

Broadband and Firm Location: Some answers to relevant policy and research issues using meta-analysis

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Résumé de l'article

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BROADBAND AND FIRM LOCATION: SOME ANSWERS TO RELEVANT POLICY AND RESEARCH ISSUES USING A META-ANALYSIS

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Abstract:

We provide a quantitative literature review on broadband and firm location. While most previous works find that broadband has positive effects on firm location, the impact is very heterogeneous across studies. We examine the role of three categories of variables (context, methodological choices and publication characteristics) in explaining the variation in previous estimates. The results indicate that broadband effects are significantly more beneficial in urban areas, whereas lesser effects are found for finance, real estate and insurance. Methodological settings, and particularly the choice of the level of analysis, of control variables and of the econometric estimator, also play a significant role in explaining the differences in previous estimates. These results are then discussed to find some answers to relevant policy and research issues.

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INTRODUCTION

Broadband access is widely assumed to foster economic development, presumably leading to stronger economic growth, a higher number of firms, increased employment, and greater competitiveness and attractiveness. To foster economic development in less densely populated areas, which are often ignored by private telecommunication operators, a number of large-scale broadband deployment programs have been initiated in many countries (e.g., "Connecting America: The National Broadband Plan" in the USA, "Connecting Canadians" in Canada, the "National Broadband Plan" in Ireland, "The French Very High-Speed Broadband Plan" in France). Massive investments are being made, not only by private operators but also by public authorities, but the genuine broadband effects remain uncertain.

Several issues are still being debated. First, does broadband deployment necessarily improve economic performance, or might it produce adverse effects in some cases? Second, in which contexts can broadband be a boon for local economic development (areas with good accessibility, well endowed with skilled labor, etc.)? Third, when significant portions of developed countries already benefit from good connections to first-generation broadband networks, will the provision of next-generation technologies (optical fiber, 4G, 5G) generate significant additional economic gains? In other words, is it worthwhile for governments to significantly invest in ultrafast broadband deployment in unserved areas when other public policies could be implemented? Fourth, if broadband does affect economic development, how much time would it take to perceive its impacts? Moreover, do the effects strengthen or lessen over time? In addition to these relevant policy issues, from a methodological point of view, what are the most relevant approaches to estimate broadband effects?

A number of studies have already provided some answers by examining broadband effects on various economic indicators, including economic growth, productivity, employment or unemployment, income, population, property values and, last but not least, firm location (see, among others, Atasoy, 2013; Bai, 2017; Briglauer & al., 2019; Czernich, 2014; De Stefano & al., 2014; Deller & Whitacre, Forthcoming; Forman & al., 2012; Guidry & al., 2012; Gurney, 2012; Ivus & Boland, 2015; Kandilov & Renkow, 2010; Kolko, 2012; Lapointe, 2015; Lehr & al., 2006; Mahasuweerachai & al., 2010; Mack, 2014; 2015; Mack & Rey, 2014; Mack & Wentz, 2017; Van Gaasbeek, 2008; Whitacre & al., 2014-a; 2014-b). Among the investigated economic outcomes, firm location is of particular interest for at least two reasons. First, as entrepreneurship is crucial for economic development, it is of utmost importance to understand its determinants. Second, fostering firm creation and attractiveness is often a specific objective of broadband deployment public programs (see, for example, the objectives of the "French Very High-Speed Broadband Plan"). While numerous studies have already been produced, the impact of broadband is still being debated, most likely because existing evidence is based on different contexts and methodologies. Thus, the present paper provides a quantitative literature review (also known as a meta-regression

analysis) on broadband and firm location in developed countries'. The aim is twofold. First, we want to identify the contexts (study areas, industries) where broadband can lead to development, which might be of particular value for policymakers. Second, we want to investigate how methodological choices (scale of analysis, measures of indicators, econometric models) have an impact on the estimated results to provide guidance for future research.

To disentangle the relative role of contextual and methodological factors in explaining the diverging results, we undertake a meta-regression analysis (hereafter MRA) (Florax & al., 2002; Glass, 1976; Stanley & Jarrell, 1989). Quantitative literature reviews offer major advantages. First, an MRA provides a systematic review of the state of the art, as it must include all existing (published and unpublished) studies and clearly explain the rules of inclusion/exclusion (Stanley & al., 2013). This ensures that no selection of results is made based on subjective judgments (e.g.: giving more weight to more recent or more significant results, to studies based on larger data sets or on specific econometric methods) (Roberts, 2005). Second, MRAs allow for quantifying the relative weight of each factor in explaining diverging results across empirical studies. Because existing studies often differ in terms of context, methodology and data, it is often difficult for narrative literature reviews to disentangle why results vary across empirical studies.

While MRAs offer significant advantages, we must remember that this "is no panacea" (Stanley & Jarrell, 1989). Obviously, while including all existing studies reduces the risk of subjectivity, it does not remove it, as the choice of "moderator variables"² in the MRA can affect conclusions. Moreover, as with every quantitative analysis, an MRA can only draw conclusions on the role of measured factors and remain silent on the effects of other factors, in contrast with narrative reviews. As such, our work is considered as complementary to previous narrative reviews (Bertschek & al., 2015; Abrardi & Cambini, 2019; Holt & Jamison, 2009).

The remainder of the study proceeds as follows. We first provide a narrative literature review. Then, we describe the data and methodology used to conduct the meta-analysis, after which the results are presented. Finally, we summarize the main findings and highlight the remaining issues at stake in the conclusion.

NARRATIVE LITERATURE REVIEW

A number of studies, mainly based on firm location theory, consider that locations with broadband access benefit from a competitive advantage over others, and thus, enjoy a higher number of firm formations. Broadband access can indeed enhance the location-specific profitability of firms in several ways. First, it allows firms to increase sales by expanding their market and to reduce costs by reaching distant suppliers and accessing outsourced services (e.g., accounting) (Lamie & al., 2011). Second, broadband access also leads to a reduction in communication costs, as it allows for easier access to information, knowledge and ideas and eases coordination with partners. Third, broadband also leads to a better matching between firms and workers and shortens the hiring process (Autor, 2001).

¹ To the best of our knowledge, this is the first meta-regression analysis on the issue of broadband and firm location. Stanley & al (2018) provide a meta-regression analysis on information and communication technologies (ICT) and economic growth but include additional technologies (landlines, cell phones, and computers), focus on economic growth and productivity, and base their work on cross-country studies.

² In MRAs, moderator variables refer to the characteristics of examined studies (data, econometric model, study area, etc.) that are supposed to influence the results obtained.

Numerous studies have empirically examined the effect of broadband on firm location considering all industrial sectors and locations (both urban and rural). Most of them find a positive association between broadband access and the number of firms in Ireland (McCoy et al., 2018), Germany (Audretsch et al., 2015) and the USA (Gurney, 2012; Lapointe, 2015; Lehr et al., 2006; Parajuli & Haynes, 2015; Prieger et al., 2017). Moreover, compared with transportation infrastructure, broadband is more conducive to entrepreneurship (Audretsch et al., 2015; Prieger et al., 2017). Other studies, however, provide more mitigated conclusions or find that there is no significant association between broadband and firm location. For example, while Parajuli & Haynes (2017) find a positive association between broadband and firm formation, they emphasize that broadband provision hardly changes the regional entrepreneurial spirit, and thus, can lead to only modest economic changes in the short run. Atasoy (2013) finds that while broadband leads to an increase in employment, it has no effect on the number of firms because the employment effect is due to an increase in the size of existing businesses rather than to the creation of a greater number of firms. Dinterman (2016) and Mack & Wentz (2017) also find no significant correlation between broadband and firm location. Finally, Van Gaasbeek (2008) concludes that broadband leads to an increase in productivity, and thus to higher payroll and employment, but to a lower number of establishments. However, these aggregated results conceal very heterogeneous effects, particularly across industries and locations.

Contextual effects

Differences across industries

Broadband access is of varying importance across industries. Firms that make advanced uses of the internet (e-commerce, customer relationship management, enterprise resource planning) should be more attracted to connected locations compared to firms that make only basic use of these technologies (Bertschek et al., 2015). In addition, firms for which market access is important and may deliver their output through the internet are more likely to be attracted by connected locations (Shideler & Badasyan, 2012). For example, software firms, which regularly interact with software engineers and programmers for information and innovation and which easily deliver their products online, should be particularly sensitive to broadband provision.

In almost all cases, previous studies have concluded that broadband impact is significantly heterogeneous across industries. Overall, positive effects are generally found in a large range of services (Audretsch et al., 2015; Duvivier et al., 2018; Gurney, 2012; Hasbi, 2017; Shideler & Badasyan, 2012). While some concerns have been raised about broadband impact on the retail trade sector (with local businesses potentially negatively affected by heightened competition with online retailers), most studies also find positive effects on the number of retail establishments. Similarly, while it is a common belief that broadband deployment often comes with a closure of local public services, most studies point to a positive relationship between broadband access and firm location in public administration, education and health services (Duvivier et al., 2018; Kandilov & Renkow, 2010; Kim & Orazem, 2017). A number of studies have also specifically focused on knowledge-intensive business services (KIBS), which are expected to be particularly sensitive to broadband provision given that they are both technology-intensive and footloose. While most studies find a positive link between broadband and KIBS establishments (Mack et al., 2011; Mack & Rey, 2014; Mack & Wentz, 2017), the impact does not appear to be stronger in this sector than in others (Mack, 2015), and negative effects were specifically found for the information sector (Kandilov & Renkow, 2010). In the end, the most beneficial effects seem to occur in the high-tech sector, which may include both manufacturing and services (Audretsch et al., 2015; Gurney, 2012; Lehr et al., 2006; McCoy et al., 2018; Prieger et al., 2017).

Effects are much more mitigated for other sectors. For manufacturing, while some studies indicate a positive relationship (e.g. Shideler & Badasyan, 2012), others indicate that the effects are much smaller compared to other sectors (Kim & Orazem, 2017) or find no significant association (Mack & Wentz, 2017). In the construction sector, results are not robust, with nearly as many estimates indicating a positive result as an insignificant association. Less evidence is available for agriculture, given that a number of studies restrict their sample to non-agricultural firms, which cannot freely choose their location. Despite this factor, the studies providing results generally point to an insignificant relationship (Mack & Wentz, 2017; Parajuli & Haynes, 2015). Finally, the least positive results are found for finance, insurance and real estate (FIRE). Although some studies find positive effects (Gurney, 2012; Parajuli & Haynes, 2015), others conclude that broadband access significantly reduces the number of firms in the FIRE sector (Duvivier et al., 2018; Kandilov & Renkow, 2010; Shideler & Badasyan, 2012). These detrimental effects would result from the fact that, with the development of online agencies, firms are able to reach distant customers, leading to the closure of small and unprofitable agencies, especially in rural areas.

In addition to the industrial sector, previous studies have shown that broadband effects can also vary across foreign and domestic firms (McCoy et al., 2018) and across small, intermediate and large firms (e.g. Mack & Grubestic 2009). Finally, while broadband impact is also likely to vary across stages of production (R&D, construction, distribution, etc.), to our knowledge, there is no study on this issue so far.

Differences across locations

Another major issue is whether broadband effects vary across locations and, in particular, between urban and rural areas. The emergence of the internet has led to considerable hopes for rural areas, with the idea that it will compensate for their geographical remoteness (Cairncross, 2001). Obviously, by reducing the cost of distance, the internet allows rural areas to broaden market access, fostering local entrepreneurship (Fairlie, 2006). It also allows for interacting with distant partners through, for instance, videoconferencing and instantaneously accessing information. For these reasons, the internet is sometimes considered a substitute for agglomeration, allowing firms that are located in connected rural areas to escape from diseconomies of agglomeration (traffic congestion, land and housing prices, pollution) without losing access to customers, suppliers, partners and information. In rural areas, broadband deployment is particularly expected to foster the location of back-office activities, land-consuming firms and creative firms, the latter being relatively more footloose and sensitive to quality of life issues than others (Beyers & Lindahl, 1996; Rasker & Hansen, 2000).

