. We find that state aid significantly increases NBNs by facilitating the deployment of new connections to 22% of households in the short term and 39.2% in the long term. By comparing the actual amounts of state aid support to the estimated impact on GDP growth, we also find it to be highly cost efficient, as the programs break even after three years on average.

Keywords

Fiber optic technology, state aid, ex-post evaluation, efficiency, OECD countries

JEL codes

C51, C54, H25, L52, O38

1 Introduction

Similar to the societal benefits of "old" (copper or coaxial cable-based) broadband infrastructures, the future importance of high-speed, and hence "new" (fiber-optic transmission based), broadband networks (NBNs)[2] relates to their general-purpose technology character (Bresnahan and Trajtenberg, 1995), which promises significant productivity improvements, product innovations, and economic growth across all major business sectors. For this reason, the deployment of NBNs has become a hot policy topic and governments in most of the developed countries have defined ambitious broadband targets in terms of desirable coverage levels. At supranational level, the European Commission (EC) first defined in 2010, in its Digital Agenda Europe (DAE) objectives for 2020, the requirement *inter alia* that "all Europeans have access to much higher internet speeds of above 30 Mbps" (European Commission, 2010, p. 19). The EC recently expressed more ambitious and long-term objectives for 2025 in its "Gigabit society strategy", which intends to promote "gigabit-ready" networks requiring *inter alia* "[a]ll European households, rural or urban, to have access to internet connectivity offering a downlink of at least 100 Mbps, upgradable to gigabit speed" (European Commission, 2016, pp. 35-36). Similar broadband plans with ubiquitous coverage targets have been implemented in most of the developed countries (OECD, 2018).

Replacing existing broadband networks with fiber-optic networks requires high investment volumes. As private investors are not ready to roll out NBNs in remote and unprofitable regions, state aid is necessary to achieve ubiquitous household coverage targets in most countries. Accordingly, the DAE already encouraged the use of national and European Union (EU)-related funding instruments to meet the broadband coverage targets (European Commission, 2010). The use of state aid to foster broadband infrastructure already started in the mid-2000s, but it has been expanded starting with the DAE. In the last two decades, public authorities in individual EU and non-EU OECD member states have become more and more inclined to see state aid for NBNs as a necessary policy. Past and current state aid programs in some of the major economies in Europe (and elsewhere) add up to two-digit billions of Euros (Feasey et al., 2018). State aid programs have been determined predominantly at national government levels and show considerable variation in design and volumes in international comparison. In the EU, state aid policies are largely meant to directly increase coverage, and thus only indirectly increase adoption of broadband services by consumers.

The actual effect of the state aid programs on the NBN rollout is both not obvious and understudied. According to the state aid guidelines in the EU (Feasey et al., 2018) and other developed countries (OECD, 2018), the state aid is typically restricted to the "white" areas, meaning only the areas where the NBN deployment is considered unprofitable under normal market conditions. Still, it might be subject to various inefficiencies, even if allocation of funds is subjected to competitive tender processes. First, the extent of white areas is endogenously determined by chosen public targets and their specific definition of desired

[2] NBN stands for new broadband network

bandwidth levels (and other quality parameters). In most cases, national or supranational targets are derived from a political process and not based on empirical evidence (Briglauer et al., 2020a). Second, public broadband targets might result in regulatory games on the side of network operators. The latter might wait and postpone investment in otherwise profitable areas if they expect state aid funds when politicians are committed to fulfil target criteria, but no *ex post* preemption by other operators. Third, as policymakers appear to have become less patient about fast deployment of NBNs, the latter exhibit many more white areas, which already received state aid. It appears that NBN-related funding is much more likely to be subject to the crowding out of private investment compared to the funding of old broadband networks, as state aid might be used too early for operators to address user demand for new services. Fourth, concerns are aggravated in view of multiple institutional funding platforms at supranational, national, and local levels with substantial risks of coordination failure and crowding out of private investments due to institutional overprovisioning of state aid (Bourreau et al., 2020). Against this background, overall efficiency properties and the effectiveness of state aid programs for NBN are *a priori* unclear.

Despite its growing financial importance and the widespread use of state aid for NBNs in most developed countries, it is astonishing that their effectiveness and efficiency has hardly received academic consideration in terms of theoretical or empirical analysis (Bourreau et al., 2020). In this paper, we aim to provide i) an empirical *ex post* evaluation that informs policy makers about the causal effects of NBN-specific state aid programs in developed (OECD) countries, and ii) contrast our estimates with average public funding expenditures to perform a rudimentary cost-benefit analysis of state aid programs. Answering the first research question allows us to assess the effectiveness, whereas answering the second research question allows us to shed some light on the overall efficiency of state aid programs.

In our empirical investigation, we employ comprehensive panel data for OECD countries comprising almost the entire period of NBN deployment (2002-2019). Our data covers real NBN investment measured in physical units rather than less direct accounting measures. Taking various sources of endogeneity into account, we employ panel estimation techniques including instrumental variables with different sets of external and internal instruments. In our estimation strategy, we further accommodate the dynamics of the investment adjustment process underlying NBN deployment. The latter not only captures real-world characteristics with disproportionally increasing deployment costs, but also allows us to disentangle the effects of state aid programs on total NBN coverage and the effects on the speed of NBN deployment.

The remainder of this paper is organized as follows. Section 2 reviews the empirical literature related to broadband state aid policies. Section 3 describes the relevant institutional and legal background of state aid programs. Section 4 presents our regression model framework and the identification strategy. Section 5 describes the data and section 6 reports our main results. Section 7 provides a cost-benefit analysis contrasting our estimation results with external estimates on the impact of NBNs on economic output (GDP) and average funding expenditures. The final section concludes the paper with a review of its main results and compiles relevant policy conclusions that follow from our analysis.

2 Literature review

Belloc et al. (2012) are the first to examine the impact of state aid measures on broadband coverage and adoption by utilizing a dataset for 30 OECD countries for the years 1995 to 2010. The authors demonstrate that the positive and statistically significant effect of demand-side policies is greater when broadband adoption is already developed, while the effect of supply-side policies decreases as the broadband market moves into its later stages. Montolio and Trillas (2013) measure how the level of broadband adoption is affected by an industrial policy variable that acts as a proxy for public policies and is calculated as government funding to private and public companies as a percentage of GDP. The authors utilize panel data for OECD and EU countries for the years 1999 to 2006. The estimation results indicate a positive, albeit insignificant, effect of public funding in all model specifications.

Other empirical studies use more disaggregated data. Akerman et al. (2015) examine a Norwegian national broadband program that rolled out old broadband networks, using Norwegian firm-level data from 2000 to 2008. The authors find that broadband coverage improves the labor market outcomes and productivity of skilled workers, but worsens it for unskilled workers. Duso et al. (2018) employ panel data on all municipalities in western Germany for the years from 2010 to 2015, to assess the impact of German state aid programs. The authors find that state aid significantly increased broadband availability in aid-receiving areas without impeding competition in broadband markets. Briglauer et al. (2019) also investigate the impact of the German state aid program for broadband deployment for the years from 2010 to 2015, but focusing only on municipalities of the German state of Bavaria. The authors find that aided municipalities have – depending on broadband quality – between a 16.8 and 23.2 percent higher broadband coverage than non-aided municipalities. This increase in broadband coverage results in a small increase of employed individuals living in the respective aid-receiving municipalities (reducing depopulation). Canzian et al. (2019) provide an impact evaluation of a local policy program aimed at adoption of basic broadband in underserved rural and sparsely populated areas in the Italian province of Trento. Utilizing data on the infrastructure upgrade between 2011 and 2014, the authors find a positive impact of broadband availability on companies' economic performance in terms of revenues and total factor productivity, but no indication that these effects are associated with changes in employment. Kandilov and Renkow (2020) estimate the rate of return of broadband loan and grant programs on the average payroll per worker using US zip code-level data for the period 1997 to 2007. The authors find that two of the smaller broadband programs likely had no effect on local payroll per worker, whereas the largest program in terms of funding and coverage likely had a positive impact. Whitacre and Gallardo (2020) are the first to include fiber-based broadband technologies in addition to basic broadband availability (25/3 Mbit/s downlink/uplink) utilizing US county-level panel data from 2012 to 2018 to assess the impacts of state aid policies on total and rural broadband availability. The authors find a positive and significant impact of state aid programs on both measures of broadband availability. Although state aid had a measurable impact across all US counties, and a slightly higher one for rural areas, the average impact was small; for a typical county with an average rural broadband availability rate of 71.5% in 2018, the presence of state aid would raise it to 73.3%.

In summary, except for one paper using US county-level panel data, all available empirical studies are based on data measuring old broadband networks. Some studies indicate that state aid programs have been effective, albeit with some only showing a limited extent. As argued in the introductory section, broadband state aid policies entail the danger of the crowding out of private investment and various other inefficiencies. These concerns appear to have some support from the empirical literature, which points to small, and in some studies also to insignificant, statistical effects of state aid programs. Only a very few studies also examine indirect welfare-related effects of state aid such as local labour market effects. As far as NBN-specific state aid programs are concerned, empirical evidence is still lacking almost entirely. [3] These gaps are remarkable in view of the enormous state aid funds that have already been provided by policy makers in the last two decades. An *ex post* evaluation of the effectiveness and efficiency of state aid programs seems to be much needed.

3 Institutional and legal background

In this section, we first outline relevant broadband access technologies and their evolution from narrowband internet to high-speed NBNs (section 3.1). We then describe the main economic rationales for the funding of NBNs (section 3.2) and the relevant EU state aid rules and state aid practice in developed non-EU countries (section 3.3).

3.1 Evolution of broadband internet access technologies

Narrowband access networks were first upgraded via xDSL technologies capable of delivering broadband services via twisted-pair copper lines some 20 years ago. Even though xDSL broadband access technologies can support the simultaneous use of voice, video, and data services on an IP-basis, their performance and capabilities were technically limited by the remaining length of the copper-based part of the local access network. This technological restriction in old broadband technologies can be mitigated by deploying NBNs based on fiber-optic transmission technologies and network infrastructures. The closer fiber connections are deployed to the customer's premise in the access network, the higher the quality characteristics (such as bandwidth levels) that can be offered to customers; wireline "fiberization" scenarios include various technologies and network architectures and give rise to different deployment costs (Briglauer et al., 2020a; Timmers et al., 2018). In simplified terms, fiber-optic cables can either be deployed to the premises of consumers ("high-end fiber") or still partly rely on "old" 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.

