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Broadband access and territorial development in times of uncertainty

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Résumé de l'article

Since the last decade of the twentieth century, internet access has become a *sine qua non* for businesses. IT as well as online commerce have been growing fast over the past decades, and many other sectors also depend more and more on internet access; even industrial services such as design and warehousing, to name but two examples, rely on and benefit from cooperation at a distance. The global boost in teleworking and particularly teleconferencing following the Covid-19 pandemic has shown how important reliable connections are.

Governments have over the past decade invested in improving their connections to the worldwide internet. Yet it is not clear whether economic clustering in fact is attracted to well-connected locations. We therefore test empirically whether the level of connectedness to the global IT infrastructure has a correlation with subsequent economic growth in sectors that use such infrastructure, or even depend on it.

We do this using a panel of US cities, in which we zoom in on a few sectors that can use the infrastructure and compare them against the background of other sectors in the same cities. As a measure for the quality of local connections, we employ a unique method: we use the latency (ping times), a network metric usually spurned in favour of the more common bandwidth.

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REVUE CANADIENNE DES SCIENCES RÉGIONALES

PING TIMES: RELATING ECONOMIC GROWTH TO INTERNET CONNECTIVITY

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Abstract: Since the last decade of the twentieth century, internet access has become a *sine qua non* for businesses. IT as well as online commerce have been growing fast over the past decades, and many other sectors also depend more and more on internet access; even industrial services such as design and warehousing, to name but two examples, rely on and benefit from cooperation at a distance. The global boost in teleworking and particularly teleconferencing following the Covid-19 pandemic has shown how important reliable connections are.

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We do this using a panel of US cities, in which we zoom in on a few sectors that can use the infrastructure and compare them against the background of other sectors in the same cities. As a measure for the quality of local connections, we employ a unique method: we use the latency (ping times), a network metric usually spurned in favour of the more common bandwidth.

Keywords: regional economic growth; internet access; broadband

1. INTRODUCTION

Pandemic-induced teleworking has given teleconferencing a tremendous boost. Apart from the environmentally beneficial decrease in flight traffic, this increased the importance of reliable and fast internet. Where internet connections from homes and offices had become faster, cheaper and more reliable in the first decade of the 21st century, a plateau seemed to have been reached, where only avid gamers complained about their latencies—the delay with which a "ping" signal from their computer reached other computers on the internet.[3]

However, office use follows their lead, and during the lockdowns of 2020–2021 it turned out a reliable video call with twenty colleagues, clients, students or friends is not so easy to achieve from just any place.[4] Some locations simply have better connections to the main highways of the internet, and these locations are therefore more attractive for heavy IT use in the "New Economy" (Hutton, 2004).

Given the uncertainty of current developments, this paper looks back at the *previous* rise in high-quality connectivity, for which we can see the subsequent changes in patterns of economic of activity. We do so by looking at latency data gathered by PlanetLab over the years 2002–2006, and subsequent development of several economic sectors among different cities in the US. The paper thus answers the call of Vu et al. (2020) to "be more creative" in measuring ICT benefits, choosing a measure that shows to be particularly relevant in the distance working trend that the 2020 lockdowns accelerated. Moreover, it offers a sectoral approach, which appears to be a novelty in the literature.

2. THEORETICAL FRAMEWORK

Bandwidth and latency

Good internet connections are important for many purposes; in this sense, they can be compared to the classical literature on the expansion of highway systems and subsequent growth (e.g. Garcia-López et al., 2015; Gerritse & Arribas-Bel, 2017; Levkovich et al., 2020). The analogy also holds in the sense that these advantages are very broad and generic. Where highways benefit households and business across many sectors, with a focus on manufacturing and with strong advantages for logistics, internet connections likewise offer benefits to households, many sectors, but this time with a focus on services and with strong advantages in ICT—which we will discuss below. An important difference lies in the negative externalities of physical infrastructure, ranging from pollution to crime (Matthews et al., 2010), but here too internet connections have generated a "digital divide" that disadvantages those with no or low-quality access and often exacerbates existing socio-economic rifts (van Dijk, 2006).

Taking the parallel with highways one step further, we can also compare the measurement of highways with that of internet connections. The classical analysis of internet infrastructure focuses on bandwidth, akin to the number of highway lanes. Although on the construction of new infrastructure a certain physical bandwidth is installed, and capacity is traded on so-called internet exchanges (Malecki, 2019), it is difficult to measure total bandwidth to other destinations, as that would imply filling up all available capacity. Instead, a strand of research analyzes the *networks* of the internet backbone (see Tranos & Gillespie, 2011, p. 37), focusing on the relative positions of cities in the network.

