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Are mobile and fixed broadband substitutes or complements? New empirical evidence from Italy and implications for the digital divide policies

Davide Quaglione [a,*], Nicola Matteucci [b], Donatella Furia [a], Alessandro Marra [c], Cesare Pozzi [d]

[a] Department of Philosophical, Pedagogical and Economic-Quantitative Sciences, G. d'Annunzio University of Chieti and Pescara, viale Pindaro 42, 65127, Pescara, Italy
[b] Department of Economic and Social Sciences, Polytechnic University of Marche, Italy
[c] Department of Economics, G. d'Annunzio University of Chieti and Pescara, Italy
[d] Department of Economics, University of Foggia, Italy

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ABSTRACT

The literature on broadband policies has been focusing on the possible role of mobile broadband as a means for addressing geographical digital divide in areas with no or inadequate fixed broadband infrastructure coverage. Broadband plans designed by most of the industrialized countries take the substitutability between fixed and mobile technologies for granted, with restrictions essentially relating only to bandwidth performance. We explore the determinants of individuals' private access (away from work) to the Internet with the smartphone through a mobile broadband connection, focusing on the role played by Internet uses and taking into account the availability of a fixed broadband connection at home. The results of our econometric exercise, carried out on microdata referred to Italian individuals, provide original and interesting evidence: a complementarity effect between mobile and fixed broadband is found for browsing, video streaming, gaming and cloud services; a substitution effect emerges for social networking and music streaming. Such increasing complexity of individuals' broadband usage patterns should be acknowledged in the way broadband coverage is mapped and policies designed, adopting a more ecosystem-oriented approach which integrates supply- and demand-side features. A first step in this direction is the inclusion of some, so far neglected, key-attributes of the demand (data traffic allowance, latency, ease of interconnection with Internet capable devices) among the relevant dimensions of policy design.

1. Introduction

Internet and broadband policies have significantly evolved in the last decades, worldwide, in connection with the fast technological and market developments experienced by telecommunications (henceforth, telecoms). Since the Nineties, many developed countries have liberalised and privatised (at least partly) telecoms, although the sector remains subject to stringent public policies – especially regulation. In fact, natural monopoly conditions persist along the access network, while other obstacles hamper the universal coverage of broadband, or a reliable access [1–4]. Such a situation dampens the potentially huge socio-economic benefits stemming from broadband as enabler of downstream information and communication technologies: these benefits span from daily business and households' activities [5–7] to public service and institutional applications [8–11].

Disappointingly, a typical market outcome of these institutional reforms was that telecoms operators invested and built broadband networks in the most profitable urban areas, while left underprovided the peripheral and rural ones, leading to various types of market failures[1] [1]. In particular, the resulting broadband infrastructural digital divide (defined as lack of coverage or insufficient service) hampered rural development priorities [12,13]. On one side, the new telecoms policy was successful in increasing the level of competition in the sector: [2] report on how access rules prevented monopolisation strategies and

* Corresponding author.
E-mail addresses: d.quaglione@unich.it (D. Quaglione), n.matteucci@univpm.it (N. Matteucci), donatella.furia@unich.it (D. Furia), amarra@unich.it (A. Marra), cesare.pozzi@unifg.it (C. Pozzi).

[1] Broadband market failures were typically caused – among the others – by the high market power of the privatised incumbents (setting high retail and wholesale prices), and by their new status of privatised operators, subject to the stock market discipline, that could not fully internalise the high social value of further deploying broadband networks in the more peripheral areas (positive externalities).

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curbed the incumbents' market power. On the other side, the further goal of incentivising private investment (network roll-out) and innovation in the digital era proved more difficult, especially in the EU and for the faster types of broadband - also called NGA (next generation access) networks - with results varying according to the different regulatory schemes adopted [14,15]. Consequently, regulation has been progressively simplified and assumed a forward-looking rationale, to give higher investment incentives to private operators.

The EU experience points to the complexity of carrying out policy-making in the broadband domain. Moreover, the EU sets the fundamental normative framework for its member States[2]; hence, this framework also shaped the broadband policy of Italy – the country featured in the following econometric analysis.

A main policy turn in the EU, more favourable to public intervention in telecoms [16], came with the first edition of the Broadband Guidelines [17] and then the Digital Agenda for Europe (or DAE, see Ref. [18]). In particular, DAE introduced a proper industrial policy in the sector, stating three policy targets: the first two mandated the (supply-side) completion of the population coverage by broadband networks (respectively, by 2013 for the first generation, by 2020 for the second, faster - the NGA one); the third targeted by 2020 the majority adoption (demand-side) of ultra-fast NGA networks (ensuring downloading speeds above 100 Mbps).

The EU broadband policy had to abide by the principles of the existing New Regulatory Framework for electronic communications (henceforth, NRF), originally introduced in 2002: in particular, its "technological neutrality" principle strictly concerns our empirical analysis. According to the 2002/21/EC Directive, the EU regulation « neither imposes nor discriminates in favour of the use of a particular type of technology», although in principle this neutrality requirement « does not preclude the taking of proportionate steps to promote certain specific services where this is justified» (Art. 18). In other words, EU norms should set the objectives, and leave to the market the technological choice of the means to achieve them.

Shortly, this is what happened in the EU broadband policy, where the achievement of the DAE targets (universal coverage) has been often conceived within a standard framework of minimization of the policy budget; as such, it stands as potentially reductionist, since it could not adequately cater for the richer connectivity requirements expressed by the EU cohesion (or regional) policy. However, according to the Digital Agenda Scoreboard key indicators[3], standard (i.e. first generation) fixed broadband coverage in Italy is nearly complete (99.8% of households, year 2018), even in rural areas (98.7%), while a significant geographical digital divide in terms of the faster NGA broadband coverage (90.2% of households versus 43.4% in rural areas, year 2018) still exists. More in general, the current NGA coverage is still very heterogeneous across Italian provinces and, in the case of ultra-fast NGA, lags behind (see figures A1, A2 and table A1 in Appendix A for the detail on the share of households covered at the level of Italian provinces). In particular, so far the enacted policy could not solve the gap of the inferior broadband opportunities available to suburban and especially rural areas [12,19]. In fact, rural areas are distant from the main Internet nodes, feature physical obstacles (e.g. mountains) and host a less dense population. These characters render wired networks,[4] whose construction involves extensive digging and cabling works, more costly to deploy in rural areas; moreover, due to the inferior population density, business prospects appear less remunerative. Instead, wireless alternatives (fixed or mobile), by using spectrum as transmission medium, are faster to deploy, display set-up cost advantages but yield less traffic capacity and often a lower service performance (see *infra*).

In various EU member States (including Italy), unsubsidized mobile broadband offers have become the main wireless market option for accessing Internet in the rural areas.[5] First, with the deployment of the third-generation mobile standard (UMTS+), the data transfer (speed) rate was enhanced; then with the fourth-generation (4G, or LTE), it has been substantially improved (remaining inferior but loosely comparable to that of the established wired alternatives, such as x-DSL and cable networks; for Italy, see Ref. [20]). Finally, pilots running for the fifth-generation (5G) suggest that this new standard might further relax the existing service constraints. In fact, by supporting the Internet of Things and Industry 4.0 paradigms, the 5G promises to further enhance the service performance and ubiquitous availability of mobile broadband, thereby reducing its gap with the better performing wired options, and increasing its appeal to those territories where wired networks are considered unviable.

The market progression pushed policy-makers to increasingly consider mobile broadband as a potential "future-proof" platform. In the EU, the 2013 version of the Broadband Guidelines [21] first labelled mobile networks as one potential future provider of NGA-level broadband services. The consensus rapidly spread [13,22]: in the Western and European countries where public budget limitations or cost-effectiveness considerations prevail, mobile platforms are now perceived as a workable regulated solution catering for the connectivity needs of the underprovided rural areas. However, even as far as 4G coverage is concerned, still about 10% of households in Italian rural areas are not reached yet.

Again, in the EU, virtually all the broadband plans adopted by European member States on the basis of the DAE strategy and subsequent integrations have been featuring the principle of technological neutrality as coupled with stringent regulatory requirements in terms of broadband bandwidth to be ensured by the subsidized networks. So far, this choice has restricted the relevance of mobile broadband coverage as a substitute for the fixed one, limiting its subsidized usage to a subset of the uncovered territories of the member States: this holds both for first and second generation (NGA) broadband.[6] In the near future (with 5G), these regulatory requirements on bandwidth may become unbinding.

Nevertheless, the policy turn in favour of mobile broadband remains contentious for diverging reasons. According to some scholars, the existing regulatory requirements on bandwidth turn out to « lead to distortions of market outcomes by engaging in "winner-picking" by explicitly favouring certain NGA technologies » without sound empirical evidence [23] (p. 15). If anything, a main motivation for the criticism would be that improvements in data compression technologies tend to ease the bandwidth constraint.[7]

[2] In telecoms, national policies have been strongly oriented by the EU institutions in a top-down way [68,69].

[3] Data can be retrieved from https://ec.europa.eu/digital-single-market/en/digital-scoreboard.