[3] A few more empirical contributions including policy reports, conducted on behalf of public institutions, exist. They do not provide, however, credible identification strategies and are thus excluded from the literature review. We also did not review simulation-based studies.

Mobile (wireless) broadband services have become very popular since the rollout of 4G networks began in 2010. Even though corresponding mobile broadband technologies have been deployed on a nationwide scale in most countries, the average quality and stability of data transmission available to individual consumers depends on a host of factors and is on average still below quality levels provided by wireline hybrid-fiber networks. This could, however, change drastically with further advances in mobile access technologies. 5G, in particular, is expected to yield disruptive changes in quality dimensions with, for example, bandwidth levels up to several Gbit/s (Briglauer et al., 2020a).

In view of the coverage targets as defined in the EC´s gigabit strategy (European Commission, 2016) and in most other developed countries (OECD, 2018), NBNs must be at least partly fiber-based in the access network in order to enable bandwidth levels of at least 100 Mbit/s. Where NBNs include hybrid-fiber technologies, 4G mobile technologies cannot, generally speaking, realize these targeted bandwidth levels. As 5G networks have not been deployed before 2020, we therefore exclude mobile broadband from our empirical analysis, which covers the deployment period 2002 to 2019.

3.2 Economic rationales for state aid

The main economic rationale for state aid refers to positive externalities from broadband networks (NBNs). Market failure can refer to suboptimal levels of geographic coverage, speed of network deployment, and suboptimal quality levels of broadband services (or all three) as perceived by consumers. Bertschek et al. (2016) review more than 60 studies that investigate the causal effects of broadband networks and related services. The authors generally find positive effects for the most relevant economic outcomes such as economic growth (e.g., Czernich et al., 2011) and employment as well as productivity (e.g., Akerman et al., 2015). Although only very few empirical studies (e.g., Briglauer and Gugler, 2019) exist that explicitly include NBN data (recently surveyed in Abrardi and Cambini, 2019), NBNs are expected to provide a similar or even a higher potential in terms of productivity increases and economic growth. Furthermore, the adoption of (high-speed) broadband services by consumers and the corresponding usage of a large variety of broadband services are most likely to create substantial amounts of consumer surplus in aggregate. Early estimates on basic broadband adoption (Greenstein and McDevitt, 2011) as well as newer studies on NBNs (Katz and Callorda, 2020) indeed suggest massive gains in consumer surplus. Overall, empirical evidence supports the key assumption underlying state aid programs according to which NBNs generate massive externalities and rents for consumers.

On this basis, state aid programs to cover white areas might accrue substantial welfare gains if implemented in an effective way and without substantially crowding out private investment. White areas will be present in most countries, because broadband deployment is particularly investment-intensive in local access networks due to construction costs related to civil work for digging and laying down optical cables, accounting for 60% to 70% of the total deployment costs, followed by duct costs and fiberglass (Curram et al., 2019). These costs are mostly fixed and, in fact, sunk. Since access networks branch out in a tree-like structure, renewing access infrastructure involves fewer customers the closer one gets to the final consumer, that is, the deeper fiber is deployed to customer premises. This means that rollout costs will be distributed among fewer customers and hence average cost per customer will be higher ("economies of density"). Given the economics of broadband (NBN) deployment, it is unlikely that private investment will be induced by market conditions on a nationwide scale including areas with low population densities. Accordingly, most EU member states – as well as other non-EU developed countries – implemented national broadband plans including state aid measures, particularly since the DAE was published in 2010, to realize predefined ubiquitous broadband coverage targets (Feasey et al., 2018).

Reference is sometimes also made to equality concerns demanding ubiquitous service provision as well as affordability of basic broadband services for all citizens and households. These policy issues are, however, typically not part of state aid programs but tackled under the so-called "universal service obligation" frameworks (the latter also provide industry or state-funded financial resources for providing universal access to (very) basic internet services, publicly available telephone services, and to directories and directory enquiry services in the EU). Whereas affordability can be a problem in urban as well as in rural areas, availability of basic broadband infrastructure is a problem specific to remote areas. Not all EU and OECD member states include broadband in their universal service framework (OECD, 2018, p. 22). In these cases, political concerns on a digital divide between rural and urban areas or across income groups are embedded as a goal in national broadband targets and related to state aid programs.

3.3 State aid rules in the European Union and international funding practice[4]

State aid is subject to legal constraints in most jurisdictions. Compliance with broadband-specific state aid rules – adopted in 2009 (European Commission, 2009) and revised in 2013 (European Commission, 2013) – should ensure that state aid does not crowd out private investment or lead to an overcompensation of the funded network operator.

In order to reach ubiquitous coverage targets and to accrue positive externalities, the EC supports state aid for broadband network (NBN) deployment in rural and underserved white areas where no broadband infrastructure exists or where no plans by private investors to roll out such an infrastructure exist for the near future. In monopolistic or so-called "grey" areas where only one private broadband network operator is present currently (and for the foreseeable future), a more detailed assessment is required for state aid approval, as market distortions and crowding out of private investment become more likely (European Commission, 2013, §44-46). State aid in competitive "black" areas with two or more broadband infrastructures existing in parallel is not permissible (European Commission, 2013, §43).[5] About 91% of all

[4] We focus on the EU legal framework, as the majority of the OECD states in our data set are EU member states.

[5] Only a very few of the developed countries refrained from providing state aid due to country-specific features related to high levels of infrastructure competition and/or demographic and topographic characteristics; a notable example is the Netherlands where duopolistic competition resulted in a nationwide "black"area with no scope for state aid policies according to the EU regulatory framework.

state aid cases in the EU reference extending NBNs to white areas, whereas the other cases refer to increasing competition and technological upgrades in grey areas as primary reasons (Feasey et al., 2018, p. 73). This can also be observed for developed countries outside the EU which are not subjected to a similar supranational jurisdiction. Accordingly, most national broadband plans are targeted to deploy broadband in rural (white) areas (OECD, 2018; Feasey et al., 2018) and – in view of ubiquitous coverage targets – to expand network coverage on the supply side rather than adoption on the demand side. Direct supply-side stimuli mostly consist of direct grants or soft loans. Governmental intervention is sometimes also based on partial public ownership and engagement models such as "private-public partnerships", where both types of partners contribute with certain comparative advantages. The most interventionist form of public engagement is in terms of direct infrastructural investment where the government owns parts of or the entire network infrastructure. Australia and New Zealand favored such interventionist approaches and so far have provided the highest per capita state aid funds.[6]

The typical funding projects involve direct grants and are subject to an open tender with a funding period of three to five years (Feasey et al., 2018, p. 73). Open tenders are designed to allow for non-discriminatory participation on the basis of *ex ante* known selection criteria (European Commission, 2013, §12). The EC´s state aid rules (European Commission 2013, § (10)) allow for different forms of state aid funds which can be implemented in combination at the EU, national, or local level. Within the EU, approximately 65% of all state aid funds were provided at national level by member states and 35% by various European funds. In addition to regional funds provided by the EC, the European Investment Bank has lent between €2-3 billion per year in soft loans to private NBN operators since 2014 (Feasey et al., 2018, p. 36-39).

4 Estimation framework

In what follows, we first discuss the economics of NBN investment (section 4.1) and then describe our estimation and identification strategy (section 4.2).

4.1 The economics of investment in NBN

4.1.1 Dynamics of investment

We use a dynamic approach to incorporate real world NBN deployment patterns. As the broadband-related empirical literature (e.g., Grajek and Röller 2012; Bacache et al., 2014; Briglauer et al., 2018, 2020b; Whitacre and Gallardo, 2020) suggests, static models are not appropriate, as these would only account for effects that have an immediate impact on the infrastructure stock. We use a partial adjustment model, since network operators are most likely not able to adjust their broadband infrastructure stock to prevalent market conditions within one period due to substantial market rigidities related to, for example, construction work

[6] Information available at https://www.crowninfrastructure.govt.nz/ufb/what/ for New Zealand and https://www.nbnco.com.au/ (last accessed July 5th 2021).

(such as shortages in civil engineering capacities) or regulations (such as rights of way, negotiations with house owners or coinvesting operators, or rigidities related to complex and bureaucratic application procedures for state aid funds). Thus, adjustment to current market shocks will not only affect the infrastructure stock contemporaneously but also in future periods, and hence adjustment to a long-run optimal infrastructure stock takes time. We first assume that this targeted or desired NBN infrastructure stock is given by

$$NBN_{it}^{*} = \boldsymbol{X}_{it}\boldsymbol{\beta}' + \alpha_i + \epsilon_{it}, \tag{1}$$

where NBN_{it}^{*} reflects the long-run optimal infrastructure stock for country *i* at time *t*. $\boldsymbol{X}_{it}$ is a vector of observations on all relevant explanatory variables, α_i represents country-specific fixed effects, and ϵ_{it} is an idiosyncratic error term. In view of ubiquitous NBN targets at EU, but also at the national level in most OECD states, the desired infrastructure stock, NBN_{it}^{*}, corresponds to a 100% household coverage based on a certain quality level in target year *t*.[7] We further assume that the change in infrastructure stock follows a partial adjustment process:

$$NBN_{it} - NBN_{i,t-1} = \lambda\left(NBN_{it}^{*} - NBN_{i,t-1}\right) + \mu_{it}, \tag{2}$$

where NBN_{it} is the actual number of deployed NBN connections in country *i* at time *t*. For every period, a constant share of the remaining gap between the desired (*) and previous infrastructure stock (*t*-1) is closed, with $0 < \lambda < 1$ and λ representing the "speed of adjustment" coefficient. Next to capturing rigidities, the adjustment coefficient also captures increasing marginal costs of NBN deployment across areas; deployment costs are lowest in (sub-)urban areas, and (much) higher in (very remote) rural areas. As discussed in section 3, white areas that received most of the available state aid funds in the past are characterized by low population densities and, hence, high average deployment costs per customer premises.