Other authors, however, have argued that broadband economic effects in rural areas are largely uncertain, if not negative, and presumably much less beneficial than in urban areas. First, as broadband adoption is much lower in rural areas (Forman, 2005; Salemink et al., 2017), economic opportunities generated by broadband access are more likely to remain untapped. Second, while broadband can partly compensate for remoteness, it cannot remedy all deficiencies (lack of skilled labor, entrepreneurship spirit, etc.), and it may be difficult for structurally weak areas to attract firms even if connected (Galloway, 2007). In addition, broadband effects are likely to be lower in rural areas, where technology-intensive firms employing skilled labor are underrepresented. Local businesses can even be adversely affected. Rural retailers sometimes suffer from increased competition from online retailers that offer more diversified products (Cumming & Johan, 2010), and FIRE agencies can also progressively shut down as online agencies develop (e.g. Kandilov & Renkow, 2010). Finally, although virtual interactions can replace "conversations", the internet cannot substitute for "handshakes" and face-to-face interactions, which still strongly matter (Leamer & Storper, 2014; Gaspar &

Glaeser, 1998). In some industries, such as knowledge-intensive and creative activities, firm concentration has even heightened (Polèse & Shearmur, 2004). Thus, in some industries, internet appears much more as a complement, rather than a substitute, for agglomeration.

It is difficult to formulate a clear conclusion from the empirical literature as to whether broadband is more beneficial for urban or rural areas. Most studies estimate that the broadband effect is positive in urban areas, whatever their size (e.g. Hasbi, 2017; Mack, 2015). The effect is particularly strong for knowledge centers and sprawling and congested cities (Mack, 2014-a; Mack & al., 2011; Mack & Rey, 2014). Estimated impacts for rural areas are more mitigated. Several works have concluded that broadband has a positive effect on firm location decisions (Kim & Orazem, 2017) and that limited connectivity strongly hurts rural businesses (Whitacre & al., 2014-b), particularly in the creative sector (Townsend & al., 2017). A majority of studies, however, find very limited (Duvivier & al., 2018; Kandilov & Renkow, 2010) or insignificant effects on firm location (Canzian & al., 2019; Mack & Wentz, 2017; Whitacre & al., 2014-a). Conley & Whitacre (2016) even show that nonmetropolitan counties with the largest increases in broadband experience the strongest drop in entrepreneurship and the number of creative workers because broadband allows individuals to be better aware of alternative job opportunities in neighboring metropolitan areas. Although studies focusing on urban areas show more positive effects than those focusing on rural areas, studies providing *direct comparisons* of broadband effects between urban and rural areas are more mitigated. While some indicate that broadband matters more in urban areas (Conley & Whitacre, 2016; Mc Coy & al, 2018³), others indicate the opposite (Atasoy, 2013; Mack, 2014-b; Prieger & al., 2017). Obviously, the diversity of results can arise from the use of different samples⁴ and definitions of urban and rural areas. In particular, broadband effects are strongly heterogeneous across rural areas, with those close to urban agglomerations often benefiting the most (Cumming & Johan, 2010; Kandilov & Renkow, 2010; Kim & Orazem, 2017; Mack, 2014-a; 2015).

In addition to the urban gradient effect, broadband impact is also likely to vary across locations depending on the level of human capital (Mc Coy & al., 2018; Tranos & Mack, 2016) and their natural amenities endowments, with rural areas offering good living environments expected to experience higher benefits (Malecki, 2003).

Timing of effects

Broadband effects are also likely to vary over time. Once infrastructures are deployed, it may take time for firms to adopt and efficiently use the internet. Holt & Jamison (2009) even argue that broadband deployment can lead to reduced economic growth in the very short run while businesses experiment with new technologies. Moreover, if broadband deployment initially attracts some firms, its impacts can then be reinforced over time through agglomeration effects. However, some papers have suggested that broadband impacts could be particularly strong in the short run due to infrastructure construction (Hasbi, 2017; Lapointe, 2015). Very little empirical work, however, has tested for nonlinear broadband effects over time. Most existing evidence focuses on very short-run effects, generally from one to four years after deployment, with very few studies on longer-run effects (Guidry & al., 2012; Mack & Wentz, 2017). Although there is very little empirical evidence on this issue, a small number of papers indicate

that effects seem to become stronger over time (Duvivier & al., 2018; Kandilov & Renkow, 2010; Mc Coy & al., 2018).

Methodological issues

Previous works have also focused attention on identifying appropriate models to assess broadband effects. The two main issues are how to measure broadband and how to control for potential methodological biases (endogeneity and spatial autocorrelation).

Measuring broadband

Depending on the studies, what is termed “broadband” refers to very different realities in terms of technologies (wired or wireless), speed and even financing (public or private)⁵.

First, most empirical evidence relates to fixed broadband effects. There is hardly any empirical evidence on the specific economic impact of mobile broadband, for which there is little data (Bertschek & al., 2015; Holt & Jamison, 2009). This is particularly unfortunate given that considerable hope is given to wireless broadband, particularly in rural areas (Prieger, 2013), and that an increasing number of agents only use mobile broadband (Manlove & Whitacre, 2019). Some studies have compared mobile and fixed broadband effects on labor productivity and GDP (Bertschek & Niebel, 2016; Edquist & al., 2018; Thompson & Garbacz, 2011), but to our knowledge, there is no evidence for firm location.

Second, existing works use very different threshold speeds to define broadband. Although more recent studies use “stricter” definitions, until recently, most USA studies defined broadband as connections of at least 200 Kbit/s downstream or upstream, without distinguishing between different technologies or speeds⁶. This threshold might not be high enough to act as a relevant factor for firm location. In contrast, other studies focus on the effect of ultrafast connections, such as optical fiber with download speeds of at least 100 Mbps (Guidry & al., 2012; Hasbi, 2017). Few studies have directly compared the effect of various broadband speeds (or technologies) to assess whether the deployment of costly ultrafast broadband truly generates additional benefits compared to first-generation technologies (Abradi & Cambini, 2019). Accessing ultrafast broadband can indeed provide significant additional benefits for businesses, such as allowing faster file transfers, high-resolution real-time collaboration (through videoconferencing and telepresence) and remote maintenance of industrial plants (Ezell & al., 2009). This could be particularly true in rural areas, where firms rely more on high-speed video conferencing to cope with the lack of face-to-face contacts (Mack, 2014-b). Some studies have tested whether higher broadband speed levels had a greater impact on firm location (Canzian & al., 2019; Mack, 2014-b; Prieger & al., 2017; Whitacre & al., 2014-b) or, similarly, whether optical fiber had a higher effect than traditional technologies (Duvivier & al., 2018; Lapointe, 2015; McCoy & al., 2018). Overall, it seems that ultrafast broadband deployment allows for attracting significantly more firms than traditional technologies, including in rural areas⁷, although the effect seems sometimes limited to firms that use advanced broadband applications, such as high-tech firms.

Existing studies also differ in the broadband metric employed, with a majority using an indicator of broadband infrastructure availability instead of a measure of broadband adoption. Although data limitation is probably one reason, investigating the economic effects of

³ More precisely, Mc Coy & al (2018) find that broadband effects are stronger in locations well-endowed with human capital, which may favor cities.

⁴ Some studies exclude from their analysis the largest cities and/or the most rural parts (e.g. Mc Coy & al, 2018).

⁵ While most studies consider broadband resulting from both private and public-sector provision, some authors focus on public infrastructure programs (Canzian & al, 2019; Duvivier & al, 2018; Kandilov & Renkow, 2010).

⁶ Most USA studies use data from the Federal Communications Commission Form 477. The data provide the number of broadband providers with at least 250 high-speed lines by zip code. The FCC broadband definition has changed over time, with broadband defined as connections of at least 4 Mbps downstream in 2010 and of at least 25 Mbps in 2015. In addition, recent studies also use data from the National Broadband Map, which provides information on speed and type of technology.

⁷ In contrast with studies focusing on optical fiber, Whitacre & al (2014-b) and Mack (2014-b) find that broadband speed has few effects on firm location. This may be due to the use of low thresholds for speed (Mack, 2014-b).

broadband availability is particularly relevant from a policy perspective, as it allows for directly testing the effect of public deployment programs (Bertschek & al., 2015). Overall, it seems that studies using adoption-related indicators conclude that broadband effects are higher and generally more positive (Bertschek & al., 2015; Whitacre & al., 2014-a; 2014-b), but in some cases, they can also be more negative (Conley & Whitacre, 2016).

Endogeneity issue

Taking into account the potential endogeneity of broadband is a key challenge when empirically assessing its economic impact. Endogeneity can arise from both reverse causality (private operators are more likely to build infrastructure in regions with a higher number of firms, as it means higher demand for broadband) and omitted variables (private operators are more likely to invest in economically dynamic regions – densely populated, with higher income, more educated population, etc. – which are also more attractive for firms). Tranos & Mack (2016) have used Granger causality tests to assess reverse causality between broadband and KIBS location in the USA and find that past levels of broadband predict current levels of KIBS in 27% of counties. Other works have shown that ordinary least squares (OLS) are likely to be upwardly biased (e.g. De Stefano & al., 2014; Kim & Orazem, 2017). Several solutions have been used to limit potential endogeneity. Some studies have restricted their analysis to new firm formation, which is expected to suffer less from reverse causality than the number of existing firms (Mc Coy & al., 2018). Others have used a lagged value of broadband to reduce potential reverse causality (Hasbi, 2017; Gurney, 2012; Lehr & al., 2006; Mack & Wentz, 2017). Most studies also introduce a large range of control variables, such as agglomeration economies, human capital, transport infrastructures, market access, factor costs (housing prices, taxes, wages) and population structure (age, ethnicity). In addition, different econometric estimators have been implemented. A number of studies have used the fixed-effects (or first-differences) estimator in order to control for unobserved location and time-specific heterogeneity (e.g. Atasoy, 2013; Hasbi, 2017; Lapointe, 2015; Van Gaasbeck, 2008). Most of them find that broadband effects are much lower when estimated by fixed-effects compared with a standard OLS model. While this outcome probably arises from the correction of endogeneity, it may also be because identification in fixed-effects models is difficult when within-location variation in broadband over time is low, which is often the case because most studies cover only a limited period of time. In this case, fixed-effects models are likely to overcorrect the “true” impact, and estimates may then provide only a lower bound for broadband effects (Kim & Orazem, 2017). Instrumental variables have also been used, with the advantage of controlling for both reverse causality and unobserved heterogeneity. The slope of terrain (or variation in elevation) is one of the most widely used instruments, with the idea that deployment costs are higher, and thus broadband access is lower, where the terrain is steeper (Kolko, 2012; Ivus & Boland, 2015). Other commonly used instruments are household density (Mack & al., 2011; Mack & Rey, 2014; Mack & Wentz, 2017; Van Gaasbeck, 2008) and pre-existing telecommunication networks, such as voice-telephony and TV networks (Czernich, 2014), with the rationale that broadband deployment costs are much lower where telecommunication networks already exist. Despite the diversity of proposed variables, it remains very challenging to find convincing instruments. One may particularly wonder whether some of them (slope of terrain, household density) have no direct impact on firm location, in addition to their effect through broadband. Some authors

also warn that instruments may be poorly correlated with broadband (weak instruments). Moreover, while some variables (slope of terrain, voice-telephony and TV networks) could explain differences in first-generation broadband coverage, they are no more likely to be good instruments for new-generation technologies (Canzian & al., 2019). In addition to the instrumental variables approach, other studies have identified broadband effects by using quasi-experimental methods (matching and/or differences-in-differences) to evaluate public programs (Canzian & al., 2019; Duvivier & al., 2018; Kandilov & Renkow, 2010). Finally, Dinterman (2012) proposes estimating a system of three simultaneous equations, with one of them specifically dedicated to model broadband deployment, in order to estimate causal relationships between population, employment (or firms) and broadband. While this type of model accounts for reverse causality, it requires having data over a significant time period.

Spatial effects

Spatial effects are another key issue when empirically investigating broadband economic effects. Existing studies have tested and accounted for spatial effects in several ways. Most of them have used spatial lag or spatial error models, depending on the nature of spatial autocorrelation, and have shown that not accounting for spatial effects can lead to strongly biased estimates (e.g. Gurney, 2012; Mack & Rey, 2014; Whitacre & al., 2014-a). Another approach, used in Mack & Wentz (2017), comprises accounting for spatial effects by controlling for neighbors’ broadband access (WX model). Finally, Parajuli & Haynes (2017) have investigated whether the association between broadband and new firm formation varied across space using a geographically weighted regression framework. According to the authors, broadband effects vary strongly across counties within one state, and thus, GWR models are preferred over standard OLS.