[4] Wired networks involve a 'tangible' access loop (telephone line, cable TV or optic fibre), while wireless transmission uses selected bands of the physical spectrum, though a variety of platforms and standards (including Wi-MAX and HSDPA). Hence, wireless broadband includes, beside fixed networks, also mobile ones, stemming from the cellular technology originally developed for digital mobile calls (GSM).

[5] In fact, compared to mobile operators, most Wi-MAX operators, mainly operating on fixed networks, remain smaller players. Of course, the market incumbency of the large multinational mobile operators played a role: since 2009, the diffusion of mobile broadband offers has been pushed by the pre-existing cellular infrastructure and the large installed base of voice subscribers.

[6] For the faster NGA networks, the reference bandwidth has been identified as the 100 Mbps in downloading (and the 30 Mbps to a lesser extent). The 100 Mbps policy requirement is still too binding for the 4G networks, even when deployed in the less populated areas.

[7] As emphasized in Ref. [23] (p.15), «most of the more relevant demand side applications that are used worldwide no longer require huge bandwidths to justify large investments in FTTP infrastructures only. As shown in his report, Williamson (2017) states that 'Skype recommends 1.5 Mbps for an HD video call, BBC iPlayer recommends up to 2.8 Mbps, Google recommends 2.5 Mbps for HD YouTube playback and Netflix recommend 5 Mbps for HD video. 4 K video is more demanding, with Netflix recommending 25 Mbps'».

Although we agree with the basic fact of the gradual obsolescence of the bandwidth requirements, we disagree on the more relevant question of the analytical reductionism underlying the process of elaboration of existing broadband policies. In fact, beside their consideration of minimal bandwidth, they typically neglect other crucial service and demand attributes, that even surpass it in relevance. Moreover, the current market lead reached by mobile broadband partly depends on idiosyncratic factors and should not be assumed as a proof of its absolute techno-economic superiority with respect to other alternatives (see also section 2).

In other words, our empirical work bears a strong normative implication, which argues that broadband policies and national plans should be designed by adequately taking into account demand-side key-attributes of the service. Specifically, an ideal broadband policy that aims at maximizing overall welfare and at minimizing distortions of private investments should take into account the evolution of demand, the patterns of usage of Internet-capable devices, and how the latter change when the Internet is accessed in mobility or at a fixed location. We believe that our work makes an interesting contribution to the digital divide literature, as it deals with both mobile broadband adoption and use, focusing on a geographic area, Italy, which is also unique and definitely under-researched.

In fact, no econometric study so far has explored in a systematic way a number of key market and policy questions: how and to what extent individuals' access to the Internet with a smartphone through a mobile broadband connection is associated to the availability of a fixed broadband connection at home (i.e. in the house which the individual lives in, and irrespective of the technology and the speed of the connection), or to different Internet uses; and whether the effect that the different Internet uses play on the probability to adopt a mobile broadband connection changes when also a fixed broadband connection is available at home.

In particular, we focus on the identification of the determinants of the private demand for mobile broadband connections, thus we exclude from the analysis those individuals who report to use a mobile connection only from the workplace. The choice to explicitly exclude those who use a mobile broadband connection exclusively at work is due to several reasons: first of all, in such cases the adoption of a mobile broadband connection is not necessarily the fruit of the worker's decision; anyway, in many jobs some uses of the Internet (for instance social networking, video streaming) are not allowed (by firm's rules, when not by firewalls), so it makes no sense to assess relationships between Internet uses and mobile broadband adoption if they might be systematically ruled out.

In other words, we must avoid any possible further restriction which would prevent us from capturing the outline of the broadband ecosystem in private uses.

As the digital ecosystem keeps evolving, the technological complementarities between types of connection, Internet-capable devices and online activities become more numerous and complex, to the extent that for some Internet activities instances of complementarities between the use of mobile and fixed broadband are clearly emerging [24,25]. From this point of view, the identification of bandwidth as the sole criterion in broadband planning may be a too narrow, or even misleading, approach. In Ref. [26], the authors give empirical evidence that the end-users' willingness to pay for bandwidth is strictly concave, with two important implications: on one side, the greatest gains in users' welfare come from improving broadband service speeds when and where they are lower; on the other side, the private benefits of deploying very high speed broadband networks through fibre-based technology might fall significantly short of the costs for their deployment. Similarly, [27] demonstrate that mobile consumers with a low income have willingness to pay for an extra GB of data each month, but not for higher download speeds. More recently, [28] add that US subscribers also value service latency (a key constraint for online gaming), and are willing to pay to reduce it to levels more common to wired services. Finally, [29] disentangle the many dimensions driving the consumer's experience on the Internet, illustrating how this may be dampened by a complex interaction of factors other than speed, spanning from the structure of the industry value chain to individual characteristics.

Hence, while our sample is not affected by the infrastructural digital divide, the conclusions drawn in terms of key service attributes and revealed demand behaviour provide crucial insights for the pursuit of 'smarter' supply-side policies, more evidence-based, to be formulated to target the areas of the country that are still uncovered or are poorly serviced - both for standard and advanced (NGA) broadband.

The paper is organized as follows. Section 2 presents a compact overview of the EU and Italian policy-making experiences, highlighting a few critical aspects of public intervention in the broadband sector. Section 3 reviews the literature on mobile broadband adoption. Section 4 describes the empirical methodology. Section 5 presents the results of the analysis and their discussion. The concluding remarks are in Section 6.

2. Critical insights into the EU broadband policy

2.1. Introduction: the common EU framework

In the EU, the issue of the broadband divide is explicitly targeted since 2010 by the Digital Agenda for Europe [18], and then by the Digital Single Market policy. If we review the 165 State Aid (SA) cases so far evaluated,[8] we uncover that nearly all of the 28 EU member States have presented at least one broadband plan (with the larger countries, such as the "big-5", presenting several SA measures each). Moreover, these plans mostly target peripheral and rural territories, featuring areas without any broadband provision ("white" areas, in the SA jargon).

The Broadband Guidelines regulate in detail the design of any SA intervention, in order to limit any distortion of competition ([21] point 78). Three principles govern the interplay among the technologies to be chosen for inclusion in the subsidized infrastructure: the most economically advantageous offer (MEAO), technological neutrality and the re-use of existing infrastructure. *De facto*, the second principle, being accompanied only by a reference criterion based on connection bandwidth, neglects other aspects which are relevant from broadband users' point of view (such as for instance: minimum Quality of Service guarantees, data caps, latency, easier interconnection with Internet capable home devices); as such, it opens the bidding contest to offers using less performing functional options, like mobile networks have been so far. Then, the MEAO and the re-use principles give to these inferior solutions a higher chance of consideration, especially when the auction design assigns weights to the qualitative criteria of adjudication[9] in a way that does not penalise too much the functional shortcomings of wireless technologies. Finally come the 'market advantages': wireless technologies, despite their functional shortcomings, are faster and cheaper to deploy, and offer a more favourable cost-revenue profile, where conditions of lower population density prevail;[10] in addition, mobile infrastructure was rolled out in rural and remote areas well before broadband and is upgradable, so that it can leverage its market incumbency [30].

[8] Updated at September 2019. The official list is available at: http://ec.europa.eu/competition/sectors/telecommunications/broadband_decisions.pdf.

[9] Differently from "lowest price" auctions, with MEAO the national authorities need to decide the weights to be assigned to the qualitative (technical) criteria, when evaluating the auction bids [3,70]: this gives the national authorities important degrees of discretion. Typically, assigning higher weights to criteria such as the achieved geographical coverage and capacity/speed guarantees, lower ones to minimum Quality of Service guarantees, data caps and latency will favour bids emphasizing mobile infrastructure.

[10] With reference to the DAE objectives, [71] estimate that the cost of deploying a wired (either fibre or copper-based) network in a rural area is on average 80% higher than doing the same within a town or village.

In other words, the EU broadband policy framework incorporates a "pro-mobile" orientation, which unfolds more likely in those countries featuring mobile incumbency, many areas with low population density, and/or with public budgets insufficient to finance a more "driving" industrial policy (in the sense specified in Ref. [31]).

From a first overview of the SA cases, examples are found both in large and small member States. Sticking to big-5 members, beside Italy (discussed *infra*), a main case is the important measure Broadband Delivery UK (case SA.33671), that foresaw a crucial role for cheaper wireless/mobile infrastructure ([32] points 42–43 and 50) in areas considered white for basic broadband (see also the findings of [33]). Then, a new measure (SA.40720) authorised in 2016 (whose insufficient funding was doubled in 2018) completes the original UK project, sharing with the first the dominant orientation to requiring compliance with criteria essentially confined to speed and coverage.

Similar 'pro-mobile' trends unfold even in smaller member States, as well demonstrated by the case of Bulgaria and Slovakia (respectively, measures SA.36234 [34] and SA. 33151 [35]).

More generally, the experience of the OECD countries shows that often people living in rural and remote areas do not have, for standard services, feasible alternatives to a mobile platform, acting in a sort of local access monopoly [13]. A similar situation will hold for the foreseeable future for NGA services.

2.2. Broadband policy in Italy

The Italian experience inherits and confirms the previous implicit 'pro-mobile' policy orientation.