Substituting equation (1) in equation (2) yields:

$$NBN_{it} = \alpha_1 NBN_{i,t-1} + \boldsymbol{X}_{it}\boldsymbol{\gamma}' + \theta_i + u_{it}, \tag{3}$$

where $u_{it} = \lambda\epsilon_{it} + \mu_{it}$, $\theta_i = \lambda\alpha_i$, $\alpha_1 = 1 - \lambda$, and $\gamma = \lambda\boldsymbol{\beta}$. Short-run effects are given by $\boldsymbol{\gamma}$, and estimates of $\boldsymbol{\beta}$ reflect the long-run effects of the variables in vector $\boldsymbol{X}$ on the desired infrastructure stock. The dynamic specification of equation (3) can be empirically tested. If α_1 is equal to 0, then there are no dynamics or inertia, whereas coefficient estimates between 0 and 1 are consistent with a dynamic adjustment process that leads to the long-run desired infrastructure stock. Besides testing the average level of dynamics in our specification, we can also test if the dynamics depend on some variables in $\boldsymbol{X}$ (we will be particularly interested in knowing if state aid changes the dynamics) by including appropriate interaction terms.

[7] For instance, the EC´s gigabit society strategy foresees 100% household coverage with at least 100 Mbit/s in 2025.

4.1.2 Determinants of investment

Network operators will base their investment decision on the net present value of a certain infrastructure project *j* (NPV_j). The project will be undertaken in case the project earns a higher discounted profit than the next best investment opportunity over a certain period of time (t = 1,…,T), that is, if[8]

$$NPV_j \;=\; \sum_{t=1}^{T} \frac{\pi_t}{(1+r)^t} > 0, \qquad (4)$$

where the parameter *r* is the discount or "hurdle" rate capturing opportunity costs of the next best alternative and uncertainty about future profit streams. The parameter π_t denotes net cash flows in period *t*, that is, revenues from operation minus costs in terms of capital and operating expenditures. During the first periods of an NBN project, capital expenditure (CAPEX) typically yields negative cash flows due to substantial physical deployment costs, including labour costs for construction work, which also includes replacement of internal wiring within buildings in the case of high-end fiber deployments, network planning and administration, equipment, and materials costs. In later periods, revenues from sales to retail consumers or from wholesale access to reselling operators will typically dominate the operating cost (OPEX), ultimately yielding positive net cash flows. Revenues are typically subject to much higher uncertainty than costs but are expected to outweigh operation costs as the latter constitute only a minor share of total costs.[9]

CAPEX crucially depends on population or household density as average deployment costs tend to be lower in (sub-)urban areas due to shorter distances to individual households and businesses and as more people can be reached by a specific investment activity ("economies of density"). Next to population density, major CAPEX determinants of NBN deployment are further related to topographical factors such as ground conditions, preexisting network infrastructure elements (such as the quality of ducts and poles and space for new fiber-optical cables or the availability of dark fibre as an alternative to ducts and poles), and finally regulations such as rights of way and provisions on network cooperation or wholesale access obligations. Note that most of these CAPEX determinants, such as the population density, either show no, or only very low, variation over time and are thus largely captured by country-specific fixed effects (θ_i's). In contrast, OPEX-related determinants, such as leases paid to owners of ducts and dark fiber as well as energy and maintenance costs, tend to be time variant but represent a small share of overall costs (Curram et al., 2019).

4.2 Estimation and identification strategy

We estimate equation (3) by instrumental variables (IV) and generalized method of moments (GMM) techniques, and use different sets of external and internal instruments for endogenous variables in $\boldsymbol{X}$. In particular, our main variable of interest, the state aid supporting NBN, is likely to be endogenous for a

[8] A report prepared for BEREC cites survey-based evidence according to which network operators indeed conduct NPV-based analysis when evaluating individual NBN projects (Curram et al., 2019).

[9] Virtually all CAPEX costs for a given area are fixed and sunk. The OPEX costs include both the fixed (but not sunk) elements, such as lease paid to the duct owners, for instance, as well as variable components, such as wages.

number of reasons. The state aid variable may to be subject to reverse causality in equation (3), as the regulators may speed up or slow down the introduction of state aid programs to take into account the current levels of NBN infrastructure deployment and the gap between the current and the desired levels. Moreover, other regulatory interventions may complement or substitute for the state aid. Most importantly, the access regulations, which aim at creating more competition in the broadband provision markets, can lead to omitted variable bias in equation (3). While we add access regulation variables, as a robustness check for our main results, the more general endogeneity concerns still require an appropriate estimation technique.[10]

Since equation (3) represents a dynamic panel data model with unobserved country-specific effects, we apply the Arellano-Bond estimator (Arellano and Bond, 1991), also known as a difference GMM estimator. GMM panel data estimators have been commonly used in ICT-related empirical studies to address the issue of endogeneity in the absence of appropriate external instruments (Bloom et al., 2012; Briglauer et al., 2018; Cardona et al., 2013; Dimelis and Papaioannou, 2011; Whiteacre and Gallardo, 2020). Additionally, we utilize the Anderson-Hsiao IV estimator (Anderson and Hsiao, 1981). Both types of estimators allow for inclusion of additional external instruments, or moment conditions in the case of GMM. While the IV estimator is less efficient than the GMM, it is also less subject to the overfitting problem (Roodman, 2009) and allows for additional specification tests on the first stage results.

As regards external instruments, we employ the following distinct sources of exogenous variation. First, we construct geographic Hausman-type instrumental variables measuring the average levels of NBN deployment and state aid in all other OECD member states in the sample (Briglauer and Gugler, 2019). Both variables are defined as the ratio of total NBN deployment (total number of implemented state aid programs) in 31 OECD states (i.e., other than the focal country *i*) to the total number of other countries (i.e., 31). Due to NBN target-related benchmarking effects, we expect that below-average states in terms of state aid provision or average NBN deployment urge national politicians to catch up.[11]

---

[10] Simple correlation analysis reveals positive relation between our measure of state aid and access regulation on one hand and net neutrality, another regulatory intervention in the broadband markets, on the other hand. While the correlations are not very strong, 0.361 and 0.227, respectively, the correlation coefficients are statistically significant. Since net neutrality has been shown to discourage NBN investment (Briglauer et al., 2020b), the potential omitted variable bias goes against our expected result on state aid thereby making our estimates more conservative. Similarly to net neutrality, access regulation has also been shown to generally discourage infrastructure investment, but the incentives may go the other way for some operators (Grajek and Röller, 2012; Briglauer et al. 2018).

[11] For instance, in its gigabit strategy, the EC explicitly acknowledges the great success of the former broadband policy target in that "[a]t national level, setting objectives has become the cornerstone of broadband deployment public policy. … Many member states have indeed aligned their national or regional NGN [=next generation networks = NBN in our context] plans to the DAE speeds" (European Commission, 2016, p. 31). This indicates that national politicians are under pressure not to fall behind broadband market developments in other comparable countries, both

Second, we construct instruments related to political ideology measuring the overall degree of governmental intervention in the economy (Montolio and Trillas, 2013) as well as the share of left-liberal legislators (Whitearce and Gallardo, 2020) in a country, hypothesizing that a high share of public expenditures in general and more left-liberal governments are good predictors for (NBN) state aid programs. These political economy variables capture the level of public participation in infrastructure projects. We expect them to positively correlate with the state aid for NBN deployment.

5 Data

We employ a balanced panel data set of 32 OECD member states for the period 2002 to 2019 for dependent and independent variables, with a maximum number of 576 observations.[12] In constructing our data, we use the following sources. First, our source for the dependent variables is the database of FTTH (Fiber to the Home) Council Europe, which includes annual numbers of deployed and adopted fiber-based broadband lines for OECD member states (section 5.1). Second, we use several OECD databases, in particular data from "Digital Economy Outlook" and "Economic Outlook". The construction of state aid variables (section 5.2) is based on our own research, publicly available information published by national government departments and regulatory agencies, as well as on personal correspondence with representatives of these institutions. Finally, we employ several other data sets to construct our control and instrumental variables (sections 5.3 and 5.4).

Table 1 (at the end of this paper) shows descriptive statistics of all variables used in the estimation of equation (3). Table A.1 in the Appendix lists the sources and provides definitions of the variables.

5.1 Dependent variable: NBN investment

Our dependent variable measures household weighted investments in new fiber-based broadband networks, denoted with *FiberCov*. Fiber investment is measured in real terms as the number of connections deployed, representing the NBN infrastructure stock in a given country (this measure of investment in broadband networks is also used in Briglauer et al., 2020b). Related to NBN investment, NBN adoption, denoted with *FiberAdop*, measures the number of adopting consumers and businesses that also show a willingness to pay for NBN-related content and services under a commercial contract.

In constructing our dependent variable, *FiberCov*, we include all relevant fiber-based broadband access architectures, which either deploy fiber-optic cables directly to the premises of consumers ("high-end fiber") or partly rely on "old" copper wire and coaxial cable connections in the remaining segment of the access network ("hybrid-fiber"). Table A.1 describes in more detail the relevant fiber-based architectures ("Fiber

---

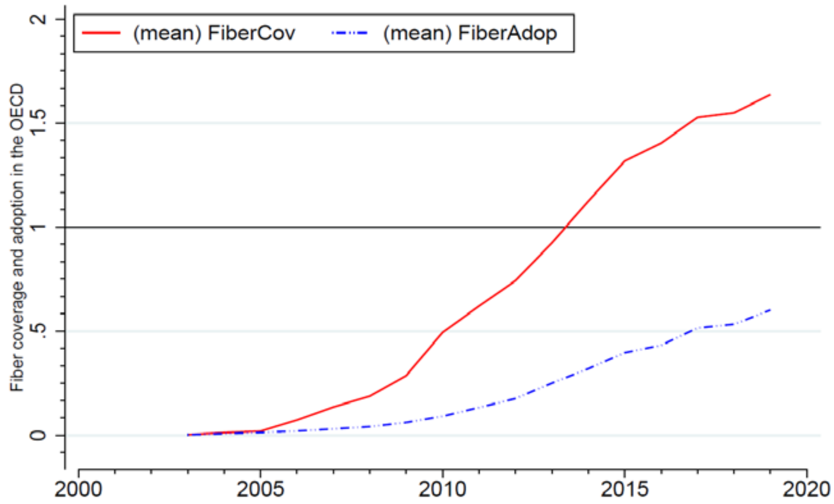
in terms of target setting and actual deployment levels; such benchmarking effects get reinforced under the supranational EU framework.