DATA AND METHODOLOGY

We now turn to a meta-regression analysis to disentangle the role of contextual and methodological variables in explaining the variation in previous results.

Selection of studies

The first step of an MRA comprises systematically searching for every academic work (including journal articles, book chapters, and working papers) that addresses broadband and firm location. To do that, we define a list of keywords to track each work, written either in English or French, which mentions “broadband” (or a related keyword)⁸ and “firms” (or a related keyword)⁹. A first series of works was found using different databases of peer-reviewed literature and working papers¹⁰. We then looked for additional works using “snowballing techniques”, i.e., we checked the reference lists of the works we found in the first round as well as the papers citing these works.

The second step comprises selecting the relevant papers. We applied the following five criteria. First, we include only evidence from Western developed countries to consider a comparable set of countries.

Second, we exclude firm-level as well as state- and country-level studies. As a result, our sample includes only zip-code to county-level studies. One advantage is that it enables us to assess whether broadband allows rural areas to compensate for their geographical remoteness, which is far from reaching a consensus¹¹. Third, we exclude every paper that does not report econometric estimates of

⁸ The following keywords were used: broadband; internet; fiber; FttH; information and communication technologies; ICT.

⁹ The following keywords were used: firms; business growth; firm productivity; economic development; economic impact; economic outcomes; economic growth; economic benefits.

¹⁰ The following databases were checked: Scopus, Web of science, REPEC, ZEW- Leibniz Centre for European Economic Research, World Bank, SSRN, NBER, FEEM working papers, CESifo-group, IZA world of labor and IAB discussion papers.

¹¹ While many previous studies provide conclusions on broadband effects at the national level, we still barely know its distributional effects within countries (Bertschek & al 2015 RNE).

Table 1. Main Features of Primary Studies

Study	Country	Scale of Analysis	Urban/Rural	Industry*	Indicator for broadband	Control for endogeneity**	Spatial model***# estimates	Average value of γ	
Atasoy (2013)	USA	County	Urban & rural	All sectors	Availability	Yes (FE)	No	1	0
Audretsch et al (2015)	Germany	County	Urban & rural	All sectors; High-tech.; Manufacturing; Services (5 industries)	Adoption	No	No	11	0.909
Canzian et al (2019)	Italy	Municipality	Rural	All sectors	Availability	Yes (DiD)	No	6	0
Dinterman (2016)	USA	County	Urban & rural	All sectors; Primary sector; Manufacturing; Services; FIRE; KIBS (19 industries)	Availability	Depends on estimates (GS2SLS; FGS3SLS)	Depends on estimates (KP model)	39	0
Duvivier et al (2018)	France	Municipality	Rural	All sectors; Manufacturing; Services; FIRE; KIBS (11 industries)	Availability	Yes (DiD)	No	114	0.351
Guidry et al (2012)	USA	Municipality	Urban	All sectors	Availability	No	No	1	0
Gurney (2012)	USA	Zip code	Urban & rural	All sectors	Availability	No	Depends on estimates (SLM)	3	1
Hasbi (2017)	France	Municipality	Urban	All sectors; Manufacturing; Services (6 industries)	Availability	Depends on estimates (DiD; FE)	No	44	0.659
Kandilov and Renkow (2010)	USA	Zip code; County	Rural	All sectors; Primary sector; Manufacturing; Services; FIRE; KIBS (19 industries)	Availability	Yes (DiD)	No	94	0.181
Kim and Orazem (2017)	USA	Zip code	Rural	All sectors; Manufacturing; Services; KIBS (9 industries)	Availability	Depends on estimates (DiD)	No	44	1
Lapointe (2015)	USA	County	Urban & rural	All sectors	Adoption	Yes (FE)	No	2	1
Lehr et al (2006)	USA	Zip code; State	Urban & rural	All sectors	Availability Adoption	No	No	7	0.571
Mack (2014-b)	USA	Census tract	Urban & rural; Rural	All sectors; Primary sector; Manufacturing; Services; KIBS (6 industries)	Availability	No	Depends on estimates (SLM; SEM)	16	0.375
Mack (2015)	USA	County	Urban & rural; Rural; Urban	All sectors; Primary sector; Manufacturing; Services; KIBS (5 industries)	Availability	No	No	66	0.242
Mack et al (2011)	USA	Zip code	Urban	KIBS	Availability	Yes (2SLS)	Depends on estimates (SLM; SEM)	8	1
Mack and Rey (2014)	USA	Zip code	Urban	KIBS	Availability	Depends on estimates (2SLS)	Depends on estimates (SLM; SEM)	108	0.926
Mack and Wentz (2017)	USA	County	Urban & rural; Rural	All sectors; Primary sector; Manufacturing; Services; KIBS (5 industries)	Availability	Depends on estimates (2SLS)	Depends on estimates (SLX)	14	0.429
McCoy et al (2018)	Ireland	Urban fields	Urban & rural	All sectors; High-tech; Low-tech	Availability	Depends on estimates (FE; RE)	Depends on estimates (SLX, SLM, SDM)	64	0.75
Parajuli and Haynes (2015)	USA	County	Urban & rural	All sectors; Manufacturing; FIRE (3 industries)	Availability	No	No	24	0.875
Parajuli and Haynes (2017)	USA	County	Urban & rural	All sectors; Manufacturing-construction; Services (3 industries)	Availability	No	Depends on estimates (GWR)	22	0.727
Prieger et al (2017)	USA	County	Urban & rural	All sectors; High-tech	Availability Adoption	Depends on estimates (FE; RE)	No	36	0.972
Shideler and Badasyan (2012)	USA	County	Urban & rural	All sectors; Primary sector; Manufacturing; Services; KIBS; FIRE (15 industries)	Availability	No	No	22	0.136
Van Gaasbeck (2008)	USA	County	Urban & rural	All sectors	Adoption	Yes (FE; 2SLS)	No	3	-1
Whitacre et al (2014-a)	USA	County	Urban & rural; Rural	All sectors	Availability Adoption	Depends on estimates (FD)	Depends on estimates (SEM)	4	0.25
Whitacre et al (2014-b)	USA	County	Rural	All sectors	Availability Adoption	No	No	4	0

Note: *Industries classified as in the moderator variable. The exact number of industries considered in each study is reported in parentheses. ** FE: fixed effects; DiD: differences-in-differences; RE: random effects; FD: first difference; 2SLS: two-stage least squares; GS2SLS: generalized spatial two stage least squares; FGS3SLS: feasible generalized spatial three stage least squares. *** KP model: Kelejian and Prucha (2004) model (simultaneous systems of spatially interrelated cross sectional equations); SLM: spatial lag model; SEM: spatial error model; SLX: spatial lag of X model; SDM: spatial Durbin model; GWR: geographically weighted regression.

broadband effects on firm location (estimated coefficients and associated standard-errors, t-values, p-values or levels of significance). Literature reviews, theoretical, qualitative and descriptive papers, and quantitative works that do not provide effect size (e.g., Mack, 2014-a; Mack & Grubestic, 2009; Tranos & Mack, 2016) are thus excluded. Moreover, some studies that use an outcome variable that we judge to be insufficiently related to firm location, such as the amount of investment or the share of nonfarm proprietors (Cumming & Johan, 2010; Conley & Whitacre, 2016), are excluded. Finally, for each selected study, we include only estimates that meet all criteria (e.g., when studies assess the effect of broadband on both firm location and employment, we include only estimates for firm location). Finally, following Ugur & al. (2018), we include all reported estimates, including robustness checks using different model specifications, econometric technics, etc., and use all existing results. Overall, our meta-analysis includes 757 estimates from 25 primary studies. Table 1 describes the main features of primary studies.

Meta-analytical model

Dependent variables

We use two successive approaches. First, a baseline analysis is carried out using a "sign and significance" approach and, second, a sensitivity analysis is provided following the more standard approach of using a common effect-size.

For the baseline analysis, we classify estimates of previous studies into three categories, based on their sign and significance (significantly negative, insignificant, significantly positive), using the 10% significance level. This three-category variable is then used as the dependent variable in an ordered-probit model. Although it differs from the more standard approach of using a common effect-size (e.g., partial correlation coefficients), the "sign and significance" approach has already been used in a number of studies (e.g., Card & al., 2010; de Groot & al., 2016; Horváthová, 2010; van Huizen & Plantenga, 2018). In our case, this approach is preferred for two reasons. First, creating a "sign and significance" variable allows us to include many more estimates in our study, compared to a partial correlation coefficient approach, which would have led us to exclude 36% of primary estimates¹². Second, this approach allows us to compare studies using very different econometric technics, such as those that provide intention-to-treat effects with those that give average treatment effects (van Huizen & Plantenga, 2018).

However, the "sign and significance" approach raises two issues. First, it does not allow for formally investigating and correcting for publication selection. Second, only a small proportion of estimates indicate that broadband has a significantly negative impact on firm location (see Appendix A.2), which may affect the ordered-probit model estimates. To address these issues, we then follow the standard approach using a common effect-size. Specifically, to be able to compare the different studies, that report different parameter estimates, we calculate partial correlation coefficients and used them as dependent variable¹³. As not every studies reports t-values and degrees of freedom, the robustness analysis only includes 485 estimates from 19 primary studies.

Moderator variables

In the literature review in Section 2, we have identified two main types of factors that are likely to moderate the broadband-firm relationship, namely, contextual effects and methodological settings. These variables are relevant in several respects: the former may help in answering relevant policy issues and the latter in identifying relevant research variables. In addition to contextual and methodologi-

cal variables, previous meta-analyses have shown that publication characteristics may also explain noticeable differences in previous estimates (de Groot & al., 2016; Stanley & al., 2018; Ugur & al., 2018). We successively describe each of these three categories of variables.

Contextual variables. We introduce three variables to assess whether variation in previous results come from differences in study areas and industries.

To investigate whether broadband effects are more beneficial for some areas, we distinguish between estimates covering both urban and rural areas, only urban areas, and only rural areas. Although it would have been interesting to further distinguish between isolated and intermediate rural areas, the number of observations is too low to do so. We also assess whether broadband effects are different between the USA and European countries.

In addition, we test whether there are noticeable differences across industries by distinguishing between seven industrial categories: primary sector, manufacturing and construction, services, high-tech activities, KIBS, FIRE, and all sectors of the economy. Following the literature review in Section 2, we expect broadband effects to be the most beneficial for high-tech activities and KIBS and to be the lowest for the primary and FIRE sectors.

Data and econometric settings. We assess the role of measurement issues, scale, econometric estimators and key control variables in explaining differences in previous estimates. Following the literature review in Section 2, we distinguish between estimates obtained using an indicator of broadband availability and adoption. We also test whether high-speed broadband (>30 Mbps¹³) has more effects on firm location than lower speed broadband. Previous studies also differ in the way they measure firm location, with some of them focusing on the total number of firms (or its variation) and others only on firm formation. As already shown for employment (Bai, 2017), we expect broadband effects to vary when using stock versus births measures of firms for several reasons. First, broadband is likely to have an impact not only on firm creation but also on firm exit (survival and delocalization), which are both included in the total number of firms. Second, the total number of firms includes both newly entering firms, probably sensitive to broadband access, and existing firms, a majority of which have located years ago without taking into account broadband provision (Kim & Orazem, 2017).

In addition to these measurement issues, broadband effects are also likely to vary depending on the scale of analysis, with more aggregated studies not taking into account the great heterogeneity in broadband access. Moreover, studies using different scales of analysis are also likely to capture different causal mechanisms. We thus distinguish between estimates conducted at the infra-municipal level (e.g., census tracts), at the municipal level, and at a more aggregated level (e.g., county level).

We also expect the econometric estimator to play a significant role. Specifically, studies not controlling for endogeneity are likely to find higher broadband effects compared to studies using instrumental variables, fixed effects or difference-in-differences approaches. Estimates obtained with a spatial estimator (typically, a spatial lag or spatial error model) are also likely to differ from those obtained without accounting for spatial autocorrelation.