Latencies, in contrast, are easy to measure, as they are the time it takes for a "ping" signal to be sent out from one server to another and to return — "the time (measured in milliseconds) that it takes to transport and receive data between two nodes on the Internet" (Dodge & Zook, 2009, p. 2). The nickname "ping" refers to sonar equipment on submarines (Denny, 2007), which performs a similar trick. Latencies are affected by the distance between places, the speed of travel across the cables (2/3 of light speed in fibre optic cables), and speed in servers (Tranos, 2010, pp. 32–33). Both bandwidth and latencies are in fact path measures (Ramasubramanian et al., 2009), with servers along the way choosing the optimal route with the fastest speed and optimal throughput. In the case of bandwidth, obstructions along the way generate bottlenecks, often including "last mile" problems, leading to delays and increased latency.

Low latencies are particularly important in data center applications (Studei et al., 2013), but also for a wide range of applications, currently including dealing rooms (Goldstein et al., 2014), videoconferencing (Rajiullah, 2015), and making music together (Smith et al., 2020); Tranos stated transnational corporations rely on "secure, fast and low latency connections" already in 2012 (Tranos, 2012, p. 322). The future may add to those uses the Internet of Things (Jiang et al., 2019), autonomous vehicles (Marai & Taleb, 2020), and virtual reality (Elbamby et al., 2018).[5]

Benefits of good internet connections: nations, households, and firms

At the national level, digitalization of the economy as a whole remains important in a direct competition between advanced economies (Holt & Jamison, 2009; van Ark & Inklaar, 2005), although some remain sceptical of such efforts ("The Broadband Myth," 2008). A large literature analyzes the general productivity bonus ICT affords, where one of the key positive impacts is internet connectivity, usually referred to simply as broadband (Stanley et al., 2018; Ford, 2018 and many others). Surveying this literature, Vu et al. (2020) conclude that 92% of all studies analysing the effect on broadband find a positive and significant impact, with the majority of those looking at the impact on GDP growth.

There is also a sizeable amount of literature on the wide advantages to households (Greenstein & McDevitt, 2009; de Vos et al., 2020), who can make use of an increasing amount of web-based services (downloading music, online music, online video, online meetings) and in general participate in the modern world. Rather counterintuitively, Mack and Grubesic (2009) point out that a result of such consumption is an increased concentration in core areas rather than deconcentration and a "death of distance". De Vos et al. (2020) recently confirmed this by showing how ICT is linked to local agglomeration effects, and seemingly aspatial digital access still benefits cities on the fringe of metropolitan centres.

At the firm level, it has been shown similar factors are important in location choice; in fact, firms wish for "secure, fast, and low latency connections" (Tranos, 2010, p. 88; Moriset, 2003). Several studies study these demands for the economy as a whole or at the service sector (Stockinger, 2017). Yet top internet access is particularly beneficial to heavy users dealing with large amounts of data, and some sectors are more likely to benefit. Among studies diving into the sectoral heterogeneity, Tranos and Mack (2016) studied KIBS in the US context and found strong correlations with broadband; a morerecent study of Deller et al. (2021) confirms those results particularly for rural entrepreneurship in the US. Several studies used surveys to ask which industries use digital technologies (Forman et al., 2003), concluding in particular that "businesses in the information sector (NAICS 51) and management of companies and enterprises (NAICS 55) had the highest adoption rates of advanced Internet uses followed by finance and insurance businesses (NAICS 52) and businesses offering professional, scientific, and technical services (NAICS 54)" (Mack & Rey, 2014). An OECD study (Calvino et al., 2018) further investigates which sectors have "gone digital", but does not zoom in within the IT sector

3 In fact, the current paper spent quite some time on a shelf, as the topic of latency was deemed "a thing of the past".

4 The difficulties become larger when true synchronization is needed, for example when making music together, as the author experienced personally.

5 Part of the hunt for low latencies focuses on wireless communication, as an ever increasing number of consumers is not connected through a fixed line or even their private network at all.

itself; however, Jaeger et al. (2009) point out in general terms that broadband access is important for data warehousing.