[12] Because our estimators involve first differencing and internal instruments lagged by two periods, up to 512 observations are used in the estimations.

to the x", FTTx). Note that by considering all relevant FTTx network architectures, we make sure to employ a measure of NBN investments that the state aid programs targeted.

Figure 1 depicts mean values of household weighted numbers of NBN investment (*FiberCov*) and adoption (*FiberAdop*) in OECD countries for the years 2003 to 2019. One can first infer that only a fraction of installed NBN connections are also adopted by consumers. Second, both operator investment and consumer adoption follow a dynamic and non-linear adjustment and adoption process, respectively. Third, one can observe overprovisioning of households on average due to multiple infrastructures in some (sub-)urban areas since 2013 (see horizontal line at 1). The Netherlands, for instance, exhibits the second highest population density in Europe, duopolistic legacy infrastructures and about eight million private households covered with multiple FTTx technologies in parallel; about 7.3 million homes are passed by FTTC/VDSL technologies based on former monopolist infrastructures and also by FTTN/DOCSIS technologies based on coaxial-cable infrastructures in 2020. In addition, new entrants deployed about 3.3 million FTTH/B connections based on own infrastructure elements (including municipalities) until the end of our period of analysis. This market situation results in an average household coverage of 2.24 FTTx lines per household. Note, however, that high average household coverage does not imply ubiquitous household coverage. On the contrary, most countries still exhibit low household coverage in rural areas (European Commission, 2020), where average deployment costs are high and the speed of adjustment is low. Fourth, low fiber adoption rates represent a serious welfare concern, as only (output-oriented) adoption to NBN connections and consumers utilizing related services and applications enables broadband as a general-purpose technology, and generates the concomitant welfare effects; the latter are expected to be much higher than those related to direct investment-related multiplier effects.

Figure 1: NBN investment and adoption household shares (OECD mean values for 2003-2019)



Source: Own calculations based on data from FTTH Council Europe

5.2 Main independent variable: State aid

Almost all funding programs in the past have been implemented at national levels and targeted the supply side (section 3.3). Therefore, in constructing our state aid variable, we focused on supply-side oriented funding programs as provided by national governments in OECD member states. Based on publicly available information published by governmental departments and regulatory agencies we collected information on funding programs that targeted rollout of the NBN technologies (Table A.2 lists all relevant sources of national- and EU-level state aid programs in OECD countries).

In line with most empirical contributions (e.g., Whiteacre and Gallardo, 2020), we construct a binary variable, denoted *StateAid*, indicating if there is a national state aid programme supporting NBN deployment in a given year in a certain country. We test the short-term and long-term effects of introducing state aid programs, which allows us to answer our research questions and derive relevant policy implications.

5.3 Control variables

As discussed in section 4.1, our controls include multiple measures of competitive intensity (***W***), costs (***C***), and revenues (***R***). The variable *FixMobSub* measures competition stemming from broadband wireless mobile networks. According to the discussion in section 3.1, 4G-based mobile broadband technologies have exerted significant competitive pressure on wireline NBN technologies since 2010. Competition within broadband wireline markets further depends on the extent of the market share of the legacy xDSL technology and infrastructure, *ShareDSL*, owned by former monopolistic incumbent operators, and measures the degree of remaining market power of incumbent operators. Next to the infrastructure-based competition from both wireline and wireless networks, service-based competition can also exist. Various mandatory access regulations, which can interfere with the state aid regulations, aim at inducing additional competition in the broadband service provision by allowing new entrants to use parts of the existing infrastructure. The variables *AccessReg* and *AccessPrice* capture those regulations, as imposed on the NBN infrastructure and older broadband infrastructure of market dominant operators, respectively.[13]

The vector of cost determinants ***C*** includes the long-term interest rate, *IntRate*, to capture opportunity costs related to NBN deployment projects. Deployment costs crucially depend on topographic and demographic characteristics, and therefore on the extent of urban and rural areas and housing structure. The variables *RuralPop* and *ShareAppr* capture the number of people living in rural areas and the number of apartments per building, and hence economies of density in broadband (NBN) deployment. Costs are further determined by construction costs; the variable *Wages* proxies the costs of construction work which represents by far the largest share of total deployment costs.

The vector of revenue covariates ***R*** contains micro-founded determinants of demand, measuring households' income by GDP per capita, *GDPpc*, and households' ICT budget, *CommExp*. The age dependency ratio, *AgeDepRatio*, measures the number of users who typically exhibit lower ICT affinity

[13] These variables are available for a subset of our sample, though.

and/or willingness to pay for ICT services. Revenues for future NBN services can also be positively affected by the price level for telecommunications services in general, *TeleServP*. The total number of internet users, *IntUsers*, measures the potential market size of consumers eventually adopting NBN services and content. Content is measured by the market entrance of Netflix, *Netflix*. Video streaming services meanwhile represent more than 60% of global internet download traffic and hence the "killer app" of NBN. Being one of the most famous providers of streaming services, Netflix represents about 15% of global internet download traffic.[14]

5.4 Instrumental variables

External instrumental variables, as noted in section 4.2, include the variable *LftWng*, which measures the share of left-liberal legislators, and the variable *GovExp*, which measures the share of public expenditures. Hausman-type geographic instruments related to the average development regarding state aid and NBN deployment in all other 31 states are denoted with *StateAid31* and *FiberCov31*, respectively.

6 Estimation results

Table 2 reports the main estimation results of our empirical model, as captured by equation (5). However, we include in Table 2 only those variables from the full set of explanatory variables, as described in Tables 1 and A.1, that turned out to be significant in our estimations at least once, and report the other results as further tests and robustness checks in Tables 3 and 3.A.

Columns (1) through (5) in Table 2 all use the same set of explanatory variables, but a different set of internal and external instruments. In particular, columns (1) through (3) follow Anderson and Hsiao's (1981) two-stage least squares (2SLS) approach; after first-differencing equation (5), which removes country-specific effects, we use lagged values of the lagged dependent variable, *FiberCov(t-1)*, and the endogenous variables, *StateAid* and *FixMobileSub*, as internal instruments, and differenced or lagged values of *StateAid31*, *FiberCov31*, *LftWng*, and *GovExp*, as external instruments.[15] Columns (4) and (5) follow a more efficient Arellano and Bond's (1991) one-step GMM approach, which also uses first-difference transformation and the same set of internal and external instruments as in columns (1) and (3), respectively, but includes further instruments, or (stacked) moment conditions, for the lagged dependent variable. Because the increased

---

[14] Information available at: https://variety.com/2018/digital/news/netflix-15-percent-internet-bandwidth-worldwide-study-1202963207/ (last accessed July 5th 2021).

[15] Next to *StateAid*, we also suspect *FixMobileSubs* to suffer from reverse causality, as the mobile operators may react to the NBN-enabled broadband offerings of fixed-line operators. Table A.4 in the Appendix reports an exemplary set of first-stage results corresponding to column (3) in Table 2, that is, the model with the smallest set of instruments. The instruments are strong, as evidenced by the F-tests of excluded instruments and the partial R^2 statistics; the coefficients have economically meaningful signs. The models in columns (1) and (2) in Table 2 add instruments by substituting the instruments based on differenced values with the ones based on levels and/or including the instruments lagged by more periods. The first-stage results of these models are available from the authors upon request.

efficiency of the Arellano-Bond estimator over the Anderson-Hsiao estimator may come at the cost of overfitting the model (Roodman, 2009), we keep the number of instruments used low and report it in Table 2 next to the number of clusters and observations in the estimation sample. A test of joint significance of explanatory variables, a test of second-order serial correlation in the residuals, and the Hansen test of over-identifying restrictions provide additional diagnostics, which show that our model is correctly specified.[16]

The results in Table 2 are robust to the use of a specific estimator, 2SLS or GMM, and a specific set of instruments across columns. For the interpretation of the results, it is important to stress that this is the cross-time variation in our data that identifies the coefficients, as the cross-sectional variation is removed by means of first differencing. The coefficient on the lagged dependent variable is highly statistically significant and ranges from 0.440 in column (1) to 0.676 in column (5), with an average of 0.563. Thus, the use of a partial-adjustment model in capturing the dynamics of NBN investment is warranted and the speed of adjustment (λ=1-α_1) is about 0.437.

The impact of control variables on NBN deployment is both non-negligible and economically meaningful in our model. The competition from mobile broadband, as captured by the variable *FixMobSubs*, shows a statistically significant (in four out of five columns in Table 2) and positive effect. Its coefficient equals 0.66 on average across columns, which means that an increase in mobile competition by one standard deviation increases NBN coverage by some 12.5 percentage points in the short term (0.66*0.19=0.1254) and 28.7 percentage points in the long term (0.1254/(1-0.563)=0.2870).

The demand shifters show a weaker impact in our model. The age dependency ratio, *AgeDepRatio*, is positive, but only marginally significant when using the 2SLS estimator, and insignificant when using the GMM estimator, in Table 2. The coefficient *AgeDepRatio* equals 0.011 on average, which means that an increase of the share of the young and the old in the population by one standard deviation leads to some 6.2 percentage points more NBN infrastructure in the short term (0.11*6.67=0.0618) and 14.1 percentage points in the long term (0.0618/(1-0.563)=0.1414). Though statistically weak, this result is unexpected. A possible interpretation is that this is the impact of the young, which more than offsets the demand of the old for NBN-based services, as compared to working age groups. The impact of GDP per capita is positive, as expected, but significant at the 10% level in only one out of five estimations in Table 2.