Finally, the results are expected to vary depending on model specifications, with estimates obtained without controlling for key control variables probably higher. To test for this trait, we include four dummy variables indicating whether the model includes an indicator of agglomeration economies, labor market (unemployment, number of

¹² T-values and degrees of freedom (or at least the numbers of observations) are needed to calculate partial correlation coefficients. Moreover, most studies do not directly report degrees of freedom. While it is possible to recalculate them from the number of observations and of covariates, it is likely to lead to calculation errors.

¹³ Partial correlation coefficients are calculated as follows: $r_{ij} = \frac{t_{ij}}{\sqrt{t_{ij}^2 + df_{ij}}}$ with t_{ij} the t-value and df_{ij} the degrees of freedom.

jobs or labor force), population structure (share of seniors, of ethnic minorities or of executives), and market access¹⁴.

Publication characteristics. One difficulty with literature reviews is that publication selection bias may be widespread, making it difficult to identify genuine effects. Publication selection may arise from several reasons: the general tendency to select statistically significant results, the fact that editors and reviewers are more likely to accept papers that match the conventional wisdom, and the inclination for some researchers to use expected effects as a specification test (Card & Krueger, 1995). As the broadband effect is widely assumed to be beneficial for economic development, existing literature may exaggerate its economic effect. Stanley & al.'s (2018) meta-analysis provides evidence of publication selection bias among studies on the internet and economic growth.

In the baseline analysis ("sign and significance" approach), we test for the presence of potential publication selection by introducing two explanatory variables. First, we create a dummy variable equal to one if the estimate comes from a peer-reviewed journal article, and zero otherwise (working paper, unpublished work, book chapter). In case of publication selection from editors and reviewers, journal articles would be more likely to report positive expected broadband effects. Second, we create another dummy variable indicating whether the study focuses on broadband and firm location. Following Stanley & al. (2018), we expect selection to be higher for papers focusing on broadband and firm location than for studies more generally investigating the effect of infrastructure (transport, educational infrastructure, and broadband) or the overall economic effects of broadband (employment, income, firms, etc.).

In the robustness analysis, we formally test for and correct publication selection by estimating the FAT-PET model (Egger & al., 1997; Stanley, 2008; Stanley & Doucouliagos, 2012), which is presented in the following subsection.

Finally, a number of additional moderator variables were considered, but because they were not significant, they were not introduced in the final model to avoid multicollinearity¹⁵. In addition, following de Groot & al. (2016), to ensure that each moderator variable refers to a sufficient number of studies, we check that every dummy variable takes a value of one in at least five studies¹⁶. The definition of each variable is given in Appendix A.1.

Estimated models

Baseline results are obtained by estimating the following ordered-probit model with the maximum likelihood:

$$\Pr(Y_i = j | X_{ki}, \beta_j) = \Phi(X' \beta) + \varepsilon_v \quad (1)$$

where Y_i is the three-category variable classifying estimates into three categories, based on their sign and significance:

$Y_i = -1$ for significantly negative relationship between internet and firm location,

$Y_i = 0$ for insignificant relationship,

$Y_i = 1$ for significantly positive relationship.

¹⁴ Following the European Commission, we use the threshold of 30 Mbps to define very high-speed broadband. The Digital Agenda for Europe is available at: <https://ec.europa.eu/digital-single-market/en/digital-agenda-europe-key-publications>

¹⁵ We tested for the role of other key control variables (human capital, transport infrastructures, amenities, wages and housing prices) but they were not significant and thus, are not included in the final model.

¹⁶ These additional variables were a dummy variable indicating whether the study uses panel data, a dummy variable indicating whether standard errors are robust, the number of observations, the average years of the data used in the analysis, the timing of effects (short run or longer run effects) and dummies for key control variables (human capital, transport infrastructures, amenities, wages and housing prices).

¹⁷ This restriction is only applied to the baseline analysis. In the robustness check, we prefer keeping the same set of moderator variables, although several moderators refer to less than five studies.

¹⁸ This is known as the FAT-PET model because it allows for testing both the FAT (Funnel Asymmetry Test; $H_0: \alpha_j = 0$) and PET (Precision Effect Test; $H_0: \alpha_0 = 0$) hypotheses.

¹⁹ *Publication Characteristics* are not included in this model as publication selection is already tested and controlled for.

²⁰ As a robustness check, we also correct for the presence of within-study dependence by estimating a random effects model (restricted maximum likelihood).

X_{ki} is the vector of previously described moderators (*Contextual variables, Data and econometric characteristics, and Publication characteristics*). Finally as estimates from the same study are likely to be correlated, standard errors are clustered by study.

In the sensitivity analysis, we consider that in the presence of publication selection, the effect sizes are correlated with their standard errors and estimate the FAT-PET model (Egger & al., 1997; Stanley, 2008; Stanley & Doucouliagos, 2012) as:

$$r_i = \alpha_0 + \alpha_j SE_i + \varepsilon_i \quad (2)$$

with r_i the partial correlation coefficient and SE_i its standard error. In case of publication selection bias, the coefficient associated to the standard error (α_j) will be statistically significant. Moreover, the intercept (α_0) indicates whether there is a genuine broadband effect once controlled for potential publication selection¹⁷.

The FAT-PET model is then extended to test for the role of the moderator variables:

$$r_i = \beta_0 + \beta_j SE_i + \sum_M \beta_i \cdot X_{mi} + \varepsilon_i \quad (3)$$

with r_i the partial correlation coefficient, SE_i its standard error and X_{mi} the vector of previously described moderators (*Contextual variables and Data and econometric characteristics*)¹⁸.

The FAT-PET model and its multivariate extension are estimated by the weighted least squares (WLS), using precision squared ($1/SE_i$) as the weight in order to give more weight to more precise estimates. Moreover, to take into account that estimates from the same study are likely to be correlated, standard errors are clustered by study¹⁹.

Descriptive statistics

Table 2 presents descriptive statistics. Regarding contextual variables, the majority of estimates focus on the USA (68%). Moreover, almost 42% of estimates relate to rural areas only and 23% to urban areas only. Most estimates also consider the effect of broadband on the services sector in general (26%) or on KIBS (21%). Turning to the broadband metric employed, a minority of estimates considers broadband adoption (6%) and high-speed broadband (16%). Regarding the econometric setting, a majority of estimates is obtained with instrumental variables, fixed-effects or differences-in-differences approaches (57%) and controlling for agglomeration economies (69%), population structure (59%) and market access (81%). In addition, most of the primary studies are published in journal articles (76% of estimates) and focus on the effect of broadband on firm location (72%).

Appendix A.2 provides additional descriptive statistics. Figure A.2.1 summarizes study findings for all studies and according to the main moderator variables. The majority of estimates (56%) conclude that broadband has a significantly positive effect on firm location, but a high proportion (41.6%) also concludes that there is no significant association between the two. A minority of estimates (2.4%) finds that broadband has detrimental effects. The most beneficial effects are found for estimates focusing on urban areas and on the high-tech sector, whereas the lower effects (although still positive on ave-

Table 2. Descriptive Statistics

	Obs.	Mean	Std. Dev.	Min	Max
Dependent Variables					
y_10p	757	0.536	0.545	-1	1
y_5p	757	0.496	0.526	-1	1
r _i	485	0.103	0.199	-0.307	0.872
fisher_r _i	485	0.120	0.255	-0.317	1.340
Moderator Variables					
<i>Contextual Variables</i>					
USA	757	0.684	0.465	0	1
Both Urban & Rural	757	0.354	0.478	0	1
Urban	757	0.229	0.420	0	1
Rural	757	0.417	0.493	0	1
All industries	757	0.218	0.413	0	1
FIRE	757	0.052	0.221	0	1
High-tech	757	0.111	0.314	0	1
KIBS	757	0.214	0.410	0	1
Manufacturing	757	0.103	0.304	0	1
Primary Sector	757	0.034	0.182	0	1
Services	757	0.268	0.443	0	1
<i>Data and Econometric Settings</i>					
Adoption	757	0.062	0.241	0	1
>30Mbps	757	0.166	0.373	0	1
Firms Births	757	0.453	0.498	0	1
Control for Endogeneity	757	0.573	0.495	0	1
Control for Spatial Autocorrelation	757	0.129	0.336	0	1
Agglomeration Economies	757	0.697	0.460	0	1
Labour Market	757	0.374	0.484	0	1
Population Structure	757	0.593	0.492	0	1
Market Access	757	0.810	0.393	0	1
Municipal Level	757	0.303	0.460	0	1
Infra-municipal Level	757	0.313	0.464	0	1
<i>Publication Characteristics</i>					
Journal Articles	757	0.769	0.422	0	1
Focus on Broadband and firms	757	0.721	0.449	0	1

rage) are found when focusing on finance, insurance and real estate. Table A.2.2 gives weighted averages of partial correlation coefficients for the full sample and by-subgroup (see Borenstein & al., 2009). Weighted averages of partial correlation coefficients are significant in most cases with values comprised between 0.014 and 0.022 for the full sample. According to Doucouliagos' (2011) guidelines for partial correlations in economics, broadband has only a small effect on firm location²⁰. Turning to weighted averages by subgroup, contextual variables, data/econometric settings and publication characteristics all seem to matter in explaining the differences in previous estimates. Studies focusing on European countries, high-tech firms and services find significantly more positive broadband effects on average, whereas the opposite is true for studies on the primary sector and on FIRE. The choice of measures for broadband and firms also seems to matter with studies considering broadband availability (instead of adoption), high-speed broadband, and firm creation (instead of stock), concluding that broadband is more beneficial. Finally, publication characteristics also likely matter as studies focusing on broadband and firm location highlight more positive effects.

²⁰ According to Doucouliagos (2011), partial correlation coefficients indicate weak association if lower than 0.07 (in absolute value).

²¹ The test was implemented in Stata using the user-written command «gologit2» (Williams, 2005).

As studies differ in several dimensions at once, we now turn to a multivariate approach to precisely estimate the role of each moderator variable.

RESULTS

Baseline analysis

Table 3 reports estimates of the baseline ordered probit model. To take into account that multiple estimates come from a single study, we estimate an ordered probit model by weighting each observation with the inverse of the total number of estimates in the given study. Giving equal weight to each paper ensures that no single study disproportionately drives the results.

Although ordered probit model results indicate the sign and level of significance of coefficients, they provide little information regarding the magnitude of the effects for each of the three categories. As a result, both coefficients (column 1) and average marginal effects (columns 2-4) are reported in Table 3. For dichotomous variables, the marginal effects show how the probability of obtaining significantly negative (column 2), insignificant (column 3) and significantly positive (column 4) estimates varies as the dummy variable changes from 0 to 1, keeping other explanatory variables constant. To provide additional guidance for the interpretation of the results, the average predicted probabilities are also given in Table A.3 of the Appendix.

The overall goodness of fit of the model is satisfactory, with a McFadden pseudo-R² of 0.57. In addition, the likelihood-ratio test of parallel lines assumption indicates that this key assumption holds²¹. Overall, the average predicted probabilities show that broadband has, in most cases, a significantly positive or an insignificant effect (Table A.3). Only studies at the municipal level find that broadband has a significantly negative impact in most cases (61.5%). This highlights that, on average, broadband is either beneficial or irrelevant for firm location.

Turning to the three categories of moderating variables, it appears that the context, data and econometric settings, as well as publication characteristics, all play a significant role in explaining the differences in previous results (i.e. the sign and significance of estimated coefficients).