Law n. 69/2009 first foresees a nation-wide public investment project ("plan") targeting the underserved areas. The national plan is drafted as two separate SA cases, with the second, SA.33807 [36], targeting also the access infrastructure. Even in this case, public investment and subsidies have to be neutral and compliant with the sole bandwidth requirement; consequently, wireless antennas able to support mobile services are also included.

In 2014, a Government–commissioned study [20] about the roll-out of NGA services formulates a list of policy implications, and first spells out the prescription that 4G mobile networks should be used as a (cheaper) NGA coverage option in place of fixed networks at least in the low density areas; this despite the perceived inadequacy of LTE mobile networks to serve as a viable substitute for NGA fixed services in rural areas ([20] p. 23). Indeed, this policy prescription has been maintained and reinforced in the subsequent steps.

In 2015, an ambitious country-wide NGA strategy is released, the "Strategia Italiana Banda Ultra-larga" (SIBU hereafter, [37]).

The SIBU strategy and its first implementing SA measure mainly concerns rural areas (SA 41647, [38]). They emphasise explicitly minimum speed and coverage requirements (point 39; see Table 1, second row), while further qualitative criteria and their weights are left to the national discretion during implementation. Once again, a certain pro-mobile favour of the SIBU strategy emerges, that may suggest a future extensive usage of mobile infrastructure for the coverage of NGA white areas.[11]

Such broadband policy contains two main possible side effects. First, we need to recall that the Italian "white" territories are often very relevant areas, hosting important agri-food and industrial districts, as well as popular touristic locations [3]. For these areas driving the competitiveness of the Italian economy, a future NGA roll-out based on the less performing wireless and/or mobile platforms appears a less desirable scenario.

Table 1
Explicit performance targets of the SIBU and its implementing SA for Italy, by cluster.

Cluster	A	B	C	D
Cluster target by SIBU	Upgrade from 30 to 100 Mbps	Upgrade from 2 to 30 to 100 Mbps	Upgrade from 2 to 30/100 Mbps	Upgrade from 2 to 30 Mbps
Minimum cluster targets mandated by SA 41647	–	–	70% HH with 100 Mbps DS and 50 Mbps US. 30% HH with 30 Mbps DS and 15Mbps US.	100% HH with 30 Mbps DS and 15 Mbps US.
Overall Italian target	100 Mbps for 85% of Italian population by 2020; 30 Mbps for the remaining 15%			
Overall DAE target	30 Mbps for 100% of Italian population by 2020, without mentioning an explicit coverage target for 100 Mbps; the latter is only featured in the third objective of DAE (as demand side take-off equal to 50% of the total population).			

Legend: upgrade at 2020 or later (plan completion) expressed as improvement on the market situation at July 2014 (t = 0). HH = households. DS = download speed. US = upload speed.
Source: our elaboration on [37,38].

Second, the Italian experience may end up confirming that national broadband policies are rigidly conditioned by the uncritical application of the related EU norms and principles. The way they are designed and implemented may give little or no relevance to (demand-side) key-features which are instead essential for users to derive the widest benefits from broadband adoption.

3. Selected literature review on the determinants of mobile broadband adoption

Empirical studies focusing on the identification of the determinants of broadband Internet adoption are relatively recent. In the first attempts, much of the attention is paid to the role of users' socio-economic features in terms of age, income, gender, education, and living area. [39] find that broadband access is positively associated with education and income, negatively with age. Similarly, [40] find that income and education are positively associated with Internet adoption, and [41] show that age and living area are among the strongest determinants for mobile Internet adoption.

Then, scholars start introducing, together with further socio-economic variables such as marital status, occupational category and monthly allowance, other users' characteristics profiling personality and attitudes. [42] finds that office workers and company executives exhibit a positive attitude toward mobile Internet usage. [43] focus on some personal attitudes, such as attitude on new offerings in general, various facets of mobile Internet experience and usage of established mobile communication services, and find only small to medium effects on mobile Internet usage.

An explicit reference to the possible complementarity between mobile and fixed broadband can be found in Ref. [24] (p. 10): "mobile data is complementary to fixed broadband access […] Thus, fixed broadband services provide additional value to mobile data services". [44] presents a general overview on the issue of substitutability/complementarity concluding that empirical explanations hinge on the interaction of positive cross-elasticities of demand [45–47].

[41] look for possible substitutability between mobile and fixed Internet adoption and find that mobile represents an alternative technology essentially for those users with no fixed internet connection at home. [48] estimate price elasticities of demand for Internet access and

[11] Additionally, the policy documents stress various legacy traits of the Italian market, that reflect such a favour: prevalence of mobile connections, slower growth and willingness to pay for fixed broadband connections, relevance of "mobile-only" broadband customers and worldwide trend of massive growth of mobile traffic).

show that, beyond the usual socio-demographic variables (net monthly income, age and gender) some attitudinal variables influence the technology choice such as use of another Internet connection before the current one, having fixed-line connection, having Internet bundled with TV, and having a secondary Internet connection.

More recently, scholars have given relevance to the role played by individuals' Internet usage. This stream of literature is really interesting in our perspective, because it is based on the assumption, which we consider essential, that the types of patterns of substitutability and/or complementarity between fixed and mobile connections depend also on the type of Internet (and devices) uses made by individuals; any related empirical investigation should be carried out taking such assumption into account. [25] investigate the determinants of mobile broadband adoption and usage employing, together with socio-economic variables, internet use behaviors, such as frequency, transmission speed preference and fixed broadband adoption and usage. Aside from the expected evidence on socio-demographic variables (smartphone adoption is less likely for people who are older, have a lower income, lower level of education and live outside the city), the authors find that lower income individuals tend to use social networking, online shopping and Internet telephone more than those with higher income, and that "those who have a smartphone tend to use it more for watching video, listening to music and social networking if they have fixed broadband services at home" (p. 749).

The question of whether some Internet usage patterns are more suited for mobile or fixed broadband connections is addressed in Ref. [49], where the author suggests that some types of information gathering are more suitable through fixed connections, while social networking is more suitable through mobile ones.

4. Data and econometric strategy

The empirical analysis is based on microdata referred to year 2016, made available by the Italian National Institute of Statistics (ISTAT) in March 2018, covering 18,500 households, about 44,400 individuals. It is a large annual sample survey that covers the resident population in private households, based on responses to questions included in two different questionnaires: a general one, filled in through a paper and pencil interview, in which the relationships among family members, the socio-demographic-economic information about the household as a whole and some individual information are gathered; the second one is handed to each member of the family (children below 14 are interviewed in proxy mode, i.e. information is provided by a parent or a relative of age) and include questions which respondents can easily deal with even without direct intervention by the interviewer; the second questionnaire allows to gather additional information about individual characteristics and behaviors. A complex and repeated process of data exploration and (both deterministic and probabilistic) correction ensures the quality and the validity of the data, while the generalizability of the data is ensured through a complex sampling design, based on both stratification and cluster sampling.

We circumscribe our econometric exercise to a sample of respondents aged between 16 and 74, being such range the one typically considered in statistics concerning digital connectivity and skills (see for instance the Digital Scoreboard provided by the Eurostat). As an additional consideration, it is realistic to assume that the individual choice to subscribe to a mobile broadband Internet service, to buy a smartphone or to use the Internet without heavy restrictions imposed by parents asks for a certain degree of individual freedom and autonomy, which can seldom be found in children aged less than 16 years. At the same time, it is useful to remind that the issues investigated in the paper would concern a very limited number of elders, who reasonably represent isolated cases.

As already mentioned, the aim of the paper is to explore the determinants of the access to mobile broadband through a smartphone, to assess if and to what extent respondents' Internet uses and availability of fixed connections at home[12] might play a role. In particular, we are interested in identifying patterns of broadband private uses, in which the substitutability and/or the complementarity between mobile and fixed broadband technologies be assessed in function of the types of individuals' Internet uses. For this reason, we remove from the sample the only 190 respondents (throughout the country) reporting that a fixed broadband connection is not available in their living area (even in 2016, fixed broadband coverage was nearly complete in Italy, 99.3% of households). Since the access to mobile broadband is the outcome of a dichotomous choice (to subscribe or not to subscribe to a mobile broadband service), in the empirical investigation we opt for a model with a binary dependent variable. However, in our case, the adoption of a mobile broadband connection is conditioned on the availability of a smartphone (respondents explicitly report their use of a mobile broadband connection with a smartphone), which implies that the observations used for the estimates of the determinants of the access to mobile broadband are not a random selection from the sample. This is a typical case of incidental truncation, since the adoption of a mobile Internet connection is observed only for those who have a smartphone. If there are factors that affect smartphone adoption which are not related to the use of a mobile Internet connection, then a simple probit would produce distorted estimates because of a sample selection problem: we might lose track of some people who are eligible to adopt a smartphone. For this reason, an explicit selection equation to the population of interest is added, in order to provide for a proper correction in the empirical analysis [50]. A typical solution to such selection problem [25,51] is the adoption of the Heckman correction procedure [52], according to which we distinguish between:

a *selection equation*:

$$Pr\left(S_j = 1 \middle| X_j\right) = \alpha + \gamma X_j + \partial I_j + \varepsilon_j \tag{1}$$

and a *response (or observation) equation*:

$$Pr\left(Y_j = 1 \middle| Z_j, S_j = 1\right) = \vartheta + \beta Z_j + \delta I_j + \eta F_j + u_j \tag{2}$$

where S_j is the dichotomous variable of the selection equation, which equals 1 if the individual has a smartphone, and 0 otherwise; X_j is the set of regressors, basically socio-demographic variables, and I_j is a set of variables related to different Internet uses (irrespective of the connection technology used for accessing the internet). In fact, it is reasonable that whichever Internet use might be related to smartphone adoption, even though we have considered Internet uses which are not exclusively related to smartphones (i.e. social networks the use of which is mapped through the variable "social" are those, not employment-oriented, that can be accessed from any mobile or fixed device and do not require specifically a smartphone, for instance Facebook and Twitter; those designed for smartphone use only, as WhatsApp and Telegram are not represented in the "social" network variable, as they were the subject of a separate question in the questionnaire). For the selection bias issue to be properly addressed, the selection equation must include at least one variable not included in the observation equation, i.e. a variable which affects selection but does not have an impact on the dependent variable of the observation equation [53,54]. For this reason, we included the dummy variable "phone", which equals 1 whether the respondent has a fixed phone at home, among the regressors in the selection equation. In fact, on the one side the literature on fixed to mobile substitution for