The cost shifters show a stronger impact on the NBN investment than the demand shifters. Both the share of rural population, *RuralPop*, and the long-term interest rate, *IntRate*, are statistically significant across all five columns in Table 2 and return an average coefficient of -4.127 and -0.017, respectively. The negative sign on the coefficients are as expected. The estimated magnitude of the effect of rural population appears high; one standard deviation increase in *RuralPop* decreases the NBN coverage by 49.5 percentage points in the short term (-4.127*0.12=-0.4952) and 113 percentage points in the long term (-0.4952/(1-0.563)=-

[16] We have also performed Hausman tests to confirm that *StateAid* and *FixMobileSub* are indeed endogenous in our model.

1.133). However, rural population is a slow-changing variable; even small changes over a short period may be informative of a longer trend, the latter being more important for long-term infrastructure investments.[17] The impact of interest rate is an order of magnitude smaller; one standard deviation increase lowers the NBN coverage by 4.9 percentage points in the short term (-0.017*2.87=-0.0488) and 11.2 percentage points in the long term (-0.0488/(1-0.563)=-0.1116).

Finally, our variable of interest, *StateAid*, proves to be highly statistically and economically significant. The coefficients are significant at the 1% level in each of the five specifications in Table 2 and the average magnitude across specifications equals 0.290. This means that the existence of a state aid program directed at NBNs increases the coverage in the studied countries by 29 percentage points on average in the short term. The long-term impact equals 66.3 percentage points (0.290/(1-0.563)=0.6632).

The inclusion of additional controls, as shown in Tables 3 and 3.A, generally leaves the main results unaffected.[18] In particular, the inclusion of time-trend variables in Table 3 does not significantly change the results. One noticeable exception is column (4) in Table 3, in which we control for the existence of regulated access to the NBN infrastructure in a subsample of our data. In this specification, the *StateAid* coefficient equals 0.209 and is significant at the 10% level. Whereas this shows the robustness of our result on state aid to controlling for other forms of state intervention (and to a significant reduction of the estimation sample size), it also behooves us to interpret the estimated magnitude of *StateAid* coefficient cautiously. Last, but not least, Table 3 provides additional evidence on the dynamic effects of state aid policies. As explained in section 4.1.1 and motivated in the introductory section, by including the interaction term *FiberCov(t-1)*StateAid(t)*, we can test whether the state aid has a real long-term impact by increasing total NBN coverage or merely whether it speeds up the investments that would take place anyway. For instance, a negative coefficient on the interaction term would mean that α_1 goes down, hence the adjustment speed, as measured by λ, goes up, in the presence of state aid regulations. A sufficient increase of the coefficient on *StateAid* accompanying this could leave the long-term impact of *StateAid* unchanged. Taken together, the state aid regulation would then only affect the speed, but not the ultimate level of deployed infrastructure. The statistically insignificant coefficient on the interaction term in column (3) suggests, however, that the state

[17] Note that rural population has a two-fold impact on the NBN profitability: an immediate one on the deployment costs and a long-term one on future revenues. If rural population migrates to small towns, for instance, this makes the case for covering small towns with NBN stronger, especially if the migration trend continuous in the long term. We also need to reiterate that the NBN coverage measure in our sample can exceed 100%, because the parallel coverage of multiple alternative infrastructures in particular in black (sub-)urban areas leads to duplication of access lines. In fact, coverage goes as high as 286% for the small state of Luxembourg where the state-owned incumbent operators offer NBN services based on all FTTx technologies. In light of this, the coefficient on *RuralPop* is not unreasonably high.

[18] For the expositional purpose, the robustness checks in Tables 3 and 3.A take column (5) in Table 2 as the baseline specification. The results of the robustness checks are, however, representative of the other specifications and available from the authors upon request.

aid had no impact on the speed of adjustment, whereas its direct impact on the NBN coverage remains strong, as evidenced by the positive and significant coefficient on *StateAid* in column (3).

7 Costs and benefits of state aid programs

Given substantial expenditures for state aid programs during NBN deployment in the last two decades, it is important to quantify total benefits and costs when evaluating the overall efficiency of such programs. In order to conduct a rudimentary cost-benefit calculation, we first relate our estimates of the average impact of state aid programs on NBN deployment to average effects of NBN on GDP using an external study (Briglauer and Gugler, 2019). In order to make a conservative assessment, we evaluate benefits on lower bounds of respective coefficient estimates. We then contrast the imputed GDP per capita benefit with external estimates on average per capita state aid expenditures (Feasey et al., 2018; Bourreau et al., 2020).

According to our analysis in section 6, state aid exerts a significant and positive impact on NBN investment. The lowest coefficient estimate for the variable *StateAid* (as reported for our main estimation results in Table 2 in column 1) is 0.220, implying that having a state aid program in place increased household weighted NBN investment on average by about 22 percentage points, or 28.2% when evaluated at the grand mean value (Table 1: $\overline{NBN} = 0.78$) in the short term. The long-term values equal 39.3 percentage points (0.220/(1-0.44)) and 50.4% (28.2%/(1-0.44)), respectively. Next, in order to find an elasticity of GDP with respect to NBNs, we refer to Briglauer and Gugler (2019), who estimate the impact of NBN adoption on GPD using various NBN-adoption variables. The authors identify the elasticity to be in the interval of 0.002 to 0.005. As one can infer from Figure 1, NBN adoption is, however, lagging far behind NBN investment. Therefore, we must consider that adoption rates, which relate NBN adoption to NBN investment, are substantially below 1. From the data underlying Figure 1, we infer that after the initial years with very low fiber deployment (and adoption), the average adoption rate was about 0.33 in the period 2005-2019. Taking all these estimates into account and evaluating at the grand mean of GDP per capita in our data (Table 1: $\overline{GDPpc} =$ \$40,000), we find a conservative estimate of the impact of state aid on increase in GDP per capita per year. The short-term impact is about \$7.45 (0.002*0.282*0.33*\$40,000), which gradually rises to \$13.30 in the long term (0.002*0.504*0.33*\$40,000).

Next, we need to identify per capita expenditures on NBN-specific state aid programs. Table 4 presents country-specific estimates of the expenditures. Within the EU, several member states spent less than €5 per capita in total over 16 years (2003 to 2018), whereas Italy and France, which top the list, spent €145.4 and €214.8 per capita, or \$9.09 and \$13.43 per capita per year, respectively. Thus, the highest state aid spending in Europe roughly corresponds to the average values in terms of the GDP increase. Outside Europe, state aid was highest in Australia (\$101.24 per capita per year), Korea (\$32.91 per capita per year), and New Zealand (\$24.55 per capita per year). Overall, based on the data from 29 out of 33 countries in our analysis over the last decade or so, the average state aid spending was \$9.32 per capita per year. Contrasting this cost figure with the average benefit, as reported above, shows that the state aid programs are indeed highly efficient. On average, the benefits outweigh the costs as early as in the second year of a program, and the programs "break even" in the third year.[19] It must be stressed that the NBN infrastructure's lifetime vastly exceeds 18 years, the time span of our analysis, so the cost-benefit calculation is even more advantageous than these numbers suggest, as the benefits remain even if the state aid spending runs out.

These figures reveal that total benefits, as measured by GDP, outweigh total costs and hence state aid programs, on average, have created value in the past. Moreover, we likely underestimate total benefits related to NBNs. First, we must acknowledge the imperfect nature of GDP as a measure of the economic benefits of broadband (NBNs), as not all value created by broadband deployment is captured in standard measures of GDP. In particular, GDP measures just income and not economic welfare. Moreover, the distinction between process and product innovations is important here. Process innovations make current products cheaper to produce, insofar that spillovers in other sectors of the economy are captured for producer surplus (profits are a part of GDP), but not for consumer surplus. Second, if more broadband leads to more product innovations in other sectors of the economy but with a time lag, we would also be underestimating the overall benefits of broadband, since we capture only contemporaneous benefits (Briglauer and Gugler, 2019). Finally, the current COVID-19 pandemic crisis shows the utmost importance of the digital economy to mitigate the damages of global economic and social shutdowns; this exhibits another major source of a positive externality during an economic crisis, which is not captured in the literature so far.

8 Conclusions and policy implications

Whereas some of the available empirical studies found only minor and even insignificant effects of broadband (NBN)-specific state aid programs, our results point to a strong average effect of state aid, which will increase the total NBN coverage by facilitating additional connections for 40% of households (or more) in the long term. These results are robust with respect to a variety of econometric specifications and control variables. Interestingly, while our results reveal strong positive effects on average, the underlying data shows significant discrepancies across countries in terms of extent to which they applied state aid. The most striking difference is between Australia and the Netherlands, which spent in total $1,721 and $1.5 per capita, respectively, during the period 2003-2018. The differences across countries are to some extent explained by the market conditions, but they also point to an unutilized potential for those countries, which lag behind.

Whereas the state aid programs increase the total NBN coverage, they seem have no effect on the speed of NBN deployment. This result seems counterintuitive, but could be explained by at least two things. First, state aid is typically subject to highly bureaucratic processes; in Europe, for instance, all the EU, national and, local government levels are involved, which creates a complex system to navigate for infrastructure

[19] The term "break even" is slightly abused here, as the GDP increase is hardly a revenue, which would be required for a proper break-even analysis. Still, we stick to this notion, as it captures well some of the major NBN related externalities that we have in mind and the main result is insensitive to the discount rate applied.

providers and for local fund applicants and may slow down the investment process. Second, there is some anecdotal evidence of regulatory gaming. Since the private infrastructure providers expect the politicians to grant state aid, if broadband targets are not met, they delay investments which would otherwise be economically viable, and wait for a subsidy (Valletti, 2016, p. 15).

Despite these potential problems, our cost-benefit analysis clearly suggests that state aid programs not only have been effective, but also efficient, as related public expenditures generated significantly higher per capita benefits, as measured by the additional GDP growth. This finding is based on conservative estimates and is further reinforced in view of other disregarded sources of major externalities of NBN, which are difficult to measure and/or not yet considered in the empirical literature. For instance, resilience to shocks, such as the one cause by the COVID-19 pandemic, as well as consumer surplus related to use of digital services and applications. Future research should be directed to quantify the positive societal impact of NBN-specific services in terms of generated consumer surplus and increasing the resilience of economies to crises.