Regarding contextual variables, it appears that studies focusing on the USA are significantly less likely to find that broadband has a positive impact on firm location than studies on Europe. Thus, while most European studies (86%) find that broadband has a significantly positive impact on firm location, the majority of USA studies (45%) find that broadband has an insignificant impact (Table A.3). Similarly, compared to estimates covering all sectors of the economy, estimates focusing on FIRE or on manufacturing also find fewer positive effects. Specifically, compared to the former, estimates focusing on FIRE (resp. manufacturing) are 9.3% (6.2%) more likely to find that broadband has a significantly negative impact on firm location but 29% (23%) less likely to find a significantly positive effect (Table 3). Does this mean that broadband is destructive for FIRE and manufacturing? The average predicted probabilities (Table A.3) show that broadband has an insignificant impact on FIRE in almost 58% of cases, a positive impact in 28% of cases and a negative impact in 13.9% of cases. Thus, although broadband appears to be the least profitable for FIRE, its effects are not, on average, particularly harmful for this sector. Turning to study areas, broadband also has more positive effects on urban areas. Specifically, it has a significantly positive impact (resp. insignificant; significantly negative) in 66% (resp. 30%; 3.2%) of cases focusing on urban areas compared to only 48% (resp. 46%; 5.6%) when considering both urban and rural

Table 3. Descriptive Statistics

	(1) Coeff.	(2) Outcome(-1)	(3) Outcome(0)	(4) Outcome(1)
<i>Contextual Variables</i>				
USA	-3.968*** (0.609)	0.155*** (0.026)	0.320*** (0.028)	-0.475*** (0.015)
Urban	0.942** (0.419)	-0.024 (0.016)	-0.157** (0.066)	0.181** (0.080)
Rural	-0.241 (0.237)	0.009 (0.008)	0.038 (0.040)	-0.047 (0.048)
FIRE	-1.611*** (0.463)	0.093** (0.045)	0.198*** (0.040)	-0.291*** (0.074)
High-tech	0.481 (0.509)	-0.009 (0.009)	-0.073 (0.081)	0.082 (0.089)
KIBS	-0.775 (0.473)	0.027 (0.026)	0.114* (0.061)	-0.141* (0.085)
Manufacturing	-1.285*** (0.347)	0.062*** (0.024)	0.172*** (0.035)	-0.235*** (0.050)
Primary Sector	-0.627 (0.403)	0.020 (0.020)	0.094 (0.060)	-0.114 (0.079)
Services	-0.656 (0.457)	0.022 (0.020)	0.098 (0.062)	-0.119 (0.081)
<i>Data and Econometric settings</i>				
Adoption	-1.029* (0.539)	0.058 (0.047)	0.109*** (0.038)	-0.167** (0.080)
>30Mbps	1.284* (0.747)	-0.037 (0.024)	-0.201* (0.105)	0.238* (0.128)
Firms Births	0.409 (0.549)	-0.010 (0.013)	-0.067 (0.096)	0.077 (0.109)
Control for Endogeneity	0.036 (0.251)	-0.001 (0.007)	-0.005 (0.037)	0.006 (0.044)
Control for Spatial Autocorrelation	0.886** (0.349)	-0.022** (0.010)	-0.138*** (0.050)	0.160*** (0.057)
Agglomeration Economies	-2.009*** (0.399)	0.103*** (0.020)	0.235*** (0.029)	-0.338*** (0.042)
Labour Market	-1.287*** (0.222)	0.072*** (0.017)	0.125*** (0.020)	-0.197*** (0.025)
Population Structure	-1.711*** (0.583)	0.073** (0.036)	0.244*** (0.055)	-0.317*** (0.088)
Market Access	3.342*** (0.795)	-0.338*** (0.114)	-0.171** (0.072)	0.509*** (0.049)
Municipal Level	-4.787*** (0.784)	0.568*** (0.081)	-0.068 (0.081)	-0.500*** (0.025)
Infra-municipal Level	1.174*** (0.231)	-0.021*** (0.007)	-0.162*** (0.039)	0.182*** (0.042)
<i>Publication Characteristics</i>				
Journal Article	-0.353 (0.244)	0.009 (0.006)	0.056 (0.041)	-0.065 (0.047)
Focus on Broadband and Firms	1.351*** (0.344)	-0.043** (0.017)	-0.215*** (0.047)	0.258*** (0.058)
No. of estimates	757		757	
No. of studies	25		25	
Pseudo R-squared	0.567			
Test of the parallel lines ass. LR chi2(22)	1.41			

Note: ***p<0.01; **p<0.05; *p<0.1. Standard errors clustered at the study level are reported in parentheses. Coefficients are reported in Column 1 and average marginal effects in columns 2-4. dy/dx for factor levels is the discrete change from the base level.

areas. Studies focusing on rural areas have, on average, a lower probability of finding that broadband has beneficial effects compared to studies on both urban and rural areas, but the difference is not statistically significant.

Turning to *Data and Econometric Settings* variables, it appears that controlling for spatial effects and for key control variables does affect the estimated impact of broadband. In particular, studies omitting key control variables (agglomeration economies, labor market, and population structure) are likely to find higher broadband effects. The scale of the analysis also strongly matters. Compared to studies at the supra-municipal level, studies at the municipal level are significantly less likely to conclude that broadband has a beneficial impact, whereas studies at the infra-municipal level are significantly more likely to find positive results. In contrast, the types of indicators used to measure broadband and firms are either not significant or significant at the 10% level (and, as will be seen later, not robust).

Publication characteristics variables provide some evidence of a publication selection bias. Indeed, papers focusing on the effect of broadband and firm location are 26% more likely to conclude in a positive impact and, respectively, 21% and 4.3% less likely to find an insignificant or a negative impact compared to other papers. This could reflect the inclination, among scholars focusing on broadband and firm location, to use expected effects as a specification test. In contrast, the *Journal Article* variable is nonsignificant, indicating that academic journals are not more likely to publish papers matching the conventional view or reporting statistically significant results.

Finally, two results are quite unexpected and require special attention. First, broadband does not seem to have a significantly more positive impact on KIBS and on the high-tech sector. For KIBS, this could be because this category finally includes heterogeneous services, of which some are expected to benefit from broadband (e.g., professional scientific and technical services; management of companies and enterprises) and others to be unaffected, or even harmed, by broadband²² (e.g., information, as suggested by Kandilov & Renkow, 2010). Second, while endogeneity is often presented as the main methodological issue when investigating the effect of broadband on economic development, we find that studies controlling for endogeneity find similar results as others. This result could arise for several reasons. First, broadband deployment is more driven by population density than by new firm formation. As a result, reverse causation is more an issue when investigating the effect of broadband on population or employment levels than on new firms (Mc Coy & al., 2018). Second, although some studies do not strictly control for endogeneity using fixed effects or instrumental variables estimators, they do mitigate this issue using a lagged value of broadband. Third, the *Control for Endogeneity* variable includes heterogeneous studies, some of them controlling only for unobserved heterogeneity (fixed-effects estimators) and others controlling for both reverse causation and unobserved heterogeneity (instrumental variables). The following section investigates more deeply the last issue and provides additional robustness tests.

Sensitivity tests for the ordered-probit model

A series of sensitivity tests are performed to examine the robustness of the results. First, the dependent variable was defined using the 5% instead of the 10% level of significance. Second, we break down the *Control for Endogeneity* variable into two categories to examine whether controlling for endogeneity with fixed effects (or differences-in-differences or first differences) leads to different results than using an instrumental variable approach. Third, as estimates from studies using the same dataset are likely to be correlated, we investigate whether results are robust when standard errors are clus-

22 Some authors also include finance, insurance and real estate in KIBS.

tered by study data. More specifically, as a number of USA studies use broadband data from the Federal Communications Commission, we re-estimate the model using an alternative clustering at the “FCC level”. This first series of robustness tests is reported in Appendix A.4. In addition, to ensure that no single study influences all the results, we estimate the baseline model by successively excluding one of the five studies with the highest number of estimates²³ (Appendix A.5).

Overall, the results are strongly robust. These additional estimations confirm that the type of indicators used to measure broadband and firms do not robustly explain the variation of the results in previous studies. Thus, while using an indicator of broadband adoption, instead of broadband availability, tends to reduce the estimated effect of broadband, the coefficient is significant in only 9 of 13 cases. In contrast, while studies examining the role of very high-speed broadband are more likely to conclude in the positive impact of broadband, the relationship is significant in only 7 of 13 cases. The limited impact of high-speed broadband can be due to most firms still using basic broadband applications. However, the impact of contextual variables is fairly robust, with studies in the USA and on FIRE and manufacturing concluding that broadband has a less beneficial impact, whereas studies focusing on urban areas conclude a more positive effect. The sensitivity analysis also confirms that introducing spatial effects and key control variables strongly affects the results, whereas controlling for endogeneity does not lead to significantly different results, whatever the estimator used (fixed effects or instrumental variables). Despite this last result, we believe that future research must be cautious regarding potential endogeneity and that robustness checks must be conducted to ensure that estimates do not suffer from endogeneity bias. Finally, the scale of analysis and the main issue of the paper also influence the results obtained.

Analysis using partial correlation coefficients

We now turn to the more standard meta-regression approach in order to formally investigate and correct for publication selection bias.

Appendix A.6 provides funnel plots, with partial correlation coefficients on the x-axis, and precision (measured by the inverse of the standard-error) on the y-axis. In the absence of publication selection, we expect estimates to be symmetrically distributed around the “true” value of broadband, represented by the vertical line (Egger & al., 1997). Figure A.6.1, which presents the distribution of partial correlations for the full sample, is skewed to the right, suggesting a positive selection or small-sample bias. The next two graphs present the distribution of partial correlations for two subsamples: studies focusing on broadband and firm location (Figure A.6.2), and studies not focusing on broadband and firm location (Figure A.6.3). Interestingly, while estimates are symmetrically distributed for studies not focusing on broadband and firm location, the distribution for the other subsample is highly skewed to the right, suggesting a strong positive selection bias. This confirms the ordered-probit estimates according to which papers focusing on the effect of broadband and firm location are more likely to conclude in a positive impact.

The existence of publication selection is more formally tested with the estimation of the FAT-PET model. Appendix A.7 provides results of the FAT-PET model using both partial correlations (Table A.7.1) and their associated Fisher’s z-transformation (Table A.7.2) as dependent variables²⁴. In each case, the model is estimated three times (using WLS with robust standard errors, WLS with standard errors clustered at the study level, and the random effects estimator). Both tables provide robust evidence of a significantly positive selection or small-sample bias as the coefficient associated with the standard error

($\hat{\alpha}_1$) is significant in all cases. Moreover, the intercept is significantly positive in 4 out of 6 cases, suggesting an overall positive – although small – effect of broadband on firm location even after controlling for publication selection.

Appendix A.7 also provides information about the extent of heterogeneity. The I^2 test indicates that about 54-59% of total variation across studies is due to heterogeneity rather than sampling error alone²⁵. In other words, the estimated impact of broadband on firm location likely depends on moderating factors. Thus, we now turn to the multivariate model to test for the role of moderating factors after formally accommodating publication selection bias.

Appendix A.8 provides results of the multivariate model using both partial correlations (Table A.8.1) and their associated Fisher’s z-transformation (Table A.8.2) as dependent variables.

Overall, even after formally controlling for publication selection, the results are fairly robust. The impact of *Contextual variables* is robust, with studies focusing on urban areas concluding that broadband has a more beneficial impact, whereas studies on FIRE find a less positive effect. Turning to *Data and econometric settings*, these estimations confirm that the type of indicators used to measure broadband and firms do not robustly affect the results in previous studies. It also confirms that introducing key control variables (population structure, market access) and the scale of analysis affect the results, whereas controlling for endogeneity does not lead to significantly different results. These additional estimations no longer indicate, however, that introducing spatial effects or focusing on the USA or on manufacturing affect the estimated effect of broadband. Moreover, it seems that studies focusing on KIBS conclude that broadband has a less beneficial effect. Remember, however, that these additional results are based on a smaller sample, with some moderating variables referring to only a few studies (see footnote 18). Finally, the estimation of this multivariate model provides robust evidence of a significantly positive selection bias.

CONCLUSION

We provide a quantitative literature review on broadband and firm location. While the majority of studies find that broadband positively affects firm location, its effects are strongly heterogeneous. What lessons can we learn from this analysis, and which answers can we provide to relevant policy and research issues?

First, the significance and magnitude of the effects vary depending on study areas and industries, with larger impacts for urban areas and lower effects in FIRE. Obviously, this result does not mean that public deployment programs in rural areas are not worthwhile. Quite the contrary: broadband is highly needed in rural areas for a large number of reasons, including access to public services. This result highlights, however, that too much faith must not be put in broadband deployment to foster firm location in rural areas and that other policies must not be disregarded. Second, we find that estimates are sensitive to methodological choices, particularly to the scale of analysis, model specification and estimator, which calls for future research to be cautious regarding these issues. In particular, while spatial models have often been disregarded, our analysis shows that spatial autocorrelation must be seriously considered. In contrast, statistical indicators for firms and broadband do not seem to matter. In particular, high-speed broadband does not seem to generate significant additional benefits in terms of firm location, perhaps because most firms still use basic broadband applications. New research is needed,

²³ Remember, however, that estimates are weighted to ensure that no single study disproportionately drives the results.