[12] In the empirical analysis, the variable related to fixed broadband takes value 1 if the respondent has no fixed broadband available at home, which means that the respondent is a "mobile-only user". In our opinion, this way of dichotomizing the dummy variable makes the interpretation of the marginal effects of the interaction variables more intuitive and straightforward. In fact, mobile-only users are those for whom some Internet uses could be negatively affected by data limits, small screen sizes, and impossibility to use home-specific devices.

voice call services (see Refs. [55–57]) provides strong and extensive evidence of a strict substitutability between fixed phones and mobile phones; on the other side, in Italy the percentage of households subscribing to fixed-mobile converged bundles in July 2016 was quite low (7%, according to the EU Digital Scoreboard 2017),[13] which implies that the endogeneity between mobile broadband and fixed phone is not a concern for our econometric exercise.

Y_j is the dependent variable of the model (response equation), which equals 1 if the respondent accesses the Internet through (a smartphone with) a mobile broadband connection, and 0 otherwise. For every j_{th} individual, Z_j is a set of socio-demographic and economic factors, I_j is a set of variables related to different Internet uses, irrespective of the technology through which the Internet is accessed (in this context, having used the Internet for each activity just signals that the respondent is aware of the possibility of performing, and deriving some utility from, each activity); F_j is a set of interaction dummies between the different Internet uses and the unavailability of a fixed broadband connection at home. In detail, the equations have the following specification (see Tables 2 and 3 for the definitions and the descriptive statistics of the variables used in our analysis, respectively).

$$\begin{aligned}\text{Selection equation: smartphone} = {} & \alpha + \gamma_1\,\text{gender} + \gamma_2\,\text{age} + \gamma_3\,\text{sit\_econ\_good} + \gamma_4\,\text{bachelor degree} + \gamma_5\,\text{work\_role} + \gamma_6\,\text{phone} + \gamma_7\,\text{area\_city} \\ & + \gamma_8\,\text{area\_country} + \partial_1\,\text{browsing} \\ & + \partial_2\,\text{social} + \partial_3\,\text{video} + \partial_4\,\text{music} + \partial_5\,\text{gaming} + \partial_6\,\text{cloud}\end{aligned}$$

$$\begin{aligned}\text{Observation equation: mobile\_broadband} = {} & \vartheta + \beta_1\,\text{gender} + \beta_2\,\text{age} + \beta_3\,\text{sit\_econ\_good} + \beta_4\,\text{bachelor degree} + \beta_5\,\text{work\_role} \\ & + \beta_6\,\text{no\_personal\_data\_manag} + \beta_7\,\text{area\_city} + \beta_8\,\text{area\_country} \\ & + \beta_9\,\text{no\_fixed\_br} + \delta_1\,\text{browsing} + \delta_2\,\text{social} + \delta_3\,\text{video} + \delta_4\,\text{music} + \delta_5\,\text{gaming} + \delta_6\,\text{cloud}\,S \\ & + \eta_1\,\text{no\_fixed\_br\#browsing} + \eta_2\,\text{no\_fixed\_br\#social} + \eta_3\,\text{no\_fixed\_br\#video} + \eta_4\,\text{no\_fixed\_br\#music} \\ & + \eta_5\,\text{no\_fixed\_br\#gaming} + \eta_6\,\text{no\_fixed\_br\#cloud}\end{aligned}$$

As is well known, in nonlinear binary response models, the coefficient of each independent variable gives information on the direction of its effect, but the magnitude of the coefficient is not especially meaningful. Thus, we are interested in assessing the effect size, the assessment of which is especially relevant when the econometric analysis is based on large samples. In these circumstances, in fact, the p-value tends to go quickly to zero (for additional details, see Ref. [58]), which implies that focusing on statistical significance and sign of a coefficient actually does not necessarily support the relevance of the impact of the explanatory variable on the dependent variable. For this reason, we focus on the marginal effects: "For nonlinear models […] marginal analysis is a more robust way— and sometimes the only way—to interpret effect size" [58] (p. 909). Since we are interested in assessing the magnitude of the effect of each variable on the probability of adopting a mobile Internet connection, and since all the independent variables included in the model are dummies or categorical, the effect size of an independent variable is calculated as the change in the predicted probability of adopting a mobile Internet connection due to the change in the considered independent variable from zero to one (or from the base category to the value of interest), holding all other variables fixed. Furthermore, for probit models the marginal effect of each independent variable is not just its coefficient but depends also on the value of all the other independent variables included in the model. There are several approaches regarding which values should be assigned to the other explanatory variables when calculating the marginal effect of a specific independent variable: we adopted the marginal effect at the mean (MEMs) approach [59], according to which the marginal effect of a variable is estimated using the means for all the other variables. In other words, the marginal effects calculated according to such approach describe the impact of a variable on the predicted probability for an "average" respondent, i.e. a respondent the characteristics of whom are defined as the mean values of the other variables in the model (unless the value of other variables is specified, as is the case in our econometric exercise, see infra).

The presence of interactions among the regressors complicates the calculation of the interaction effect but does not alter the essence of the approach. Because of the non-linearity of the probit model, and the consequent circumstance that the marginal effect of a variable depends also on the values of the other variables, a separate effect for the interaction term cannot be directly calculated [59]. In fact, the interaction term cannot change independently of the values of the component terms. This implies that the interaction effect is not just the first derivative of the cumulative distribution function with respect to the multiplicative term but must be calculated as the cross partial derivative of the cumulative distribution function with respect to each of the variables included in the interaction [60,61]. Furthermore, when, as in our case, the interactions involve couples of dummies (for instance V_1 and V_2), then the interaction effect for each interaction is properly calculated through a discrete double difference: the change in predicted probability when V_1 changes from 0 to 1 when V_2 equals 1 minus the change in predicted probability when V_1 changes from 0 to 1 when V_2 equals 0.

In the present work we are primarily interested in assessing whether there are differences in the probability of adoption of a mobile connection depending on both the types of Internet uses and the availability of a fixed broadband connection at home. For this reason, we included in the model also the set of interaction dummies F_j. Based on the above, the interaction effect involving for instance "browsing" and

[13] See https://ec.europa.eu/digital-single-market/en/news/telecommunications-data-files-digital-scoreboard-2017. In July 2017 the percentage of households subscribing to a fixed-mobile converged bundle remained relatively low, 9%. Furthermore, the statistics provided in the EU Digital Scoreboard 2017 do not distinguish but include any offer that integrates mobile voice and/or mobile broadband. Thus, the percentage of households subscribing to fixed-mobile bundles is, in all likelihood, below the figures just mentioned. Lastly, the bundle does not necessarily involve all the members of the household (it could, for instance, include just one mobile SIM), which further lowers the chance of endogeneity.

Table 2
Description of the variables.