Whereas almost all state aid programs in the past were based on supply-side stimuli, such as direct grants, future research should investigate the complementary role of demand-side NBN policies. In an early empirical analysis, Belloc et al. (2012) suggested that demand-side policies should be enhanced in the late phase of broadband deployment where coverage is already at high levels. This resonates well with the data that we present (and use for the cost-benefit analysis) in Figure 1, which shows that only some 33% of the available NBN connections are used by subscribers. Consumers with limited willingness to pay for more expensive NBN connections could, however, receive public support, for example, via vouchers or tax reliefs, closing the gap to the actual deployment costs of the local network operators. Demand-side policies could also be targeted to increase “E-literacy”, which indirectly increases the number of consumers ultimately adopting NBN services. Indeed, in view of still rather low NBN adoption rates, a one-sided supply funding focus is unlikely to be efficient in terms of realizing potential welfare gains. While still unstudied, the demand-side programs have a potential to generate similar, or even higher, welfare gains.

Appendix

Table A.1: Variable descriptions and sources

Variable	Description	Source[*]
	Dependent variable	
FiberCov	Household weighted number of "homes passed" by relevant FTTx technologies: Fiber to the Cabinet (FTTC) based on VDSL technology, Fiber to the Node (FTTN) based on DOCSIS 3.0 technology, Fiber-to-the Building (FTTB), and Fiber to the Home (FTTH) technologies. In FTTH/FTTB scenarios, the final connection to the subscriber is optical fiber and terminates inside the premises, on an external wall of the subscriber's premises, or no more than 2m from an external wall. "Homes passed" is the total number of premises. The premises is a home or place of business.	FTTH Council Europe[(a)], own research
	Main variable: State aid	
StateAid	Dummy variable that takes the value 1 if there is a national state aid program implemented, supporting NBN deployment in a given year in the respective country.	Own research (see Table A.2)
	Competition and regulation variables	
ShareDSL	Absolute number of wired broadband subscribers using DSL technology divided by absolute number of standard analogue telecommunication access lines. DSL lines include bandwidth levels >= 256 kbit/s but excludes leased lines.	OECD Broadband Database[(b)]
FixMobSub	Share of the total number of mobile-cellular broadband subscriptions to the total number of mobile-cellular broadband subscriptions and total number of active fixed broadband subscriptions.	MarketLine Advantage[(c)]
AccessReg	NBN wholesale access regulation including all remedies imposed on FTTx infrastructures of market-dominant operators. NBN access regulation is measured as a binary indicator, which is equal to 1 in years in which at least one of the available access remedies are in force in a given OECD member state (otherwise zero).	Own research (Briglauer et al., 2018)
AccessPrice	Average access price for full local loop unbundling in € which is calculated as the regulated monthly fee plus the regulated fixed connection fee distributed over three years.	Own research (Briglauer et al., 2018)
	Revenue variables	
CommExp	Percentage of total household expenditure used for ICT goods in the respective year.	MarketLine Advantage[(c)]
GDPpc	Gross domestic product per capita converted to thousands of US dollars using current prices and current purchasing power parities.	OECD National Accounts Database[(d)]
AgeDepRatio	Ratio of dependents (people younger than 15 or older than 65) per 100 working-age individuals.	WorldBank[(e)]

Table A.1: Variable descriptions and sources (continued)

IntUsers	Internet users are people with access to the World Wide Web network, measured in percentage of the population.	ITU[f]
TeleServP	Index (2010 = 100) putting in relation the prices of telecommunications services in different years.	Euromonitor[g]
Netflix	Dummy variable which takes on value 1 if Netflix streaming services were available (otherwise zero).	Own research
	Cost variables	
RuralPop	Rural population measured as the percentage of the total population living in rural areas, calculated as difference between total population and urban population (as defined by national statistical offices).	World Bank World Development Indicators[i]
IntRate	Long-term interest rates refer to government bonds maturing in ten years. The interest rates are generally measured as averages of daily rates, expressed as a percentage.	OECD Finance Database[i]
ShareApprt	Total number of households by type of dwelling (apartment).	Euromonitor[g]
Wages	Average annual wages per capita in thousands of US dollars.	Market Line Advantage[c]
	Instrumental variables (external instruments)	
GovExp	Total government expenditure as percentage of GDP.	Market Line Advantage[c]
LftWng	Share of the population of country *i* in year *t* voting for (rather) left-wing parties.	Own research (Briglauer et al., 2020b)
StateAid31 *FiberCov31*	Hausman-type geographic instruments constructed as described in Section 4.2.	Own research

Notes: [*] All sources listed below last accessed May 25th 2021:
[a] The FTTH Council Europe is a non-profit industry organization that provided data to FTTH Council Europe members in the past at: http://www.ftthcouncil.eu/resources?category_id=6
[b] Data is publicly available at: https://data.oecd.org/broadband/fixed-broadband-subscriptions.htm#indicator-chart
[c] Data is commercially available at: https://advantage.marketline.com/HomePage/Index?returnUrl=Home
[d] Data is publicly available at: https://www.oecd-ilibrary.org/economics/gross-domestic-product-gdp/indicator/english_dc2f7aec-en
[e] Data is publicly available at: https://data.worldbank.org/indicator/SP.POP.DPND
[f] Data is publicly available at: https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx
[g] Data is commercially available at: http://www.portal.euromonitor.com/portal/account/login
[h] Data is publicly available at: https://data.worldbank.org/indicator/SP.RUR.TOTL
[i] Data is publicly available at: https://www.oecd-ilibrary.org/finance-and-investment/interest-rates/indicator-group/english_86b91cb3-en.

Table A.2: Sources for national state aid programs in OECD member states

CC*	NBN state aid program name and source♣
AUS	WIK (2009); Analysis Mason (2010); Given (2010); Beltrán (2014)
AUT	WIK et al. (2020); European Commission♦
CAN	Analysis Mason (2010); Berkman Center (2011); Financial Post: http://business.financialpost.com/fp-tech-desk/crtc-declares-high-speed-internet-a-basic-service-creates-750-million-fund; OECD: http://www.ic.gc.ca/eic/site/119.nsf/eng/home
CZE	European Commission♦; European Commission: https://ec.europa.eu/digital-single-market/en/country-information-czech-republic#national-and-regional-broadband-financing-instrume
DNK	European Commission♦; European Commission: https://ec.europa.eu/digital-single-market/en/country-information-denmark#national-and-regional-broadband-financial-instrume
EST	WIK et al. (2020); European Commission♦
FIN	WIK et al. (2020); European Commission♦
FRA	WIK et al. (2020) European Commission♦
DEU	WIK et al. (2020); European Commission♦
GRC	WIK et al. (2020); European Commission♦
HUN	WIK et al. (2020); European Commission♦
IRL	WIK et al. (2020); European Commission♦
ITA	WIK et al. (2020); European Commission: http://europa.eu/rapid/press-release_IP-16-2363_en.htm; European Commission♦
JPN	WIK (2009); OECD: http://www.oecd.org/internet/ieconomy/43404360.pdf
KOR	WIK (2009); Analysis Mason (2010); Ministry of Information and Communication Republic of Korea: http://www.vus.sk/broadband/nbbs/kr_nbbs.pdf; ANACOM: https://www.anacom.pt/render.jsp?categoryId=340674
NLD	WIK et al. (2020); European Commission♦
NZL	Government of New Zealand: https://www.beehive.govt.nz/release/ultra-fast-broadband-investment-proposal-finalised; WIK (2009); Given (2010); Beltrán (2014); OECD: https://ufb.org.nz/nz-govt-increases-internet-connectivity-investment-to-2b/
NOR	Norwegian Government: https://www.regjeringen.no/en/dokumenter/meld.-st.-23-2012-2013/id718084/sec1; Store Norske Leksikon: https://snl.no/H%C3%98YKOM-programmet; Telecompaper.com: https://www.telecompaper.com/news/norwegian-govt-provides-nok-160-mln-in-broadband-subsidies--1005412
POL	WIK et al. (2020); European Commission♦
PRT	WIK et al. (2020); European Commission♦
SVK	European Commission♦; European Commission: https://ec.europa.eu/digital-single-market/en/country-information-slovakia
SVN	European Commission♦; European Commission: https://ec.europa.eu/digital-single-market/country-information-slovenia
ESP	WIK et al. (2020); European Commission♦
SWE	WIK et al. (2020); European Commission♦; European Commission: https://ec.europa.eu/digital-single-market/country-information-sweden
CHE	Berkman Center (2011)
GBR	WIK et al. (2020); European Commission♦; WIK (2009); Digital Britain: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/228844/7650.pdf
USA	WIK (2009); Analysis Mason (2010); NTIA: https://www2.ntia.doc.gov/; FCC: https://www.fcc.gov/general/national-broadband-plan

Notes: * Three digit-ISO 3166-1 country codes reported in column 1. For Belgium (BEL), Chile (CHL), Iceland (ISL), Israel (ISR), Mexico (MEX), and Turkey (TUR) to the best of our knowledge no, or only minimal (i.e., under *de minimis* rules), public subsidies have been granted for NBN deployment. In Luxemburg, we consider NBN deployment by the 100% state owned incumbent POST Luxembourg as state aid. ♣: All links last accessed July 5th 2021. ♦: Data for all European Union member states were retrieved from the EC's website (https://ec.europa.eu/competition/elojade/isef/index.cfm?clear=1&policy_area_id=3), the Official Journal of the European Union and Feasey et al. (2018).