²⁴ Correlation coefficients are not normally distributed when their value is close to |1|, which may affect estimates. To ensure robustness, we thus calculate Fisher’s z-transformation of correlation coefficients as follows: $z = 0.5(\ln(1+r) - \ln(1-r))$, where r is the partial correlation coefficient.

²⁵ We prefer using the I^2 test rather than the Cochran’s Q to test for heterogeneity. For more explanations, see Higgins & al. (2003).

however, to test whether high-speed broadband is being increasingly valued over time as bandwidth-hungry applications develop.

Although previous literature has already provided a number of answers, several issues remain open. We have identified four main avenues for future research. First, more work is needed to assess the role of mobile broadband, which may provide additional benefits since it provides greater flexibility for users. This issue is crucial in terms of policy recommendations, as it may indicate whether public authorities should concentrate on deploying mobile or fixed broadband networks. Second, the literature on broadband and firm location still remains silent regarding the potential nonlinearities over time. Thus, additional tests are required to understand when effects occur and how they evolve over time. Third, new research is needed to assess whether broadband has different effects across stages of production (R&D, construction, distribution, etc.). An important issue is whether broadband fosters the de-concentration of basic, low-skilled and low-paid activities in rural areas and increases the concentration of knowledge-intensive activities in cities. Last, but not least, another open issue is whether there are threshold effects depending on internet coverage. Specifically, is there a lower bound under which broadband coverage is too low to generate any economic effects? In contrast, is there a maximum coverage level above which any additional broadband deployment does not generate any additional economic effects? Identifying these threshold effects would help in defining optimal coverage levels for public deployment programs.

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APPENDIX

A.1. Definitions of variables

Dependent Variable	
y_10p	Variable equal to -1 if broadband effect is significantly negative, 0 if insignificant, 1 if significantly positive (10% level of significance)
y_5p	Variable equal to -1 if broadband effect is significantly negative, 0 if insignificant, 1 if significantly positive (5% level of significance)
r _i	Partial correlation coefficient of broadband and firm location
fisher_r _i	Fisher's z-transformed partial correlation coefficient
Moderator Variables	
USA	Dummy equal to 1 if the estimate focuses on the USA, 0 if on Europe
Urban and Rural	Dummy equal to 1 if the estimate is both on rural and urban areas, 0 otherwise (reference category)
Urban	Dummy equal to 1 if the estimate focuses on urban areas, 0 otherwise
Rural	Dummy equal to 1 if the estimate focuses on rural areas, 0 otherwise
All industries	Dummy equal to 1 if the estimate covers all industries, 0 otherwise (reference category)
FIRE	Dummy equal to 1 if the estimate focuses on FIRE, 0 otherwise
High-tech	Dummy equal to 1 if the estimate focuses on high-tech firms, 0 otherwise
KIBS	Dummy equal to 1 if the estimate focuses on KIBS, 0 otherwise
Manufacturing	Dummy equal to 1 if the estimate focuses on manufacturing and/or construction, 0 otherwise
Primary Sector	Dummy equal to 1 if the estimate focuses on the primary sector, 0 otherwise
Services	Dummy equal to 1 if the estimate focuses on services, 0 otherwise
Adoption	Dummy equal to 1 if an indicator of broadband adoption is used, 0 if indicator of broadband availability
>30Mbps	Dummy equal to 1 if focus on very high speed broadband (>= 30 Mbps), 0 if lower-speed broadband
Firms Births	Dummy equal to 1 if an indicator of firms births is used, 0 if the number of firms is used instead
Control for Endogeneity	Dummy equal to 1 if endogeneity is controlled for with fixed-effects, first differences, differences-in-differences, random effects, or an instrumental variables approach
Fixed-effects	Dummy equal to 1 if endogeneity is controlled for with fixed-effects, first differences, differences-in-differences or random effects
Instrumental Variables	Dummy equal to 1 if endogeneity is controlled for with an instrumental variables approach
Control for Spatial Autoc.	Dummy equal to 1 if spatial autocorrelation is taken into account, 0 otherwise
Agglomeration Economies	Dummy equal to 1 if a control variable is introduced for agglomeration economies, 0 otherwise
Labour Market	Dummy equal to 1 if a control variable is introduced for labour market, 0 otherwise
Population Structure	Dummy equal to 1 if a control variable is introduced for population structure, 0 otherwise
Market Access	Dummy equal to 1 if a control variable is introduced for market access, 0 otherwise
Supra-municipal Level	Dummy equal to 1 if the study is carried out at the supra-municipal level, 0 otherwise (reference category)
Municipal Level	Dummy equal to 1 if the study is carried out at the municipal level, 0 otherwise
Infra-municipal Level	Dummy equal to 1 if the study is carried out at the infra-municipal level, 0 otherwise
Journal Articles	Dummy equal to 1 if the estimates comes from a peer-reviewed journal article, 0 otherwise
Focus on Broadband and Firms	Dummy equal to 1 if the estimates comes from a study focusing on broadband and firms location, 0 otherwise

Figure A.2.1. – Sign and significance approach

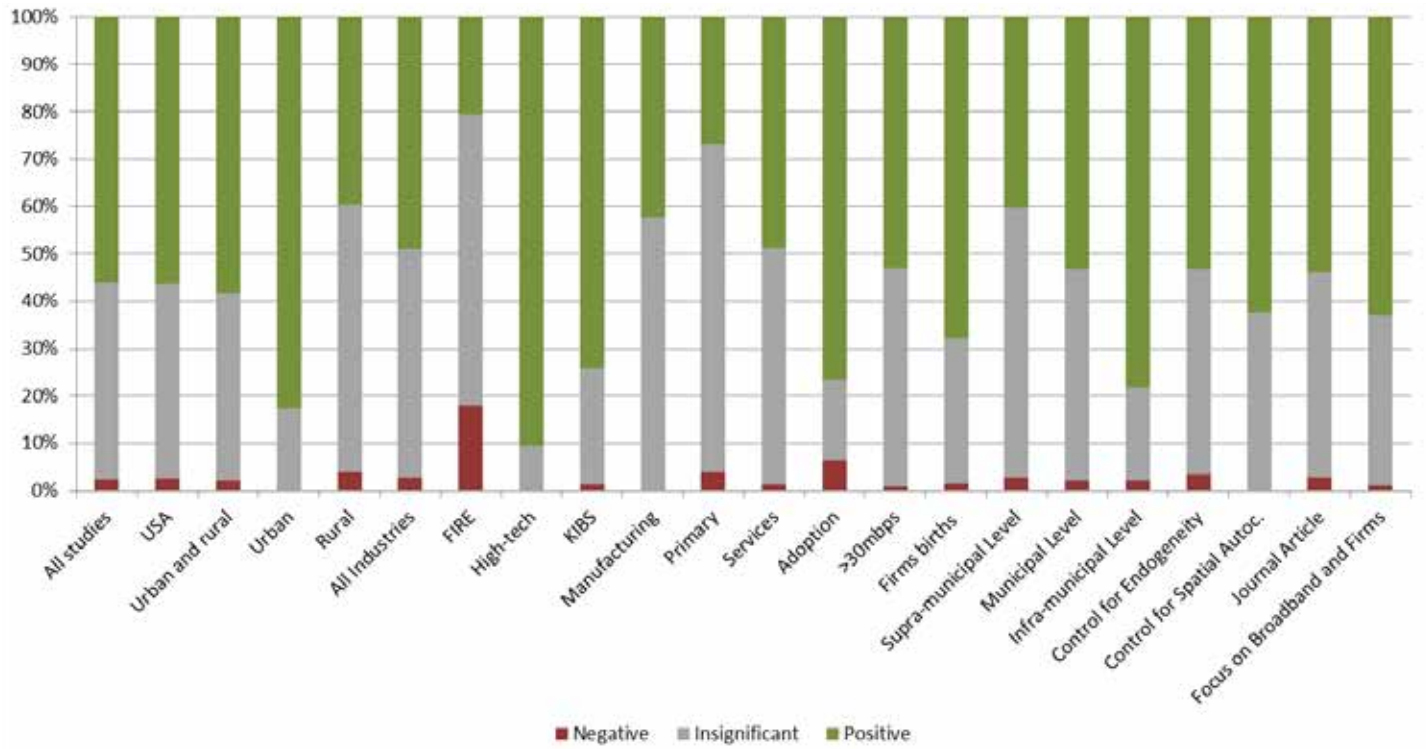


Table A.2.2 – Weighted averages of the estimated effects (partial correlations coefficients)

	(1)	(2)	(3)		(1)	(2)	(3)
	Robust SE	Cluster-Robust SE	Random Effects		Robust SE	Cluster-Robust SE	Random Effects
Full Sample	0.014*** (0.001)	0.014*** (0.003)	0.022*** (0.002)	Control Endog=1	0.014*** (0.002)	0.014* (0.007)	0.013*** (0.002)
Contextual Variables				Control Endog=0	0.014*** (0.002)	0.014*** (0.002)	0.037*** (0.004)
USA=1	0.013*** (0.001)	0.013*** (0.003)	0.013*** (0.002)	Control Spatial=1	0.022*** (0.005)	0.022 (0.013)	0.018*** (0.004)
USA=0	0.026*** (0.002)	0.026*** (0.005)	0.033*** (0.003)	Control Spatial=0	0.014*** (0.001)	0.014*** (0.003)	0.025*** (0.003)
Urban	0.022*** (0.003)	0.022 (0.000)	0.023*** (0.003)	Agglo. Eco	0.038*** (0.004)	0.038* (0.018)	0.027*** (0.003)
Urban & Rural	0.014*** (0.002)	0.014*** (0.002)	0.029*** (0.004)	Labour Market	0.014*** (0.001)	0.014*** (0.002)	0.022*** (0.002)
Rural	0.014*** (0.003)	0.014 (0.013)	0.013*** (0.003)	Pop. Structure	0.025*** (0.003)	0.025*** (0.004)	0.020*** (0.003)
All Sectors	0.010*** (0.002)	0.010*** (0.003)	0.017*** (0.005)	Market Access	0.017*** (0.002)	0.017*** (0.005)	0.022*** (0.002)
FIRE	-0.020*** (0.005)	-0.020 (0.013)	-0.017 (0.010)	Supra municipal	0.012*** (0.001)	0.012*** (0.001)	0.015*** (0.002)
High-Tech	0.016*** (0.001)	0.016** (0.003)	0.035*** (0.004)	Municipal	0.025*** (0.002)	0.025** (0.005)	0.029*** (0.002)
KIBS	0.068** (0.031)	0.068 (0.067)	0.005 (0.010)	Infra municipal	0.015*** (0.004)	0.015 (0.014)	0.023*** (0.007)
Manufacturing	0.027*** (0.006)	0.027** (0.011)	0.021*** (0.006)	Publication Characteristics			
Primary Sector	0.012 (0.007)	0.012 (0.011)	0.023 (0.015)	Journal Article=1	0.016*** (0.004)	0.016 (0.013)	0.035*** (0.004)
Services	0.041*** (0.006)	0.041* (0.020)	0.030*** (0.004)	Journal Article=0	0.013*** (0.001)	0.013*** (0.002)	0.015*** (0.002)
Data and Econometric Settings				Focus BB & Firms=1	0.044*** (0.004)	0.044* (0.023)	0.035*** (0.003)
Adoption=1	0.010*** (0.001)	0.010*** (0.000)	0.016*** (0.002)	Focus BB & Firms=0	0.010*** (0.001)	0.010*** (0.002)	0.012*** (0.002)
Adoption=0	0.017*** (0.002)	0.017** (0.006)	0.023*** (0.002)	No. of Estimates			
>30Mbps=1	0.023*** (0.002)	0.023*** (0.001)	0.023*** (0.002)	485			
>30Mbps=0	0.013*** (0.001)	0.013*** (0.003)	0.025*** (0.003)	No. of Studies			
Firms Births=1	0.016*** (0.002)	0.016** (0.005)	0.031*** (0.003)	19			
Firms Births=0	0.009*** (0.002)	0.009* (0.005)	0.012*** (0.003)				