Variables	Description
Dependent variables	
smartphone	Availability of a smartphone (i.e. mobile phone with Internet capabilities). 1 = Yes
mobile_broadband	Use (away from work) of a mobile broadband connection (at least 3G) with a smartphone in the last 3 months. 1 = Yes
Independent variables	
gender*	Gender of the respondent. 1 = male.
age*	Age of the respondent Age of the respondent. 1 = age between 16 and 17. Age of the respondent. 2 = age between 18 and 34. (reference group) Age of the respondent. 3 = age between 35 and 44. Age of the respondent. 4 = age between 45 and 54. Age of the respondent. 5 = age between 55 and 64. Age of the respondent. 6 = age between 65 and 74.
sit_econ_good*	Availability of economic resources for the needs of family. 1 = Excellent or adequate. Reference group: scarce or totally inadequate.
bachelor_degree*	Education level of the respondent. 1 = University degree or postgraduate education.
no_personal_data_manag	Whether the respondent has undertaken any actions to manage access to personal information on the Internet. 1 = None.
work_role*	Professional position 1 = entrepreneur; executive or self-employed professional. 2 = supervisor; employee. 3 = chief labourer; labourer apprentice; homeworker on behalf of firms. 4 = member of a cooperative; occasional worker. (reference group)
phone*	Whether the respondent has a fixed telephone at home. 1 = Yes.
no_fixed_br*	Fixed broadband Internet connection at home (DSL, ADSL, VDSL, fibre optics). 1 = Not available.
browsing	Whether the respondent has used the Internet to gather information, visit online news websites in the last 3 months. 1 = Yes.
social	Whether the respondent has used the Internet to participate in social networks (Facebook, Twitter, etc), online blogs or forums, video calls in the last 3 months. 1 = Yes.
video	Whether the respondent has used the Internet to see movies, tv series, streamed TV in the last 3 months. 1 = Yes.
music	Whether the respondent has used the Internet to listen to music or radio in streaming in the last 3 months. 1 = Yes.
gaming	Whether the respondent has used the Internet to download or play games in the last 3 months. 1 = Yes.
cloud	The respondent has been using the Internet over the last 3 months for cloud services (Internet storage space and/or file-sharing services). 1 = Yes.
area_met*	Type of municipality. 1 = Metropolitan area.
area_country*	Country macro areas 1 = Northern Italy. (reference group) 2 = Central Italy 3 = Southern Italy and Islands.

Note: the variables denoted with the * have been gathered through a paper and pencil interview, the others through respondent's self-report.

"no_fixed_br" is obtained by calculating the marginal effects of "browsing" at two representative values (zero and one, which represent "with fixed broadband" and "no fixed broadband" respectively) of the variable "no_fixed_br". The difference between the marginal effect of "browsing" when "no_fixed_br" is first set to one and then to zero (holding all the other variables fixed at their mean) represents how much the effect of "browsing" changes for a unit change in "no_fixed_br": extending such approach to all of the independent variables, we will see how the marginal effect of each of them, and in particular of those related to Internet uses, changes when a fixed connection is available at home.

Table 3
Descriptive statistics.

Binary Variables (0/1)	Mean	Std. Dev.
Dependent variables		
smartphone	0.5319	0.4990
mobile_broadband	0.4589	0.4983
Independent variables		
gender	0.4903	0.4999
sit_econ_good	0.6070	0.4884
bachelor_degree	0.1524	0.3594
no_personal_data_manag	0.3107	0.4628
phone	0.5665	0.4956
no_fixed_br	0.3939	0.4886
browsing	0.4942	0.5000
social	0.5538	0.4971
video	0.2474	0.4315
music	0.3414	0.4742
gaming	0.2032	0.4024
cloud	0.4939	0.5000
area_met	0.2055	0.4041
Categorical Variables	Proportion	Std. Dev.
Independent variables		
age		
1	0.0272	0.0009
2	0.2303	0.0024
3	0.1847	0.0022
4	0.2215	0.0023
5	0.1779	0.0021
6	0.1582	0.0020
work_role		
1	0.0746	0.0015
2	0.2737	0.0025
3	0.3095	0.0026
4	0.3421	0.0027
area_country		
1	0.4184	0.0028
2	0.1765	0.0021
3	0.4051	0.0027

N. of observations for each variable: 31,895.

We adopt the one-step Stata command 'heckprobit' (the selection and observation equations are estimated jointly, through a full maximum likelihood approach), and thus we rely on the procedure à la Heckman assuming that the errors of the two equations are normally distributed and correlated among themselves. In order to assess the existence of such a correlation between the errors, and the consequent need to adopt the Heckman correction procedure, we run a Wald test. The Wald test rejects the hypothesis of no correlation between errors with a 1% significance (see Table 4), thus confirming that a selection bias problem exists.

Given the inclusion in the model of a set of interaction dummies among the regressors, we also check for the possible existence of multicollinearity, running a Variance Inflation Factor (VIF) test. According to the results of the test, the average VIF is 1.96, and the interaction 'no_fixed_br#social' shows the highest value (4.18). None of the regressors is associated to a VIF higher than 10, the threshold most commonly used to indicate the presence of severe multicollinearity problems. Thus, though acknowledging the limitations of the Variance Inflation Factor tool and the 'rule of thumb' nature of the threshold 10 [62,63], we assume that the collinearity among the independent variables of the regression is not a serious issue in our econometric exercise.

As anticipated, the dependent variable of the selection equation is dichotomous (smartphone) and takes the value 1 if the respondent has a smartphone (i.e. a mobile phone with Internet connection capabilities) and 0 otherwise; more than 53% of the respondents report to have a smartphone. As for the response equation, the dichotomous dependent variable (mobile_broadband) takes value 1 if the respondent has used a mobile broadband connection (away from work and at least with a 3G

Table 4
Results of the econometric analysis based on the Heckman correction procedure.

VARIABLES	Selection Equation Marginal Effects	(a) Observation Equation ME (no fixed bb)	(b) Observation Equation ME (with fixed bb)
gender	−0.0130*	0.0130*	0.0137*
	(0.00783)	(0.00768)	(0.00816)
age16_17	0.0801***	0.0702***	0.109***
	(0.0211)	(0.0156)	(0.0241)
age35_44	−0.0656***	−0.114***	−0.141***
	(0.0114)	(0.0113)	(0.0116)
age45_54	−0.154***	−0.165***	−0.193***
	(0.0111)	(0.0144)	(0.0117)
age55_64	−0.271***	−0.202***	−0.228***
	(0.0121)	(0.0210)	(0.0148)
age64_74	−0.418***	−0.270***	−0.286***
	(0.0129)	(0.0327)	(0.0206)
sit_econ_good	0.0480***	−0.00152	−0.00160
	(0.00812)	(0.00840)	(0.00889)
bachelor_degree	0.0391***	0.0466***	0.0508***
	(0.0121)	(0.0102)	(0.0111)
work_role1	0.0858***	−0.0287*	−0.0321*
	(0.0168)	(0.0151)	(0.0171)
work_role2	0.0331***	−0.0874***	−0.0925***
	(0.0109)	(0.0105)	(0.0122)
work_role3	−0.00589	−0.0600***	−0.0652***
	(0.00981)	(0.0104)	(0.0115)
phone	−0.0376***		
	(0.00852)		
no_personal_data_manag		−0.0421***	−0.0437***
		(0.00827)	(0.00901)
no_fixed_br		0.282***	0.282***
		(0.0135)	(0.0135)
browsing	0.173***	−0.00484	0.0895***
	(0.00945)	(0.0191)	(0.0123)
social	0.507***	0.225***	0.202***
	(0.00724)	(0.0414)	(0.0240)
video	0.0134	−0.0225	0.0629***
	(0.0114)	(0.0209)	(0.0106)
music	0.0584***	0.0510***	0.0275***
	(0.0105)	(0.0176)	(0.0107)
gaming	0.114***	0.0305*	0.0472***
	(0.0110)	(0.0179)	(0.0106)
cloud	0.198***	0.0539**	0.121***
	(0.00990)	(0.0216)	(0.0134)
area_met	−0.0134	−0.0218**	−0.0228**
	(0.00962)	(0.00929)	(0.00948)
area_center	0.00984	0.0315***	0.0328***
	(0.0109)	(0.0103)	(0.0108)
area_south	−0.0314***	0.0404***	0.0424***
	(0.00872)	(0.00868)	(0.00952)
Wald Test (Chi2)	16.86***		
Observations	31,895	31,895	31,895

The standard errors are corrected for heteroskedasticity. ***, **, * signify that the coefficient is statistically different from zero at 1%, 5% and 10%, respectively.

technology) with a smartphone in the last three months; which is the case for approximately the 46% of respondents. As for the explanatory variables, we include some commonly used controls for the socio-demographic and geographic characteristics of the respondents (gender, age, education level, economic situation, working condition and geographic area), the unavailability of a fixed broadband connection at home (39.4%), the availability of a fixed phone at home (56.7%), and the activities carried out on the Internet as reported by respondents. Among these, the participation in social networking is the most spread (55.4%), followed by browsing and cloud services (around 49.4%), music (34.1%) and video streaming (24.7%); gaming (20.3%) is at the bottom of the list. 31% of the individuals in the sample report not to have undertaken any action to manage access to personal information on the Internet, circumstance used in our context as a proxy for respondent's awareness of privacy issues in online activities (or, more broadly, as a proxy for respondent's digital awareness).

5. The econometric analysis: results and discussion

The marginal effects related to the selection equation (eq. (1) above) regression are presented in Table 4, column 1.

As for the socio-demographic covariates, they all show signs consistent with those reported in the literature on the determinants of smartphones adoption [25,64,65]. Males are slightly less likely to adopt smartphones (−1.3%) than females, while a positive effect is associated to higher education (+3.9%) and satisfaction with economic condition (+4.8%). Age shows a negative association: older people are less likely to use a smartphone: for individuals aged between 55 and 64 the use of a smartphone is 27.1% less probable than for those aged 18–34; for those over 64, the probability is nearly halved (−41.8%). On the contrary, younger respondents (aged 16–17) show a higher probability of smartphone adoption. Even being entrepreneurs, executives, self-employed individuals and white collars makes the adoption of a smartphone more probable (+8.6%) as, to a lesser extent, being an employee (+3.3%). Living in a metropolitan area does not seem to have a role, while respondents living in the South and in the Islands of Italy are associated to a lower propensity to adopt a smartphone (−3.1%). As widely expected, having a fixed phone at home makes the adoption of a smartphone less likely (−3.8%).