Table A.3: Further robustness checks

Dep. Var.: ***FiberCov(t)***	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
FiberCov(t-1)	0.692***	0.677***	0.648***	0.676***	0.673***	0.677***	0.678***
	(0.078)	(0.083)	(0.091)	(0.092)	(0.100)	(0.087)	(0.082)
StateAid(t)	0.279**	0.357***	0.293***	0.382***	0.358***	0.353***	0.361***
	(0.112)	(0.088)	(0.111)	(0.086)	(0.087)	(0.086)	(0.087)
FixMobSub(t)	0.524***	0.462**	0.557***	0.484**	0.497**	0.483***	0.491***
	(0.182)	(0.189)	(0.203)	(0.199)	(0.198)	(0.182)	(0.184)
AgeDepRatio(t)	0.003	0.002	0.005	0.001	0.002	0.002	0.001
	(0.007)	(0.007)	(0.007)	(0.009)	(0.007)	(0.007)	(0.006)
GDPpc(t)	0.002	0.003	0.003	0.003	0.004	0.004	0.004
	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.004)	(0.005)
RuralPop(t)	-2.422*	-3.202**	-2.158	-3.343**	-3.129**	-2.888**	-3.163**
	(1.466)	(1.279)	(1.739)	(1.305)	(1.345)	(1.314)	(1.322)
IntRate(t)	-0.020**	-0.020**	-0.021**	-0.018**	-0.021**	-0.021**	-0.021**
	(0.008)	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)
ShareDSL(t)	0.193						
	(0.146)						
CommExp(t)		-0.030					
		(0.037)					
IntUsers(t)			0.003				
			(0.003)				
TeleServP(t)				-0.001			
				(0.001)			
Netflix(t)					0.002		
					(0.043)		
ShareApprt(t)						0.007	
						(0.015)	
Wages(t)							-0.000
							(0.003)
F-test (p-value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AR(2) test (p-value)	0.759	0.624	0.705	0.718	0.620	0.628	0.618
Hansen test (p-value)	0.153	0.103	0.129	0.151	0.128	0.119	0.118
# of instruments	27	27	27	27	27	27	27
# of groups/clusters	32	32	32	30	32	32	32
# of observations	512	512	512	480	512	512	512

Notes: All regressions use a one-step GMM-diff. estimator (Arellano and Bond, 1991) and extend the results from Table 1, column (5) by including additional explanatory variables, as listed in the table. Standard errors in parentheses are clustered at the group (i.e., country) level and robust to arbitrary forms of heteroscedasticity.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.4: First-stage results

	(1)	(2)	(3)
Dep. Var.:	***ΔFiberCov(t-1)***	***ΔStateAid(t)***	***ΔFixMobSub(t)***
ΔAgeDepRatio(t)	0.008	0.003	0.010**
	(0.015)	(0.023)	(0.004)
ΔGDPpc(t)	0.011***	0.000	0.002
	(0.003)	(0.007)	(0.002)
ΔRuralPop(t)	-1.941	0.843	-1.064
	(2.504)	(3.782)	(0.763)
ΔIntRate(t)	0.004	0.008	-0.001
	(0.006)	(0.008)	(0.001)
StateAid(t-2)	0.027	-0.097***	0.009**
	(0.024)	(0.015)	(0.004)
FixMobSub(t-2)	-0.037**	0.093***	-0.093***
	(0.017)	(0.034)	(0.011)
FiberCov(t-2)	-0.005	-0.020	0.015***
	(0.012)	(0.013)	(0.004)
ΔStateAid31(t)	0.066	0.225	0.369***
	(0.123)	(0.235)	(0.045)
ΔFiberCov31(t-1)	0.910***	0.303*	0.313***
	(0.138)	(0.161)	(0.038)
ΔLftWng(t)	0.001*	-0.002	-0.000
	(0.000)	(0.002)	(0.000)
ΔGovExp(t)	0.007**	-0.000	0.004**
	(0.003)	(0.005)	(0.002)
F-test of excluded instruments (p-value)	0.000	0.000	0.000
Partial R^2 of excluded instruments	0.155	0.078	0.243
# of groups/clusters	32	32	32
# of observations	512	512	512

Notes: All first-stage regressions pertain to the model reported in Table 1, column (3). Standard errors in parentheses are clustered at the group (i.e., country) level and robust to arbitrary forms of heteroscedasticity.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

References

Abrardi, L. & Cambini, C. (2019). Ultra-Fast Broadband Investment and Adoption: A Survey. *Telecommunications Policy* 43(3), 183-198.

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

Analysys Mason (2010). Contemporary FTTH stimulus packages study – v.3. Report for the FTTH Council Europe.

Anderson, T.W. & Hsiao, C. (1981). Estimation of Dynamic Models with Error Components. *Journal of American Statistical Association* 76, 598-606.

Arellano, M. & S. Bond (1991). Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations. *Review of Economic Studies* 58, 277-297.

Bacache, M., Bourreau, M. & Gaudin, G. (2014). Dynamic Entry and Investment in New Infrastructures: Empirical evidence from the Telecoms Industry. *Review of Industrial Organization* 44, 179-209.

Belloc, F., Nicita, A., & Rossi, M.A. (2012). Whither Policy Design for Broadband Adoption? Evidence from 30 OECD Countries. *Telecommunications Policy* 36, 382-398.

Beltrán, F. (2014). Fibre-to-the-home, high-speed and national broadband plans: Tales from Down Under, *Telecommunications Policy* 38(8-9), 715-729.

Berkman Center (2011). Next Generation Connectivity: A review of broadband Internet transitions and policy from around the world February 2010. Final Report at Harvard University

Bertschek, I., Briglauer, W., Hüschelrath, K., Kauf, B., & Niebel, T. (2016). The Economic Impacts of Telecommunications Networks and Broadband Internet: A Survey. *Review of Network Economics* 14, 201-227.

Bloom, N., Sadun, R. & Van Reenen, J. (2012). Americans Do IT Better: US Multinationals and the Productivity Miracle. *American Economic Review* 102(1), 167-201.

Bourreau, M., Feasey, R., & Ambre N. (2020). Assessing fifteen years of State Aid for broadband in the European Union: A quantitative analysis. *Telecommunications Policy* 44(7), 101974.

Bresnahan, T. & M. Trajtenberg (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, 613-652.

Briglauer, W. & Gugler, K. (2019). Go for Gigabit? First Evidence on Economic Benefits of High-Speed Broadband Technologies in Europe, *Journal of Common Market Studies* 57(5), 1071-1090.

Briglauer, W., Dürr, N., Falck, O. & Hüschelrath, K. (2019). Does state aid for broadband deployment in rural areas close the digital and economic divide? *Information Economics and Policy* 46, 68-85.

Briglauer, W., Stocker, V., & Whalley, J. (2020a). Public Policy Targets in EU Broadband Markets: The Role of Technological Neutrality. *Telecommunications Policy* 44 (5), Article 101908.

Briglauer, W., Gugler, K., Cambini, C. & Stocker, V. (2020b). Net Neutrality and High-Speed Broadband Networks: Evidence from OECD Countries. Working Papers / Research Institute for Regulatory Economics., WU Vienna University of Economics and Business, Vienna.

Canzian, G., Poy, S., & Schüller, S. (2019). Broadband upgrade and firm performance in rural areas: Quasi-experimental evidence. *Regional Science and Urban Economics* 77, 87-103.

Cardona, M., Kretschmer, T. & Strobel, T. (2013). ICT and Productivity: Conclusions from the Empirical Literature, *Information Economics and Policy* 25(3), 109-125.

Curram, S., Exelby, D., Cadman, R., Warren, & K. Graham, A. (2019). Study on the determinants of investment in VHCN – a System Dynamics approach, report prepared for BEREC BoR (19) 246.

Retrieved from: https://berec.europa.eu/eng/document_register/subject_matter/berec/-reports/8933-study-on-the-determinants-of-investment-in-vhcn-8211-a-system-dynamics-approach.

Czernich, N., Falck, O., Kretschmer, T., & Woessmann, L. (2011). Broadband infrastructure and economic growth. *Economic Journal* 121(552), 505-532.

Dimelis, S.P. & Papaioannou, S.K. (2011). ICT Growth Effects at the Industry Level: A Comparison Between the US and the EU. *Information Economics and Policy* 23(1), 37-50.

Duso, T., Nardotto, M., & Sledeslachts, J. (2018). A Retrospective Study of State Aid Control in the German Broadband Market, mimeo DIW, Berlin, presentation available at: https://www.iwf.rw.fau.de/files/2018/12/Presentation-Tomaso-Duso.pdf.

European Commission (2009). Community Guidelines for the application of State aid rules in relation to rapid deployment of broadband networks, COM (2009) 235/04, Brussels.

European Commission (2010). A Digital Agenda for Europe. Brussels. Retrieved from: https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A52010DC0245.

European Commission (2013). EU Guidelines for the Application of State Aid Rules in Relation to the Rapid Deployment of Broadband Networks, Official Journal C/25/2013, Brussels.

European Commission (2016). Connectivity for a Competitive Digital Single Market – Towards a European Gigabit Society. *COM(2016)*587 final, Brussels.

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

Feasey, R., Bourreau, M. & Nicolle, A. (2018). State Aid for Broadband Infrastructure in Europe – Assessment and Policy Recommendations. CERRE report, available at: https://www.cerre.eu/sites/cerre/files/CERRE_StateAidBroadband_FinalReport_0.pdf.

Given, J. (2010). Take your partners: Public private interplay in Australian and New Zealand plans for next generation broadband. *Telecommunications Policy* 34(9), 540-549.

Grajek, M., & Röller, L. H. (2012). Regulation and investment in network industries: evidence from European telecoms. *Journal of Law and Economics* 55(1), 189-216.

Greenstein, S. & R. McDevitt (2011). The Broadband Bonus: Estimating Broadband Internet's Economic Value, *Telecommunications Policy* 35, 617-632.

Kandilov, K and Renkow, M. (2020), The impacts of the USDA broadband loan and grant programs: moving towards estimating a rate of return. *Economic Inquiry* 58, (3), 1129-1145

Katz, R. & Callorda, F. (2020). Assessing the economic potential of 10G networks, NCTA (US), October 2020, available at: http://www.teleadvs.com/wp-content/uploads/Assessing-the-Economic-Potential-of-10G-Networks.pdf.

Montolio, D., & Trillas, F. (2013). Regulatory Federalism and Industrial Policy in Broadband Telecommunications. *Information Economics and Policy* 25, 18-31.

OECD (2018). Bridging the Rural Digital Divide, OECD digital economy papers No. 265, Paris.