Benefits of Good Internet Connections: Regions

Several studies translate the advantages to firms and households to the regional level, in line with our approach. We will briefly discuss five of these in turn; all are included in the review of Vu et al. (2020). In a very early study, Ford & Koutsky (2005) analyze broadband in the Florida municipality of Lake County, relating retail sales to the precise event of municipal broadband provision, and comparing Lake County to a control group. Around the same time, Cieślik and Kaniewska (2004) show in a panel of Polish regions that improvements in telecommunications are related to increases in retail sales. They focus on simple telephone connections are their measure of communications infrastructure, but employ a panel setting with Granger causality checks.

In 2012, a number of papers started to link broadband infrastructures to regional economic growth. Jed Kolko (2012) related broadband providers to employment growth over 1999–2006 in US zip code areas, finding positive relationships both across the economy as a whole and, importantly for the current paper, for specific sectors. Those effects are highest for the sector "management of companies and enterprises", followed at quite some distance by "professional, scientific and technical services" and "administrative and business support services" (Table 3, p. 106). Kolko stresses, however, that although the number of jobs grew, average pay per employee didn't, and he is critical of place-based policies in broadband. In addition, Kolko finds "implausibly high" or "unconvincingly high" (both p. 109) coefficients in the instrumental variables version of his model, but he suggests OLS results may be a lower boundary for the true effect.

In the same year, Emmanouil Tranos published a paper on European city regions (Tranos, 2012). In contrast to the papers above, he used a network approach, calculating the centrality of city regions, and relating that to per capita GDP. Here again Granger causality tests are employed, and a positive and statistically significant impact of access to the internet backbone on GDP is found.

Finally, Jayakar and Park (2013) link broadband availability in US counties to unemployment rather than a measure of growth. In a cross-sectional setting they find broadband availability to households and the associated speeds is negatively related to county unemployment rates, but not to the dynamics of these rates.

Policy

In general, the location patterns of IT-based industries follow the existing economic structure (Vinciguerra et al., 2010), and so does broadband access (Tranos & Gillespie, 2009). Yet governments have also striven to drive new developments by pushing for broadband access in promising or lagging regions (Grubesic & Mack, 2015; Salemink & Strijker, 2016). Several authors have pointed to the high degree of path dependence in economic development based on access to the digital highway (van Geenhuizen, 2007), going so far as to call it "neo-endogenous development" (Salemink & Strijker, 2016), where fierce competition between market players and governments plays out. Others point to the simple fact that cables are not enough for a "death of distance" (Cairncross, 1997); human capital, venture capital, and a generally creative environment remain important factors (Moriset, 2003).

While general access to high-quality internet connections is good for a region, by far the best access is at very local hubs—so-called internet exchanges. Given that access to extremely high-quality internet is thus very much localized,[6] the development of such new nodes can lead to considerable government attention and media expectations, as policy makers seem to believe that good connections could become a key boost to the local economy (van Winden & Woets, 2004). This was the case, for example, when in 2001 the northern Netherlands received a direction connection to the US by transatlantic cable, at the peak of the dot-com bubble. In the end, the cable boosted IT-related activities in the city of Groningen to a moderate degree, but it led to a local Google data warehouse (van Geenhuizen, 2007; Ruiken, 2018). The initial enthusiasm evolved into a more ambiguous stance as clear spinoffs never materialized (Mayer, 2021).

3. DATA AND METHOD

Our ping times were gathered by the now-defunct planetlab project, that started in 2002 and ran until 2020, coming from the distributed systems community (Peterson, 2020). Their original purpose was to optimize the infrastructure itself (e.g., Madhyastha et al., 2006). The site is archived at https://planetlab.cs.princeton.edu/, and some data is still available there. The data used in this analysis was scraped from their extensive logs in 2008. It comprises latencies measured by "pinging", i.e. sending a "traceroute" command, from each participating server to each of the other participating servers. Most servers were located at universities in major cities, thus providing a somewhat level playing field but also a very optimistic estimate of actual connectivity for those at less well-endowed locations.

First Stage

Data was available for the years 2003 to 2007. For practical reasons, we scrape only a small sample of all available data. The pinging was done every 15 minutes, resulting in a "big data" flood of measurements; for reasons of efficiency we choose to save only three pings every day (at 02:00, 12:00 and 22:00 UTC), and for these three moments we saved the minimum reported latencies in a month, i.e. the fastest response. As for the servers observed, those without an IP address and a URL were dropped; the others were then matched to cities based on the planetlab database, a whois query or, if both of those failed, the URL. Finally, the obtained pings were averaged across months and servers within the same city to obtain values for each quarter-city combination.