All the Internet uses, but video streaming which is statistically not significant, show a positive association with smartphone adoption: in particular, and not surprisingly, the most significant effect is associated to the participation in social networking (+50.7%), followed at some distance by cloud services (+19.8%) and browsing (+17.3%), then gaming (+11.4%) and music streaming (+5.8%). The absence of a statistical linkage between video streaming and smartphone adoption is consistent with our interpretation of the facts (see next section for details), i.e. that video streaming is an activity more typically carried out with devices that ensure a higher quality of fruition (TV sets, tablets) and smartphones might only play an ancillary role when a fixed broadband connection is available at home.

Regarding the response equation, as already clarified, the marginal effect for each explanatory variable is calculated at two different representative values (one and zero) of the variable no_fixed_br and use the means for the other variables. The overall idea is to assess what is the effect of each explanatory variable on the probability of adopting a mobile Internet connection and, at the same time, how such effects change when a fixed broadband connection becomes available from unavailable. Thus, in the first one, we set the value of the variable no_fixed_br so as to imply the lack of availability of a fixed broadband connection at home (column 2); in the second configuration (column 3), we set the value of the variable no_fixed_br so as to imply the availability of a fixed broadband connection at home (of course, the value of the interaction dummies will vary correspondingly). By construction, the difference between the marginal effects related to each independent variable (i.e. the difference between the values in column 3 and in column 2) quantifies the differential predicted probability that can be traced back to the availability of a fixed broadband at home.

In general, the marginal effects of the socio-demographic controls show the expected sign: being male, having a satisfactory economic situation and a bachelor's degree show a positive marginal effect, while the probability of using a mobile broadband connection decreases with age. The adoption of a mobile broadband connection is less likely also for individuals living in metropolitan areas, while a positive association is reported for those living in the Center and in the South of Italy. A possible explanation of such results could be related to the availability of public wifi networks, more abundant in metropolitan areas and in the North of Italy. People having not undertaken any actions to manage access to their own personal information on the Internet (no_personal_data_manag) are less likely to use a mobile broadband connection, which can be interpreted as a signal that individuals fearing for possible negative consequences due to privacy and security issues concerning personal data are less willing to go online.

As a general rule, the lack of a fixed broadband connection at home has a positive impact on the probability of adopting a mobile broadband connection (+28.2%), implying a form of substitutability between fixed and mobile connections, but the different Internet uses seem to heterogeneously affect such relationship.

In fact, when marginal effects are calculated assigning value 1 to the variable no_fixed_br so as to imply the lack a fixed broadband connection at home (column (2)), those associated to browsing and video streaming are not statistically significant. Social networking is identified as the 'killer application' for mobile broadband adoption: those who are engaged in these activities have a 22.5% higher probability of having access to the Internet through a mobile broadband connection, while other activities (music streaming, gaming and cloud services) play a positive, though smaller, role (+5.1%, +3.1% and 5.4% respectively).

The marginal effects calculated assigning value 0 to the variable no_fixed_br (to signify the presence of a fixed broadband connection at home) are, sometimes significantly, different. Social media are still the most important among the Internet uses associated with mobile broadband adoption (+20.2%), but the marginal effect is lower than in the case of no fixed broadband at home (the difference with the previous case is negative: −2.3%). There is a negative difference also with reference to music streaming (−2.35%). Negative differences signal that, when the Internet is used for social networking and for music streaming, the adoption of a mobile Internet connection is relatively less likely for those having a fixed broadband connection, which denotes the existence of some form of substitutability between fixed and mobile broadband connection.

In contrast with the former case, browsing and video streaming now show substantial, statistically significantly different from zero, marginal effects (+8.95% and +6.3% respectively). Cloud services show a more important effect on mobile broadband adoption when a fixed broadband is available at home: its marginal effect (+12.1) more than doubles the marginal effect when no fixed broadband is available at home. A slight increase in the marginal effects is detected also for gaming activities (+1.7%).

In other words, as far as video streaming, cloud services, browsing and gaming are concerned, the results show that the probability of adopting a mobile broadband connection are higher for those who use a fixed broadband connection at home, implying that for such Internet activities the pattern of mobile and fixed broadband connections uses is characterized by some forms of complementarities.

Consequently, the results of our econometric exercise provide original and interesting insights. First, they (partly) challenge the received wisdom of the scientific literature, that were predominantly stating a generalised substitutability relation between fixed and mobile broadband access. Second, our analysis empirically corroborates the few – mainly qualitative – contributions that had proposed a more nuanced picture, arriving to suggest that usage patterns may affect the fixed-mobile relation, but failing to provide robust empirical tests (see the review in Section 3).

Indeed, in principle, mobile broadband can be assumed as a substitute for the fixed one. Mobile connections enable individuals to access the Internet independently from whether they are in mobility or at a fixed location, provided that there is service coverage. However, individuals access the Internet to carry out a variety of activities, many of which demanding specific network requirements, through a variety of Internet capable devices. It is precisely this set of specificities that shapes individuals' connections and devices usage. For some Internet activities (according to our results: video streaming, cloud services, gaming and Internet browsing), it can be argued that the value that individuals gain is higher when they are carried out combining fixed and mobile access, in line with [24]. For some other online activities (in our case those related to the participation to social networking and music streaming), mobile and fixed broadband appear to be mere substitutes.

The underlying reasons for such a promiscuous nature of the relationship between mobile and fixed broadband, in our opinion, must be sought within the different technological and usage complementarities that each online activity activates within the digital ecosystem. There are several differences when the Internet is accessed through a mobile rather than fixed broadband connection: these differences go far beyond the obvious distinction between being on the move or at a fixed location. First of all, mobile subscriptions typically include a limited monthly traffic allowance, while no restriction is generally applied in fixed broadband subscriptions. For this reason, data intensive Internet activities (video streaming and cloud computing certainly belong to such category) are seldom carried out systematically on a mobile broadband connection. In 2016, year which our data refer to, premium mobile plans hardly included traffic allowances bigger than 5 GB, which made them unlikely to be systematically chosen to access to video contents in place of a fixed connection with unlimited data traffic. Rather, mobile broadband access can be complementary to fixed broadband access, for instance when « consumers use Internet access via mobile data to sample online content but complete their online activity using fixed Internet access at home, with no download limit» [24] (p. 2). Furthermore, mobile and fixed broadband connections are not necessarily used with the same sets of Internet capable devices. Some devices are typical of the Internet access from home and are not natively endowed with mobile broadband connection capabilities (at most they have wifi connectivity), and this could make a big difference in users' experience, especially when specific online activities are considered: for instance, desktop computers (with monitors with adequate size) and smart-TVs, the ideal tools for the fruition of video contents, are almost exclusively fed through fixed broadband connections. As regards cloud services, complementarities between mobile and fixed broadband connections may arise because users could find valuable the option of accessing on the move contents uploaded into the cloud from devices at home (documents, videos, photos), or of accessing from home contents initially generated through mobile devices but processed with other more powerful and adequate devices (for instance, photos edited through professional software on personal computers; notes taken with a smartphone/tablet and edited, formatted and paginated on a personal computer).

In such a picture, the importance of bandwidth as the key enabling feature of the broadband Internet experience – the only one typically subjected to specific requirements in broadband plans and policies – is to be scaled down.[14] Here comes the second crucial contribution of our paper – its policy message and the quest for more evidence-based policy-making in the telecoms sector. In fact, according to the proposed interpretation of the results of our empirical analysis, other dimensions emerge as equally critical for generating value to users – both individually and socially. In particular, data caps and a less immediate integration with home Internet capable devices make mobile broadband connections a poor substitute for fixed broadband connections: with the words of [66], smartphones help those without fixed broadband get online, but do not necessarily bridge the digital divide. Rather, they justify the complementary use of these two types of connections. Moreover, such circumstance has major relevance precisely for those Internet uses which the most significant positive impact on society is expected from, in terms of social and economic cohesion.

All in all, put in a broader perspective, our paper confirms for broadband the received wisdom of the literature that the ICT domain is more challenging for policy-making compared to other non-ICT utilities, such as electricity, energy supply, waste treatment and others. In fact,

[14] In support of this claim, we notice that in 2016 in Italy the average Internet speed via fixed connections was 8 Mbps, while the average Internet speed via mobile connections was 10.8 Mbps [72].

while in these utilities alternative supplying platforms do not differ in terms of functional fruition of the basic service, that remains somehow homogeneous across delivery sources, in the broadband case the fixed-mobile alternative implies rather different patterns of delivery, usage and welfare; so far, market outcomes and policy-making have dealt rather unsatisfactorily with this peculiarity, excluding the less advantaged users from reaping the full benefits of the ICT revolution.