A.3. Predicted Probabilities

	(1)	(2)	(3)
	Outcome(-1)	Outcome(0)	Outcome(1)
Contextual Variables			
USA = 0	0.002 (0.002)	0.130*** (0.008)	0.868*** (0.008)
USA = 1	0.157*** (0.026)	0.450*** (0.033)	0.393*** (0.015)
Urban and Rural	0.056*** (0.010)	0.461*** (0.029)	0.483*** (0.033)
Urban	0.032*** (0.010)	0.304*** (0.054)	0.664*** (0.060)
Rural	0.065*** (0.010)	0.499*** (0.029)	0.436*** (0.030)
All industries	0.046*** (0.005)	0.381*** (0.030)	0.573*** (0.030)
FIRE	0.139*** (0.045)	0.579*** (0.051)	0.282*** (0.078)
High-tech	0.037*** (0.010)	0.308*** (0.072)	0.655*** (0.080)
KIBS	0.073*** (0.026)	0.495*** (0.056)	0.432*** (0.076)
Manufacturing	0.108*** (0.025)	0.553*** (0.037)	0.338*** (0.040)
Primary Sector	0.066*** (0.022)	0.475*** (0.072)	0.459*** (0.090)
Services	0.067*** (0.021)	0.479*** (0.050)	0.454*** (0.065)
Data and Econometric settings			
Adoption = 0	0.038*** (0.011)	0.439*** (0.018)	0.523*** (0.016)
Adoption = 1	0.096** (0.041)	0.548*** (0.041)	0.356*** (0.072)
>30Mbps = 0	0.064*** (0.014)	0.484*** (0.023)	0.453*** (0.027)
>30Mbps = 1	0.027* (0.015)	0.283*** (0.096)	0.690*** (0.108)
Firms Births = 0	0.050*** (0.006)	0.479*** (0.043)	0.471*** (0.043)
Firms Births = 1	0.040*** (0.013)	0.411*** (0.060)	0.549*** (0.072)
Control for Endogeneity = 0	0.050*** (0.007)	0.455*** (0.023)	0.495*** (0.023)
Control for Endogeneity = 1	0.049*** (0.006)	0.449*** (0.030)	0.502*** (0.031)
Control for Spatial Autocorrelation = 0	0.054*** (0.007)	0.469*** (0.020)	0.477*** (0.019)

Control for Spatial Autocorrelation = 1	0.032*** (0.009)	0.330*** (0.044)	0.638*** (0.050)
Agglomeration Economies = 0	0.017** (0.007)	0.274*** (0.030)	0.709*** (0.029)
Agglomeration Economies = 1	0.120*** (0.021)	0.508*** (0.027)	0.372*** (0.023)
Labour Market = 0	0.032*** (0.009)	0.374*** (0.024)	0.594*** (0.022)
Labour Market = 1	0.104*** (0.019)	0.500*** (0.026)	0.396*** (0.017)
Population Structure = 0	0.044*** (0.004)	0.267*** (0.059)	0.689*** (0.058)
Population Structure = 1	0.117*** (0.037)	0.512*** (0.027)	0.371*** (0.036)
Market Access = 0	0.347*** (0.113)	0.545*** (0.087)	0.108*** (0.032)
Market Access = 1	0.009** (0.004)	0.374*** (0.022)	0.617*** (0.022)
Supra-municipal Level	0.047*** (0.005)	0.379*** (0.027)	0.574*** (0.026)
Municipal Level	0.615*** (0.082)	0.311*** (0.081)	0.074*** (0.003)
Infra-municipal Level	0.026*** (0.009)	0.217*** (0.024)	0.756*** (0.026)

Publication Characteristics

Journal Article = 0	0.042*** (0.006)	0.413*** (0.035)	0.545*** (0.038)
Journal Article = 1	0.051*** (0.006)	0.469*** (0.022)	0.479*** (0.021)
Focus on Broadband and Firms = 0	0.068*** (0.013)	0.576*** (0.033)	0.356*** (0.035)
Focus on Broadband and Firms = 1	0.025** (0.010)	0.361*** (0.028)	0.614*** (0.031)

No. of estimates

757

No. of studies

25

Note: ***p<0.01; **p<0.05; *p<0.1. Standard errors clustered at the study level are reported in parentheses.

A.4. Robustness Tests-1: Dependent Variable, Endogeneity, and Clustering of Standard Errors

	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline		Variable for endogeneity		SE Clustered by Study Data	
	y_10pc	y_5pc	y_10pc	y_5pc	y_10pc	y_5pc
Contextual Variables						
USA	-3.968*** (0.609)	-2.901*** (0.631)	-3.961*** (0.615)	-2.912*** (0.636)	-3.968*** (0.209)	-2.901*** (0.757)
Urban	0.942** (0.419)	0.960** (0.427)	0.960** (0.376)	0.906** (0.401)	0.942*** (0.021)	0.960*** (0.110)
Rural	-0.241 (0.237)	-0.124 (0.236)	-0.252 (0.274)	-0.067 (0.284)	-0.241 (0.302)	-0.124 (0.245)
FIRE	-1.611*** (0.463)	-0.751** (0.357)	-1.613*** (0.462)	-0.749** (0.356)	-1.611*** (0.206)	-0.751** (0.349)
High-tech	0.481 (0.509)	0.469 (0.511)	0.480 (0.507)	0.464 (0.517)	0.481*** (0.063)	0.469*** (0.150)
KIBS	-0.775 (0.473)	-0.147 (0.416)	-0.760 (0.523)	-0.213 (0.497)	-0.775*** (0.260)	-0.147 (0.443)
Manufacturing	-1.285*** (0.347)	-0.755*** (0.228)	-1.286*** (0.347)	-0.754*** (0.227)	-1.285*** (0.404)	-0.755*** (0.016)
Primary Sector	-0.627 (0.403)	-0.136 (0.514)	-0.624 (0.395)	-0.154 (0.505)	-0.627*** (0.096)	-0.136 (0.282)
Services	-0.656 (0.457)	-0.328 (0.330)	-0.658 (0.455)	-0.325 (0.330)	-0.656 (0.528)	-0.328 (0.203)
Data and Econometric settings						
Adoption	-1.029* (0.539)	-0.348 (0.378)	-1.030* (0.540)	-0.334 (0.372)	-1.029* (0.531)	-0.348 (0.319)
>30Mbps	1.284* (0.747)	1.022 (0.754)	1.257* (0.756)	1.115 (0.813)	1.284 (0.795)	1.022 (0.663)
Firms Births	0.409 (0.549)	0.884 (0.642)	0.410 (0.547)	0.883 (0.647)	0.409 (0.828)	0.884 (1.130)
Control for Endogeneity	0.036 (0.251)	0.118 (0.224)	-	-	0.036 (0.170)	0.118 (0.200)
Fixed-effects	-	-	0.072 (0.229)	-0.011 (0.316)	-	-
Instrumental Variables	-	-	-0.037 (0.504)	0.396 (0.613)	-	-
Control for Spatial Autocorrelation	0.886** (0.349)	0.780** (0.380)	0.918*** (0.339)	0.685* (0.388)	0.886*** (0.303)	0.780*** (0.274)
Agglomeration Economies	-2.009*** (0.399)	-1.061** (0.438)	-1.993*** (0.416)	-1.107** (0.490)	-2.009*** (0.225)	-1.061 (0.657)
Labour Market	-1.287*** (0.222)	-1.149*** (0.226)	-1.295*** (0.231)	-1.115*** (0.224)	-1.287*** (0.194)	-1.149*** (0.130)
Population Structure	-1.711*** (0.583)	-1.528** (0.616)	-1.719*** (0.578)	-1.511** (0.616)	-1.711*** (0.172)	-1.528*** (0.252)
Market Access	3.342*** (0.795)	2.156** (0.946)	3.338*** (0.796)	2.168** (0.962)	3.342*** (0.833)	2.156* (1.236)
Municipal Level	-4.787*** (0.784)	-4.001*** (0.627)	-4.803*** (0.771)	-3.940*** (0.588)	-4.787*** (0.500)	-4.001*** (0.122)
Infra-municipal Level	1.174*** (0.231)	0.924*** (0.170)	1.157*** (0.251)	0.977*** (0.216)	1.174*** (0.138)	0.924*** (0.105)
Publication Characteristics						
Journal Articles	-0.353 (0.244)	-0.509* (0.261)	-0.364 (0.252)	-0.479* (0.281)	-0.353*** (0.029)	-0.509*** (0.159)
Focus on Broadband and Firms	1.351*** (0.344)	1.247*** (0.309)	1.368*** (0.326)	1.198*** (0.311)	1.351*** (0.151)	1.247*** (0.093)
No. of estimates	757	757	757	757	757	757
No. of studies	25	25	25	25	25	25
Pseudo R-squared	0.567	0.498	0.567	0.500	0.567	0.498

Note: ***p<0.01; **p<0.05; *p<0.1. Standard errors reported in parentheses (clustered at the study level in columns (1) to (4)). Baseline estimates are reported in Column (1). The dependent variable is defined using the 5% level significance in columns (2), (4) and (6). An alternative variable is used for studies controlling for endogeneity in columns (3) and (4). Standard errors are clustered by study data in columns (5) and (6).

A.5. Robustness Tests-2: Exclusion of Studies

	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline	y_10pc	y_10pc	y_10pc	y_10pc	y_10pc
Contextual Variables						
USA	-3.968*** (0.609)	-4.227*** (0.661)	-4.015*** (0.611)	-4.245*** (0.690)	-4.035*** (0.617)	-4.121*** (0.627)
Urban	0.942** (0.419)	0.879 (0.541)	1.030** (0.438)	0.899* (0.467)	1.120** (0.526)	0.765* (0.418)
Rural	-0.241 (0.237)	-0.211 (0.224)	-0.258 (0.247)	-0.289 (0.286)	-0.125 (0.303)	-0.256 (0.238)
FIRE	-1.611*** (0.463)	-1.492*** (0.544)	-1.604*** (0.464)	-1.790*** (0.537)	-1.648*** (0.472)	-1.708*** (0.472)
High-tech	0.481 (0.509)	0.665 (0.600)	0.499 (0.516)	0.503 (0.579)	0.518 (0.505)	0.783 (0.712)
KIBS	-0.775 (0.473)	-0.855 (0.531)	-0.699 (0.490)	-0.768 (0.544)	-0.852 (0.600)	-0.751 (0.473)
Manufacturing	-1.285*** (0.347)	-1.465*** (0.380)	-1.297*** (0.351)	-1.412*** (0.395)	-1.337*** (0.376)	-1.359*** (0.391)
Primary Sector	-0.627 (0.403)	-0.780** (0.372)	-0.646 (0.415)	-0.561 (0.517)	-0.614 (0.569)	-0.663 (0.413)
Services	-0.656 (0.457)	-1.081*** (0.381)	-0.665 (0.458)	-0.640 (0.525)	-0.696 (0.505)	-0.725 (0.491)
Data and Econometric settings						
Adoption	-1.029* (0.539)	-1.204** (0.573)	-1.015* (0.543)	-1.121 (0.682)	-1.041* (0.544)	-1.209** (0.552)
>30Mbps	1.284* (0.747)	1.920* (1.119)	1.258* (0.751)	1.410* (0.836)	1.243 (0.776)	1.796* (0.938)
Firms Births	0.409 (0.549)	0.428 (0.637)	0.415 (0.553)	0.407 (0.645)	0.387 (0.567)	0.383 (0.530)
Control for Endogeneity	0.036 (0.251)	-0.026 (0.253)	0.016 (0.256)	0.059 (0.320)	-0.012 (0.277)	0.035 (0.272)
Control for Spatial Autocorrelation	0.886** (0.349)	1.035** (0.440)	0.859** (0.370)	0.895** (0.387)	0.939** (0.366)	0.881** (0.373)
Agglomeration Economies	-2.009*** (0.399)	-2.116*** (0.420)	-2.019*** (0.405)	-2.234*** (0.402)	-1.954*** (0.398)	-2.107*** (0.421)
Labour Market	-1.287*** (0.222)	-1.363*** (0.280)	-1.313*** (0.242)	-1.397*** (0.244)	-1.333*** (0.227)	-1.262*** (0.226)
Population Structure	-1.711*** (0.583)	-1.583*** (0.613)	-1.692*** (0.588)	-1.755*** (0.605)	-1.757*** (0.626)	-1.642** (0.646)
Market Access	3.342*** (0.795)	3.131*** (0.804)	3.356*** (0.797)	3.565*** (0.855)	3.336*** (0.817)	3.313*** (0.848)
Municipal Level	-4.787*** (0.784)	-5.314*** (0.885)	-4.831*** (0.792)	-5.062*** (0.886)	-4.988*** (0.798)	-5.083*** (0.878)
Infra-municipal Level	1.174*** (0.231)	1.219*** (0.254)	1.230*** (0.254)	1.334*** (0.272)	1.051*** (0.274)	1.217*** (0.251)
Publication Characteristics						
Journal Article	-0.353 (0.244)	-0.351 (0.250)	-0.339 (0.248)	-0.366 (0.303)	-0.365 (0.259)	-0.303 (0.228)
Focus on Broadband and Firms	1.351*** (0.344)	1.517*** (0.327)	1.348*** (0.349)	1.426*** (0.431)	1.456*** (0.364)	1.390*** (0.333)
No. of estimates	757	643	649	663	691	693
No. of studies	25	24	24	24	24	24
Pseudo R-squared	0.567	0.604	0.564	0.602	0.579	0.586