We then ran a first-stage regression on the latencies, explaining them with dummies for the time of day as well as dummies for the city of origin for every quarter, as follows:

$$L_{ijt} = \alpha + \delta_{Jt} + \tau + \epsilon \qquad 1$$

where L_{ijt} stands for reported minimum latency from server i to server j at quarter t, δ_{Jt} is the time-specific dummies for the city J in which server j is located; and τ is a set of time dummies for the different moments of the day observed. As usual, α is a constant, and ϵ denotes the error term.

Resulting values of δ_{Jt} for the 35 US cities in our dataset can be found in Appendix A. These values—which are not actual latencies, but "latency effects"—provide the input for the second stage regressions. Summary statistics are provided in Table 1.[7]

Table 1. Descriptive statistics for the city latency effects (in μs)

year	mean	st.dev.	minimum	maximum
2003	7,404	13,184	-8,369	63,553
2004	46,568	34,855	10,485	167,180
2005	93,574	30,686	43,457	258,167
2006	79,180	38,853	-60,467	266,547
2007	90,433	28,448	42,532	160,741

6 Internet exchanges are a very local instance of the worlwide web: "In the Gambia, and for much of West Africa, the internet lives at the offices of OG Financial Services Ltd., 76 Kairaba Avenue in Serrekunda, the country's biggest city." (Jacobs, 2016)

7 The full first-stage regressions are available upon request.

Table 2. Descriptive statistics for employment across the four sectors studied

year	Employment in Adm. and support services (561) mean in data	mean US	st.dev. in data	Employment in Data processing, hosting, and related services (518) mean in data	mean US	st.dev. in data
2003	63275	7402	102706	4110	675	6520
2004	72109	7765	114275	3674	641	5942
2005	73632	8006	117171	3829	645	5860
2006	77183	8222	121516	4020	643	6119
2007	78167	8291	122675	2554	566	3918
2008	73763	7926	117766	2108	539	3220
2009	61926	6996	102540	2081	507	3458
2010	63290	7197	102082	1944	486	3086

year	Employment in Telecom (517) mean in data	mean US	st.dev. in data	Employment in Prof., scientific, and technical services (541) mean in data	mean US	st.dev. in data
2003	8659	1159	12895	80107	6794	125842
2004	9132	1108	12380	81678	6924	127047
2005	8357	1064	11992	80312	7047	130126
2006	8437	1043	11353	91408	7405	137512
2007	8029	1105	11702	92238	7633	143221
2008	9041	1106	13620	97004	7850	146101
2009	6857	1035	11064	79505	7452	123241
2010	7138	965	11198	85398	7503	136780

Second stage

In the second stage, we combine the city-level latencies with the US Quarterly Census of Employment and Wages, which reports by 3-digit NAICS sector and by Metropolitan Statistical Area (MSA). In particular, we single out four sectors, and gather employment numbers as well as average weekly wages for 2003–2010, the longer timeframe allowing us to look at a longer effect of better connections on subsequent employment growth. We choose two sectors in more generic services (541 and 561), and two sectors that are more specialized in ICT, one being the more traditional telecommunications sector (517), the other the more modern data processing and hosting sector (518), where our expectations to find an effect are highest (cf. Forman et al., 2003). Summary data is provided in Table 2. We select employment data for the MSA as a whole. Since we look only at a sample of cities which actually hosted planet.lab servers, most of which are in large universities, average employment in these MSAsis much higher than that across all of the US, but trends are similar. In particular, we note a steep decline after 2006 in employment in data processing, hosting and related services, which is probably related to increased efficiency. The other three sectors show a rise followed by a fall, matching the general recession. Since our latency data concerns 2003–2007, we look mainly at rises in employment.

In addition to the wage provided by the census data, we calculate specialization within these four sectors by including the location quotient for each sector. The location quotient is a straightforward common indicator of local overconcentration (Beaudry & Schiffauerova, 2009), and we use a slightly more robust standardized version which puts the average at 0 and limits the location quotient to values between -1 and +1:

$$LQc = \frac{LQ-1}{LQ+1}, \text{ where } LQ = \frac{emp_{ir}/emp_r}{emp_i/emp},$$

i indicates the sector, and r indicates the region

Summary statistics for wages and location quotients are found in Table 3. Location quotients show average values well above 0, indicating predictable overconcentration in the cities studied, but also a large standard deviation. Average wages for sector 561 (administrative and support services) are less than half of those in the other three sectors, where better payment probably corresponds to more difficult jobs. The data processing sector has by far the highest maximum wages; these are in Palo Alto (Silicon Valley), Santa Barbara, and San Francisco.