Lastly, even though this is an empirical paper, it bears also a strong theoretical implication. The evolution of broadband is such that theoretical models based only on the linkages between supply-side variables are misleading and miss, or trivialize, demand-side dimensions which are, or will soon be, just as important. For instance, the assessment of substitutability or complementarity relationships between fixed and mobile broadband on the basis of the cross-price elasticity without taking into account Internet uses, preferred devices, traffic data allowances, etc. is a simplification which might bring to inaccurate predictions ([67]). According to our results, the reference theoretical model must be enhanced, in the direction of the broadband ecosystem conceptualisations.

6. Conclusions

Our paper investigates the determinants of the adoption of mobile Internet connections, focusing on the effects of the possible different Internet uses and on the way these effects change when the mobile adopter has also a fixed broadband connection at home. The results of our empirical analysis give evidence that the relationship between fixed and mobile broadband, i.e. whether there is substitution or complementarity in their adoption, is complex and depends on the Internet type of usage. In fact, framed within a broadband ecosystem with increasing complexity, different Internet uses imply different broadband requirements and other (preferred) features, not only in terms of bandwidth: traffic data allowances and ease of connectivity with other Internet capable devices are just a couple of examples. In general, Internet uses which are more bandwidth and data demanding (video streaming, cloud services), or are best experienced with typical home devices (browsing on desktops with large monitors, video streaming on smart-TVs) are associated to a stronger effect on mobile connection adoption when a fixed broadband connection is available at home.

These considerations have some relevant, though preliminary, planning and policy implications. First of all, broadband policies and plans should include coverage targets based not only on bandwidth levels, but also on minimum requirements related to the other features emerging as relevant for the user' experience on the Internet [29]. According to the interpretation of the results of our analysis, for instance, a minimum amount of monthly data traffic allowance is indispensable to preserve the link between broadband availability and value to users.[15] More in general, given the rapid technological and usage developments of the broadband ecosystem, a benevolent policy maker should regularly monitor the evolution of individuals' Internet usage patterns and the relevant broadband technical specifications, to ensure their consistency with the key-attributes of the demand-side over time.

By extension, the same complexity should be embedded in the approach to broadband coverage mapping. Absolute digital divide indicators, based only on bandwidth, are not suitable for producing a picture of the real opportunities available to users in terms of access capabilities to the various Internet uses. Decisions taken and plans designed by the policy maker on this basis are liable to result in failures to extend broadband benefits to laggard areas, as well as in distortions of market outcomes in violation of the principle of technological neutrality. Since Italy is still lagging behind in the development of ultra-fast NGA broadband networks (and to a lesser extent of NGA), and given that current mobile technologies (3G and LTE) cannot be considered equivalent alternatives, we believe that these principles could be usefully implemented in both digital divide mapping and related public intervention design, in the direction of a more evidence-based policy-making. Policies that solely set formal goals in terms of broadband coverage and bandwidth thresholds are destined to produce only formal results, irrespective of the broadband uses actually enabled. Especially in the framework of technological neutrality, policy effectiveness requires a preliminary clear and in-depth understanding of the needs to fulfil.

The findings of our econometric exercise suggest that further research is needed to better understand the implications of the increasing complexity of the broadband ecosystem and to inform sound, more evidence-based policies. Many are the possible developments in order to gather a deeper understanding of the usage relationship between fixed and mobile broadband, of the relevance of other broadband features such as bandwidth, data allowance, latency and jitter (especially important for online gaming), Internet capable devices, and so on. Future research should thus focus on a deeper investigation of consumers' behaviors, taking into account a richer set of theoretical and empirical connections. Furthermore, it would be very interesting if such analyses be carried out also along the time dimension, taking into account possible idiosyncratic and time-persistent factors. As is often the case, the toughest hurdle is data availability. For such analyses to be carried out adequately, a high-quality, specific database is required, with panel data or several waves of cross-sectional data longitudinally related, which can be built only through the administration (on a yearly basis) of ad-hoc designed questionnaires. Were panel or pseudo-panel data available, the adoption of a dynamic probit model would allow to assess the causal relationship between the variables, the presence and the magnitude of state dependence phenomena, as well as whether individuals' broadband-related behaviors are affected by cumulative phenomena.

CRediT authorship contribution statement

Davide Quaglione: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Project administration. **Nicola Matteucci:** Conceptualization, Investigation, Writing - original draft, Writing - review & editing. **Donatella Furia:** Methodology, Formal analysis, Writing - original draft. **Alessandro Marra:** Writing - original draft, Writing - review & editing. **Cesare Pozzi:** Supervision.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.seps.2020.100823.

[15] Interestingly, as reported in Ref. [13] (p. 24) «in July 2016, the United Kingdom consulted on a proposed specification for a broadband Universal Service Obligation that provides a minimum download speed of 10 Mbps, upload speed of 1 Mbps, minimum standards of latency, a maximum contention ratio of 50:1, and a data cap of at least 100 GB per month». Analogously, in the US the deployment of rural broadband has been subjected to several performance requirements, among which speed, latency and monthly usage (at least 150 GB).

APPENDIX A

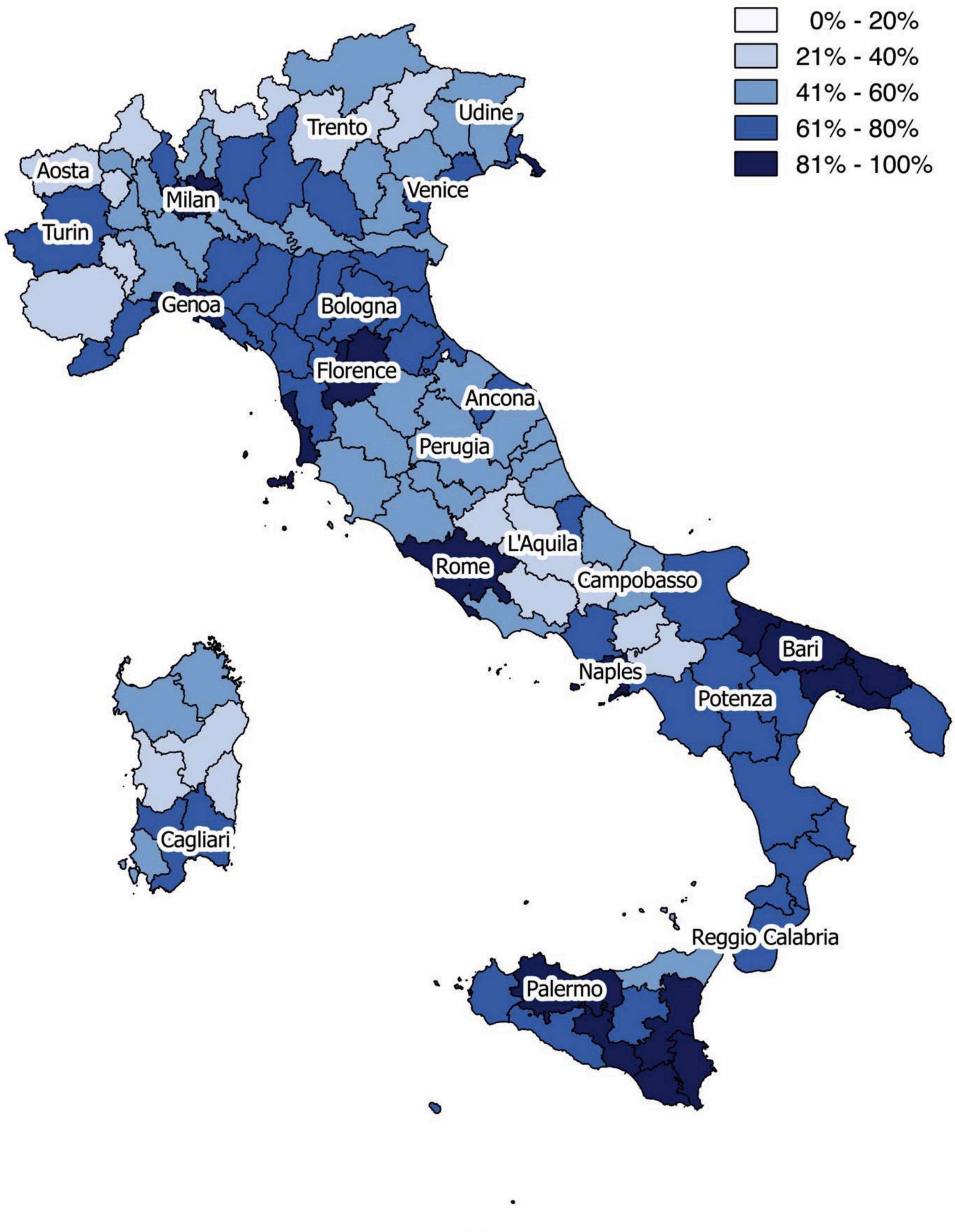

Fig. A1. Share of households covered by a connection at least at 30 Mbps, by Italian province.
Source: authors' elaboration on AGCM data (2019). Labels identify the Capitals of the Regions.