Note: ***p<0.01; **p<0.05; *p<0.1. Standard errors clustered at the study level are reported in parentheses. Baseline estimates are reported in Column 1. The following studies are successively excluded from the analysis: Duvivier et al (2018) in Column 2; Mack and Rey (2014) in Column 3; Kandilov and Renkow (2010) in Column 4; Mack (2015) in Column 5; Mc Coy et al (2018) in Column 6

Figure A.6.1. Full Sample

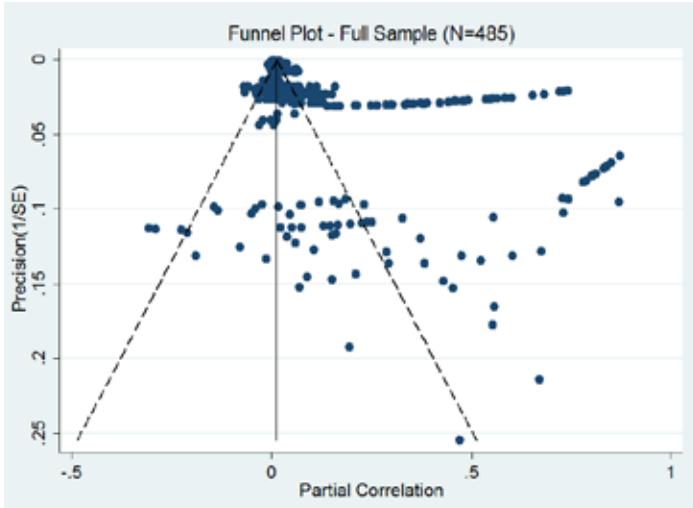


Figure A.6.2. Subgroup: Studies Focusing on Broadband and Firms

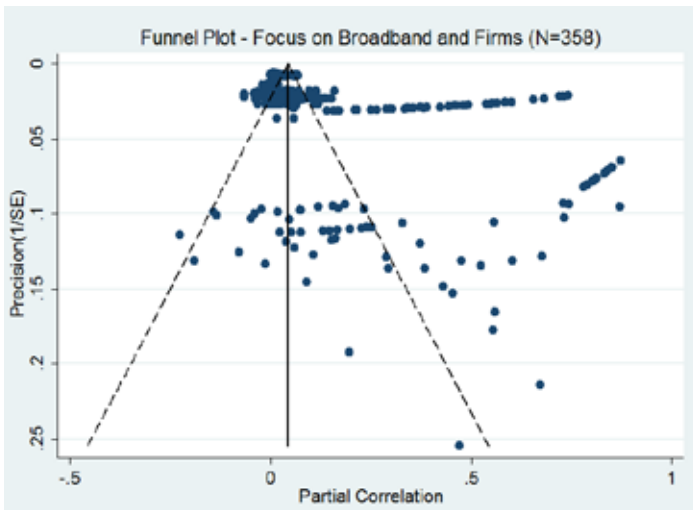


Figure A.6.3. Subgroup: Studies Not Focusing on Broadband and Firms

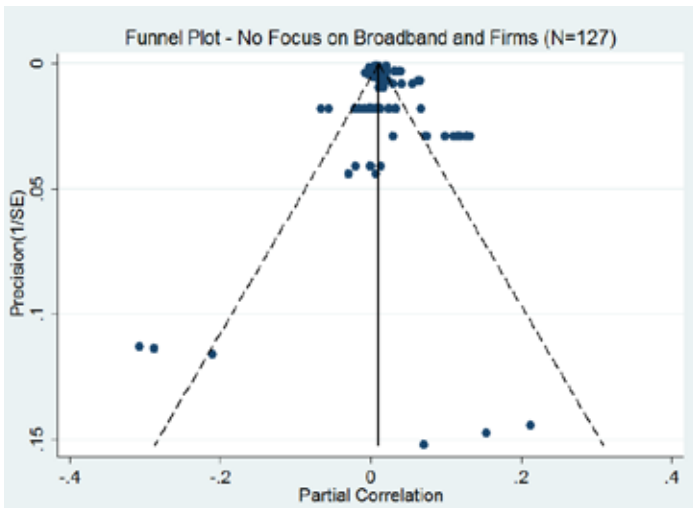


Table A.7.1. – Partial Correlation Coefficients

	(1)	(2)	(3)
	Robust SE	Cluster-Robust SE	Random Effects
SE	3.097***	3.097*	0.613***
{FAT}	(0.298)	(1.567)	(0.150)
Intercept	0.003**	0.003	0.013***
{PET}	(0.001)	(0.004)	(0.003)
No. of Estimates	485	485	485
No. of Studies	19	19	19
R-squared	0.197	0.197	-
Adj R-squared	-	-	26.58%
I²	-	-	58.85%

Note: ***p<0.01; **p<0.05; *p<0.1. Standard errors in parentheses. Column (1): WLS with robust standard errors. Column (2): WLS with robust standard errors clustered at the study level. Column (3): random effects panel estimator (restricted maximum-likelihood random-effects).

Table A.7.2. – Fisher’s z-transformed Partial Correlation Coefficients

	(1)	(2)	(3)
	Robust SE	Cluster-Robust SE	Random Effects
SE	3.018***	3.018*	0.685***
{FAT}	(0.283)	(1.509)	(0.147)
Intercept	0.003**	0.003	0.012***
{PET}	(0.001)	(0.005)	(0.002)
No. of Estimates	485	485	485
No. of Studies	19	19	19
R-squared	0.212	0.212	-
Adj R-squared	-	-	34.86%
I²	-	-	54.04%

Note: ***p<0.01; **p<0.05; *p<0.1. Standard errors in parentheses. Column (1): WLS with robust standard errors. Column (2): WLS with robust standard errors clustered at the study level. Column (3): random effects panel estimator (restricted maximum-likelihood random-effects).

Table A.8.1. – Partial Correlation Coefficients

	(1)	(2)	(3)
	Robust SE	Cluster-Robust SE	Random Effects
Contextual Variables			
USA	-0.047 (0.033)	-0.047 (0.078)	-0.142*** (0.019)
Urban	0.133*** (0.022)	0.133* (0.066)	0.041*** (0.012)
Rural	0.049* (0.028)	0.049 (0.045)	0.023** (0.011)
FIRE	-0.093*** (0.015)	-0.093*** (0.027)	-0.054*** (0.012)
High-tech	-0.001 (0.003)	-0.001 (0.004)	0.017** (0.007)
KIBS	-0.041* (0.022)	-0.041* (0.021)	-0.026** (0.012)
Manufacturing	-0.016 (0.014)	-0.016 (0.010)	-0.009 (0.008)
Primary Sector	-0.059*** (0.017)	-0.059* (0.030)	-0.004 (0.015)
Services	-0.022* (0.012)	-0.022 (0.014)	-0.005 (0.006)
Data and Econometric Settings			
Adoption	-0.005 (0.003)	-0.005*** (0.001)	-0.016*** (0.005)
>30Mbps	-0.020** (0.009)	-0.020 (0.019)	-0.008 (0.007)
Firms Births	0.044*** (0.014)	0.044 (0.052)	0.007 (0.007)
Control for Endogeneity	-0.002 (0.003)	-0.002 (0.010)	-0.001 (0.005)
Control for Spatial Auto.	-0.027** (0.013)	-0.027 (0.036)	0.007 (0.007)
Agglomeration Eco.	0.032** (0.015)	0.032 (0.045)	0.011 (0.008)
Labour Market	-0.029* (0.016)	-0.029 (0.039)	-0.020** (0.008)
Population Structure	-0.036*** (0.010)	-0.036 (0.032)	-0.026*** (0.007)
Market Access	0.099*** (0.029)	0.099 (0.076)	0.070*** (0.014)
Municipal Level	-0.157*** (0.037)	-0.157* (0.088)	-0.152*** (0.021)
Infra-municipal Level	0.055*** (0.014)	0.055* (0.028)	0.027*** (0.007)
Publication Bias			
SE	5.222*** (0.461)	5.222*** (1.348)	0.967*** (0.192)
Constant	-0.060*** (0.020)	-0.060 (0.052)	0.096*** (0.017)
No. of Estimates	485	485	485
No. of Studies	19	19	19
R-squared	0.506	0.506	-
Adj. R-squared	-	-	67.98%
I²	-	-	47.45%

Note: ***p<0.01; **p<0.05; *p<0.1. Standard errors in parentheses. Column (1): WLS with robust standard errors. Column (2): WLS with robust standard errors clustered at the study level. Column (3): random effects panel estimator

Table A.8.1. – Partial Correlation Coefficients

	(1)	(2)	(3)
	Robust SE	Cluster-Robust SE	Cluster-Robust SE
Contextual Variables			
USA	-0.040 (0.030)	-0.040 (0.068)	-0.128*** (0.018)
Urban	0.121*** (0.021)	0.121* (0.070)	0.033*** (0.011)
Rural	0.043* (0.026)	0.043 (0.043)	0.020* (0.010)
FIRE	-0.090*** (0.014)	-0.090*** (0.027)	-0.054*** (0.011)
High-tech	-0.001 (0.003)	-0.001 (0.004)	0.016*** (0.005)
KIBS	-0.039** (0.020)	-0.039* (0.020)	-0.026** (0.011)
Manufacturing	-0.017 (0.012)	-0.017* (0.009)	-0.010 (0.007)
Primary Sector	-0.057*** (0.015)	-0.057* (0.029)	-0.003 (0.014)
Services	-0.020* (0.011)	-0.020 (0.013)	-0.005 (0.006)
Data and Econometric Settings			
Adoption	-0.005 (0.003)	-0.005*** (0.001)	-0.011*** (0.004)
>30Mbps	-0.018** (0.008)	-0.018 (0.017)	-0.006 (0.007)
Firms Births	0.032** (0.013)	0.032 (0.045)	0.003 (0.007)
Control for Endogeneity	-0.002 (0.003)	-0.002 (0.010)	-0.004 (0.004)
Control for Spatial Auto.	-0.029** (0.012)	-0.029 (0.033)	0.006 (0.007)
Agglomeration Eco.	0.021 (0.013)	0.021 (0.039)	0.012* (0.007)
Labour Market	-0.021 (0.014)	-0.021 (0.035)	-0.016** (0.007)
Population Structure	-0.032*** (0.010)	-0.032 (0.034)	-0.021*** (0.007)
Market Access	0.090*** (0.027)	0.090 (0.071)	0.053*** (0.012)
Municipal Level	-0.133*** (0.033)	-0.133 (0.079)	-0.132*** (0.019)
Infra-municipal Level	0.049*** (0.013)	0.049* (0.027)	0.020*** (0.006)
Publication Bias			
SE	5.229*** (0.468)	5.229*** (1.648)	0.848*** (0.203)
Constant	-0.055*** (0.020)	-0.055 (0.059)	0.095*** (0.016)
No. of Estimates	485	485	485
No. of Studies	19	19	19
R-squared	0.477	0.477	-
Adj. R-squared	-	-	84.56%
I²	-	-	40.54%

Note: ***p<0.01; **p<0.05; *p<0.1. Standard errors in parentheses. Column (1): WLS with robust standard errors. Column (2): WLS with robust standard errors clustered at the study level. Column (3): random effects panel estimator.