Roodman, D. (2009). Practitioners' Corner: A Note on the Theme of Too Many Instruments. *Oxford Bulletin of Economics and Statistics* 71, 135-157

Timmers, M., Zhao, R., Mau, J. & Salgado, J. (2018). Migrating from Copper to Fibre: The Telco Perspective. A White Paper by the Deployment & Operations Committee, available at: http://www.ftthcouncil.eu.

Valletti, T. (2016). The role of broadband targets. In: European University Institute: The future of broadband policy: Public targets and private investment. Report prepared by the Florence School of Regulation.

WIK (2009). Breitband/Bandbreite für alle: Kosten und Finanzierung einer nationalen Infrastruktur. WIK-Diskussionsbeitrag Nr. 330, Bad Honnef.

WIK, VVA, Squire Patton Boggs,& LE Europe (2020). The role of State Aid for the broadband networks rapid deployment of in the EU. Report prepared for the European Commission, Directorate-General for Competition, Brussels.

Whitacre, B., & Gallardo, R. (2020). State broadband policy: Impacts on availability. *Telecommunications Policy* 44(9), 102025.

Table 1: Summary statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Dependent var.:					
*FiberCov**	512	0.78	0.74	0	2.86
FiberAdop					
Main var.:					
StateAid	512	0.53	0.50	0	1
Control vars.:					
FixMobSub	512	0.60	0.19	0.08	0.90
ShareDSL	512	0.39	0.22	0.01	1.59
CommExp	512	2.84	0.69	1.39	4.94
GDPpc	512	40.00	15.67	10.87	120.98
Netflix	512	0.37	0.48	0	1
IntUsers	512	74.68	16.97	14.58	99.01
TeleServP	480	98.79	16.80	48.80	258.70
AgeDepRatio	512	50.38	5.67	36.21	68.28
RuralPop	512	0.23	0.12	0.02	0.49
IntRate	512	3.71	2.87	-0.49	22.50
Wages	512	41.08	19.99	7.70	97.20
ShareApprt	512	41.48	15.68	6.91	70.16
AccessReg	327	0.42	0.49	0	1
AccessPrice	204	11.30	3.92	5.34	31.30
Instrumental vars.:					
LftWng	512	39.25	12.11	9.80	69.09
GovExp	512	42.69	8.16	19.12	65.03
FiberCov31	512	0.75	0.59	0.01	1.67
StateAid31	512	0.50	0.21	0.12	0.73

Notes: We used linear interpolation to close the gaps in our time series. Some 0.88% of the observations were calculated this way. Mexico and Chile also had OECD membership status during our period of analysis. However, they were excluded because of the missing information on the external instruments. Missing values are not related in any systematic pattern with regard to NBN deployment or state aid programs.

Table 2: Main estimation results

Dep. Var.: ***FiberCov(t)***	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
FiberCov(t-1)	0.440***	0.562***	0.508***	0.628***	0.676***
	(0.112)	(0.096)	(0.137)	(0.097)	(0.084)
StateAid(t)	0.220***	0.279***	0.345***	0.249***	0.356***
	(0.084)	(0.077)	(0.108)	(0.060)	(0.087)
FixMobSub(t)	0.903***	0.574**	0.611	0.717***	0.496***
	(0.310)	(0.238)	(0.397)	(0.224)	(0.187)
AgeDepRatio(t)	0.019*	0.012*	0.015*	0.007	0.002
	(0.011)	(0.007)	(0.008)	(0.008)	(0.007)
GDPpc(t)	0.010*	0.007	0.008	0.005	0.004
	(0.006)	(0.005)	(0.006)	(0.004)	(0.004)
RuralPop(t)	-5.141***	-4.376***	-4.682***	-3.325***	-3.110**
	(1.238)	(1.200)	(1.416)	(1.268)	(1.326)
IntRate(t)	-0.015**	-0.015**	-0.016**	-0.020**	-0.021**
	(0.007)	(0.006)	(0.006)	(0.009)	(0.009)
F-test (2SLS)/χ^2 (GMM) (p-value)	0.000	0.000	0.000	0.000	0.000
AR(2) test (p-value)	0.802	0.727	0.668	0.729	0.625
Hansen test (p-value)	0.110	0.426	0.340	0.767	0.115
# of instruments	18	15	11	42	26
# of groups/clusters	32	32	32	32	32
# of observations	480	512	512	480	512

Notes: Columns (1), (2), and (3) are based on a 2SLS estimator (Anderson and Hsiao, 1981), which uses various IV-style internal and external instruments that differ only in the lag structure. Columns (4) and (5) are based on a one-step GMM-diff. estimator (Arellano and Bond, 1991), which additionally uses GMM-style instruments for the lagged dependent variable. Standard errors in parentheses are clustered at the group (i.e., country) level and robust to arbitrary forms of heteroscedasticity.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Tests and robustness checks

Dep. Var.: ***FiberCov(t)***	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
FiberCov(t-1)	0.687***	0.690***	0.605**	0.582***	0.287
	(0.136)	(0.110)	(0.257)	(0.141)	(0.254)
StateAid(t)	0.279**	0.239**	0.374***	0.209*	0.347**
	(0.137)	(0.113)	(0.114)	(0.113)	(0.152)
FixMobSub(t)	0.354**	0.341**	0.537**	0.643**	0.989**
	(0.151)	(0.148)	(0.261)	(0.269)	(0.482)
AgeDepRatio(t)	0.002	0.008	0.003	-0.011	0.008
	(0.007)	(0.006)	(0.007)	(0.013)	(0.017)
GDPpc(t)	-0.000	0.001	0.005	0.016**	0.013
	(0.004)	(0.004)	(0.005)	(0.007)	(0.008)
RuralPop(t)	-2.961*	-2.561*	-3.337**	-4.566***	-7.081***
	(1.709)	(1.476)	(1.559)	(1.351)	(2.187)
IntRate(t)	-0.020**	-0.020**	-0.021**	-0.021*	-0.019**
	(0.009)	(0.009)	(0.009)	(0.012)	(0.009)
TimeTrend(t)	0.009	0.018			
	(0.021)	(0.016)			
$TimeTrend^2(t)$		-0.001			
		(0.000)			
*FiberCov(t-1) * StateAid(t)*			0.059		
			(0.228)		
AccessReg(t)				0.019	
				(0.077)	
AccessPrice(t)					-0.004
					(0.004)
χ^2-test (p-value)	0.000	0.000	0.000	0.000	0.000
AR(2) test (p-value)	0.692	0.818	0.510	0.185	0.142
Hansen test (p-value)	0.109	0.777	0.129	0.374	0.284
# of instruments	27	28	27	27	19
# of groups/clusters	32	32	32	27	21
# of observations	512	512	512	327	204

Notes: All regressions use a one-step GMM-diff estimator (Arellano and Bond, 1991) and extend the results from table 1, column (5) by including additional explanatory variables, as listed in the table. Standard errors in parentheses are clustered at the group (i.e., country) level and robust to arbitrary forms of heteroscedasticity.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: State aid expenditures on NBN

Country	State aid per capita (US$)	Period	# of years	State aid per capita per year (US$)
Australia	1,721	2003-2019	17	101.24
Austria	125.5	2003-2018	16	7.84
Belgium	*n/a*	*n/a*	*n/a*	*n/a*
Canada	41.4	2002-2019 (except 2013-2015)	15	2.76
Czech Rep	1.2	2003-2018	16	0.08
Denmark	8.4	2014-2019	6	1.41
Finland	30.3	2003-2018	16	1.89
France	214.8	2003-2018	16	13.43
Germany	87.3	2003-2018	16	5.46
Greece	44.2	2003-2018	16	2.76
Hungary	*n/a*	*n/a*	*n/a*	*n/a*
Iceland	*n/a*	*n/a*	*n/a*	*n/a*
Ireland	40.2	2003-2018	16	2.51
Italy	145.4	2003-2018	16	9.09
Japan	11.6	2006-2010	5	2.33
Korea	362.0	2002-2012	11	32.91
Luxemburg	*n/a*	*n/a*	*n/a*	*n/a*
Netherlands	1.5	2003-2018	16	0.09
New Zealand	270.0	2009-2019	11	24.55
Norway	60.5	2002-2014	13	4.65
Poland	17.7	2003-2018	16	1.11
Portugal	10.1	2003-2018	16	0.63
Slovak Rep	21.0	2003-2018	16	1.31
Spain	34.3	2003-2018	16	2.14
Sweden	7.0	2003-2018	16	0.44
Switzerland	4.3	2007-2019	13	0.33
Turkey	*n/a*	*n/a*	*n/a*	*n/a*
UK	59.5	2003-2018	16	3.72
USA	129.9	2009-2019	11	11.81
Estonia	16.8	2003-2018	16	1.05
Israel	*n/a*	*n/a*	*n/a*	*n/a*
Slovenia	75.5	2009-2019	11	6.86
Average	136.21		14.2	9.32

Sources: own calculations based on Feasey et al. (2018) and sources cited in table A.2

Recent ESMT Working Papers

	ESMT No.
Contracting, pricing, and data collection under the AI flywheel effect	**20-01 (R3)**
Huseyin Gurkan, ESMT Berlin Francis de Véricourt, ESMT Berlin	
Beyond retail stores: Managing product proliferation along the supply chain	**19-02 (R2)**
Işık Biçer, SchulichSchool of Business, YorkUniversity Florian Lücker, Cass Business School, City, University of London Tamer Boyaci, ESMT Berlin	
Informing the public about a pandemic	**20-03 (R2)**
Francis de Véricourt, ESMT Berlin Huseyin Gurkan, ESMT Berlin Shouqiang Wang, Naveen Jindal School of Management, The University of Texas at Dallas	
Human and machine: The impact of machine input on decision-making under cognitive limitations	**20-02**
Tamer Boyaci, ESMT Berlin Caner Canyakmaz, ESMT Berlin Francis de Véricourt, ESMT Berlin	
Queueing systems with rationally inattentive customers	**18-04 (R1)**
Caner Canyakmaz, ESMT Berlin Tamer Boyaci, ESMT Berlin	