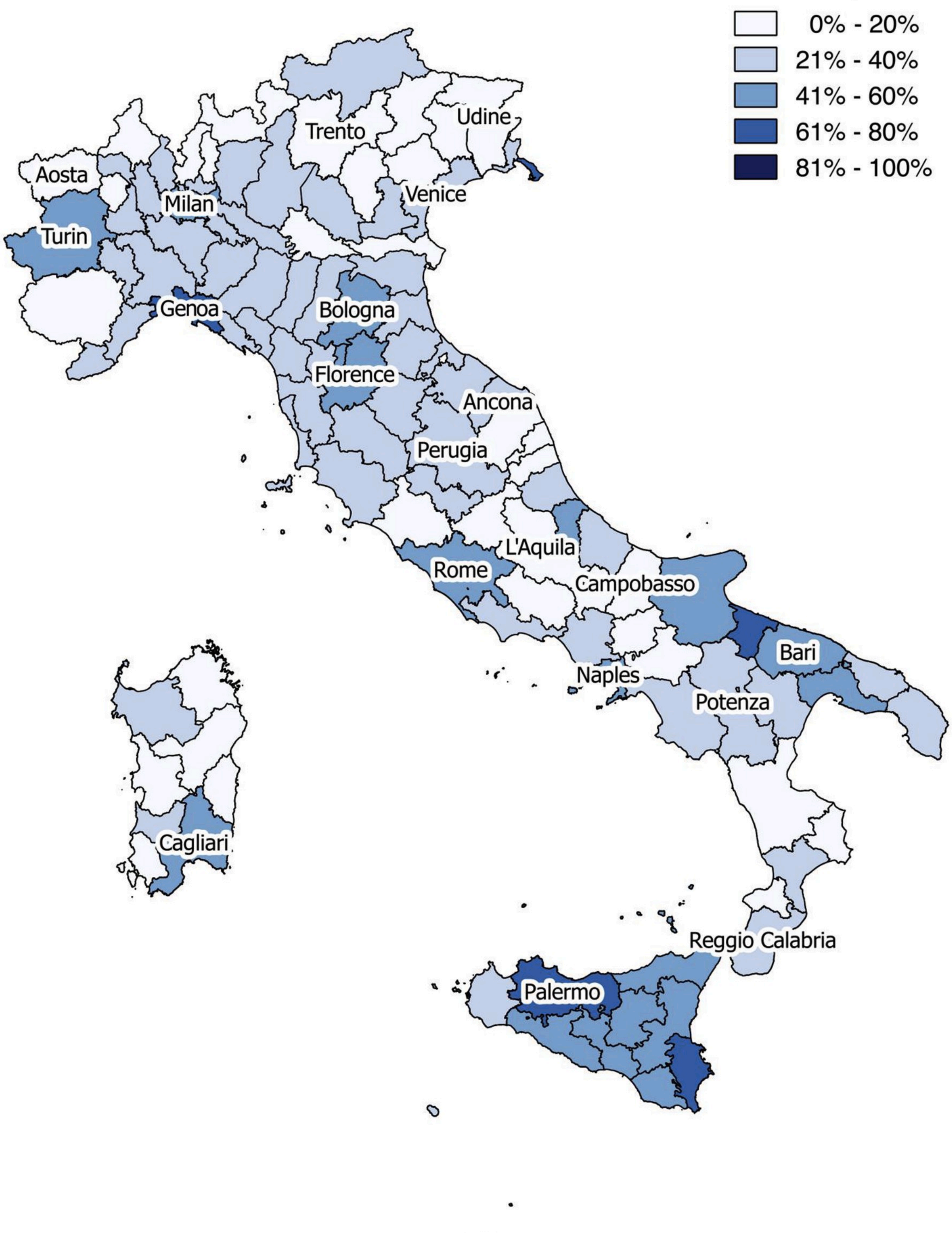

Fig. A2. Share of households covered by a connection at least at 100 Mbps, by Italian province.
Source: authors' elaboration on AGCM data (2019). Labels identify the Capitals of the Regions.

Table A1
Share of households (HH) covered by at least 30Mbps and 100 Mbps connections, by Italian province

Province	30 Mbps	100 Mbps	Province	30 Mbps	100 Mbps	Province	30 Mbps	100 Mbps	Province	30 Mbps	100 Mbps	Province	30 Mbps	100 Mbps
Agrigento	76%	50%	Caserta	73%	31%	La Spezia	68%	29%	Padua	57%	27%	Sassari	60%	25%
Alessandria	51%	30%	Catania	86%	58%	Latina	60%	30%	Palermo	83%	64%	Savona	69%	37%
Ancona	67%	36%	Catanzaro	72%	27%	Lecce	72%	25%	Parma	70%	41%	Siena	53%	25%
Aosta	37%	17%	Chieti	43%	22%	Lecco	54%	19%	Pavia	51%	23%	Siracusa	90%	66%
Arezzo	55%	24%	Como	51%	16%	Livorno	82%	41%	Perugia	59%	32%	Sondrio	37%	14%
Ascoli Piceno	49%	20%	Cosenza	68%	15%	Lodi	57%	25%	Pesaro-Urbino	57%	26%	Taranto	85%	51%
Asti	39%	25%	Cremona	55%	26%	Lucca	70%	24%	Pescara	63%	46%	Teramo	53%	30%
Avellino	40%	14%	Crotone	79%	15%	Macerata	42%	18%	Piacenza	62%	32%	Terni	55%	29%
Bari	92%	55%	Cuneo	38%	17%	Mantova	48%	17%	Pisa	63%	28%	Trapani	76%	41%
Barl.-Andr.-Trani	89%	62%	Enna	73%	49%	Massa Carrara	73%	24%	Pistoia	73%	23%	Trento	37%	19%
Belluno	36%	13%	Fermo	47%	13%	Matera	77%	30%	Pordenone	60%	18%	Treviso	52%	17%
Benevento	37%	12%	Ferrara	61%	29%	Medio Campidano	65%	23%	Potenza	61%	22%	Trieste	83%	64%
Bergamo	65%	22%	Florence	81%	46%	Messina	60%	43%	Prato	91%	57%	Turin	75%	51%
Biella	40%	17%	Foggia	75%	46%	Milan	83%	55%	Ragusa	84%	58%	Udine	43%	17%
Bologna	78%	56%	Forlì Cesena	67%	34%	Modena	75%	38%	Ravenna	66%	35%	Varese	69%	25%
Bolzano	44%	27%	Frosinone	38%	10%	Monza-Brianza	86%	37%	Reggio Calabria	72%	25%	Venice	73%	40%
Brescia	69%	26%	Genoa	85%	62%	Naples	89%	54%	Reggio Emilia	70%	32%	Verb-Cus-Ossola	40%	10%
Brindisi	84%	38%	Gorizia	75%	27%	Novara	59%	28%	Rieti	33%	18%	Vercelli	50%	26%
Cagliari	78%	44%	Grosseto	57%	28%	Nuoro	40%	17%	Rimini	77%	32%	Verona	72%	36%
Caltanissetta	81%	56%	Imperia	65%	31%	Ogliastra	33%	1%	Rome	85%	59%	Vibo Valentia	69%	16%
Campobasso	41%	17%	Isernia	31%	1%	Olbia Tempio	42%	17%	Rovigo	49%	13%	Vicenza	51%	18%
Carbonia Iglesias	51%	13%	L'Aquila	34%	13%	Oristano	40%	14%	Salerno	62%	26%	Viterbo	50%	17%

Source: AGCM data (2019).

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Davide Quaglione is Full Professor of Applied Economics at the Department of Philosophical, Pedagogical and Economic-Quantitative Sciences of the University "G. d'Annunzio" of Chieti and Pescara and Research Fellow at GRIF, Gruppo di Ricerche Industriali e Finanziarie, LUISS Guido Carli University, Rome. He is supervisor of the Electronic Communications Division of the Network Industries Observatory, GRIF, LUISS Guido Carli University. He has extensive research and advisory experience in innovation policy, research policy, cultural policy, industrial economics, structural change, regional policies, regulatory and antitrust issues.

Nicola Matteucci is Senior Researcher in Applied Economics at the Department of Economic and Social Sciences of Marche Polytechnic University (Ancona). His main research interests are the economics of telecoms and Internet media, antitrust and regulation. He serves as board member in national and international academic journals, and has worked in several international projects and studies - particularly as a consultant for the EU Commission.

Donatella Furia is Senior Researcher in Economics at the Department of Philosophical, Pedagogical and Economic-Quantitative Sciences of the University "G. d'Annunzio" of Chieti and Pescara. Her research interest mainly focuses on cross-cutting topics related to sustainability, cultural and innovation policies.

Alessandro Marra is Associate Professor of Applied Economics at the University "G. d'Annunzio" of Chieti and Pescara, where he teaches Economics of Innovation and carries out research on industrial economics, economics of innovation and urban economics. He is a Research Fellow at GRIF 'Fabio Gobbo', LUISS 'Guido Carli' University, Rome.

Cesare Pozzi is Full Professor of Applied Economics at the Department of Law of the Luiss Guido Carli University and vice-Director at GRIF, Gruppo di Ricerche Industriali e Finanziarie, LUISS Guido Carli University, Rome. He has extensive research and advisory experience in industrial economics, regional policies, regulatory and antitrust issues.