Table 3. Descriptive statistics for concentration and average weekly wages (in $) across the four sectors studied

	NAICS sector	mean	st.dev.	min	max
LQc	561	0.61	0.72	-1.000	0.999
	518	0.45	0.77	-1.000	0.998
	517	0.69	0.63	-1.000	0.998
	541	0.72	0.60	-1.000	0.999
wage	561	460	242.5	0	1118
	518	1078	798.3	0	5761
	517	1111	555.3	0	3688
	541	1143	543.2	0	2345

4. RESULTS

We regress the number of employees in each city-industry on the latency effect. We control for nominal[8] wages in the industry in question, concentration of the sector (a location quotient), the general service orientation of the local economy (in the form of employment in administrative and support services). Finally, we include employment in the city-industry in the previous quarter. This last variable is normally an excellent predictor of employment in the current quarter, and hence our other variables can only pick up changes in employment. Our regression for each sector s is as follows, where T indicates $t\text{-}1$, δ indicates our city-specific latency effects estimated

8 Since all of our analysis takes place within the US, inflation is not an issue for our analysis.

Table 4. Regression results

	(1)	(2)	(3)	(4)
Dependent: employment	**Adm. and support services**	**Data processing, hosting, and related services**	**Telecom**	**Prof., scientific, and technical services**
latency	-0.0563 (-1.38)	-0.00834** (-2.71)	-0.00339 (-1.37)	-0.0184 (-0.82)
wage	20.80 (1.13)	1.678*** (5.26)	0.841* (2.47)	6.657 (1.94)
concentration (LQc)	4149.3 (0.71)	239.7 (0.84)	735.9** (2.61)	5348.1* (2.00)
lagged employment in adm. and support services	(see below)	0.0162*** (9.51)	0.00485*** (3.47)	0.146*** (7.88)
lagged employment in own sector	0.938*** (57.22)	0.502*** (13.86)	0.916*** (63.90)	0.869*** (51.64)
constant	-2753.6 (-0.45)	-760.0* (-2.38)	-898.0** (-2.98)	-8742.8** (-3.16)
observations	422	415	422	422
within R^2	0.0427	0.186	0.577	0.478
between R^2	0.996	0.968	0.996	0.998

t statistics in parentheses | * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5. Standardized coefficients for Table 1

	(1)	(2)	(3)	(4)
Dependent: employment	**Adm. and support services**	**Emp. in data processing, hosting, and related services**	**Emp. in telecom**	**Prof., scientific, and technical services**
latency	-0.021	-0.063**	-0.012	-0.006
wage	0.040	0.201***	0.039*	0.025
concentration	0.024	0.030	0.040**	0.023*
lagged employment in adm. and support services	(see below)	0.324***	0.047***	0.124***
lagged employment in own sector	0.929***	0.508***	0.924***	0.862***

in the first stage, and the LQc and employment variables are as described in the previous section:

$$Emp_{sJt} = \alpha + \delta_{Jt} + wage_{sJt} + LQc_{sJT} + Emp_{561JT} + Emp_{sJT} + \epsilon \quad (2)$$

Results are shown in Table 4. Latencies are indeed statistically significantly correlated with employment in the most obvious sector, that of data processing, hosting, and related services (NAICS 518). This relationship is negative, as expected, indicating lower latencies go hand-in-hand with increased employment. To interpret the coefficient of -0.00926, we look at the standard deviations in latencies, which are about 40 thousand units. This implies an increase of 370 employees for each standard deviation improvement of the latency. We can also look at the standardized coefficients for insight into the relative importance of different variables (see Table 5).

Clustering of the city-industry is important only in telecom; however, the presence of administrative and support services are important for all other sectors—we interpret this as a linkage in the value chain. We also note that employment in data processing, hosting, and related services depends very little on previous employment in that sector; apparently, employment there fluctuates considerably from year to year. Are data services quicker to move between cities than other sectors? And if so, are these moves in answer to changes in internet connectivity? To test this hypothesis, we show results for longer timeframes for the data services sector in Table 6, relating

Table 6. Expanded time lags for sector 518, data processing, hosting, and related services. Each model includes control variables as in Table 3

time lag of latency	coefficient	t value	observations	within R^2
1 quarter	-0.00834**	-2.71	415	0.186
2 quarters	-0.00907**	-2.85	415	0.138
3 quarters	-0.00754**	-2.74	414	0.266
1 year	-0.00745*	-2.29	414	0.120
1¼ year	-0.00380	-1.54	395	0.256
1½ years	-0.00665*	-2.27	396	0.194
2 years	-0.0113***	-4.19	375	0.159
2½ years	-0.0103***	-3.92	320	0.244

employment in that sector to latencies at various points in the past. The coefficients estimated are stable for at least a whole year after a given change in the latency has occurred—in many cases, that will be a decrease, as connections often improve. Beyond that year, they fluctuate a bit more[9],but in the longest run available, the estimated coefficient becomes larger and its statistical significance increases, suggesting a stronger, perhaps cumulative, effect. This is particularly valuable if the latencies improve, although in the real world they also get worse as traffic intensifies over time (cf. Figure A1).

9 Our panel shows some gaps (see Figure A1); the set of cities included in the separate regressions shown in Table 6 therefore varies in its composition.

Causality

The time lags shown in Table 6 also point to the direction of the causality—it is improvements in latency that influence employment growth, not the other way around. In line with Tranos (2012) and other studies, we perform a Granger causality test (Dumitrescu & Hurlin, 2012; Lopez & Weber, 2017). This, however, necessitates a completely balanced panel, whereas our data contains some gaps. To perform the test, we therefore interpolate the panel by using time-lagged values. In each sectoral regression, we then drop some cities for which there are too few observations to run the Lopez & Weber (2017) panel routines. The results in Table 7 are therefore an approximation. They confirm the causality runs from latency to employment, and not the other way around, for each of the four sectors, as the null hypothesis that latencies do *not* Granger-cause employment is rejected in each case (at $\alpha = 5\%$).

Table 7. Granger causality test

sector	Granger metric	coefficient	p value
Adm. and support services (561)	Z-bar	3.58	0.0003
	Z-bar tilde	2.36	0.0184
Data processing, hosting, and related services (518)	Z-bar	3.26	0.0011
	Z-bar tilde	2.10	0.0357
Telecom (517)	Z-bar	4.75	0.0000
	Z-bar tilde	3.26	0.0011
Prof., scientific, and technical services (541)	Z-bar	9.64	0.0000
	Z-bar tilde	7.09	0.0000

5. CONCLUSIONS

We have investigated the development of four sectors given the improvement in internet connections for a series of American cities in a panel setting. We found in particular that data processing, hosting and related services benefit, as was to be expected. Our results imply an increase of 370 employees in that sector for each standard deviation improvement of the latency. Given that mean employment by county or SMA in the US is about twice that amount (see Table 2), this is a considerable effect, and it suggests data infrastructure could be a useful tool for regional development—at least in the timeframe we considered, but we expect low latencies to be as valuable now as they were then, or even more so.

Three findings stand out in particular.

First of all, our focus on individual sectors sets our analysis apart from the more common analysis of ICT benefits for productivity. Our results show clustering of individual sectors that relate directly to broadband is expected, and we suggest future research to expand this line of research to new internet-dependant services such as virtual reality companies.

Secondly, we used time lags to prevent reverse causality (Baltagi, 2008), but our results indicate that over a longer time frame effects may actually be getting stronger. This points to cumulative causation, suggesting future research may take an evolutionary perspective on the development of the geography of the internet.

Finally, we showed how latencies, which are fairly easy to obtain, can be used to proxy for "good" internet connections. The measure is very well-known in computer science, and as video conferencing has taken a leap in the Covid-19 pandemic, the usefulness of low latencies has also become apparent to the general public. Since the servers that generated our data are located in universities, and particularly in departments of computer science, which traditionally have cutting-edge connections, latencies in the real world out there will typically be much larger. Future research into the distance decay effect and the microgeographical location choice of firms might offer interesting insights here—who needs to locate right next to a university or data center, and who is fine with a location a bit further removed from the prime location?

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APPENDIX A

Figure A1. Latency effects based on the planetlab ping dataset. The vertical axis shows the city-specific latency effect in milliseconds, the horizontal axis the time dimension.