Quality of Communications Infrastructure, Local Structural Transformation, and Inequality

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Abstract

We analyze the impact of communication infrastructure quality on local growth and structural transformation. Our treatment is the county's Internet speed offered to businesses. As an instrument, we use ARPANET, a military network that preceded the modern Internet and whose location we determine using historical government reports. We find that faster Internet stimulates short and long-run growth, shifts counties' economic activity towards high-skilled services, and increases local earnings inequality. Industry linkages, migration, and the sorting of workers in ICT-related occupations explain our results. Our findings relate to predictions of the Hecksher-Ohlin-Vanek model and to the presence of capital-skill complementarities.

JEL Codes: F16, H54, L86, N92, R12

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You can see the computer age everywhere but in the productivity statistics
- Robert M. Solow

1 Introduction

Communications infrastructure differs from other types of infrastructure like roads or railroads. First, it facilitates the transmission of ideas, as modern communication technology primarily "moves" non-rival services, whereas transportation infrastructure primarily moves rival goods or workers. Second, it allows individuals to consume digital services produced in any location. Third, it allows a region to reduce its communication costs with any location, while roads or railroads reduce trade costs only between locations connected by them.[1] The importance of communication infrastructure is such that U.S. lawmakers recently allocated 10 billion dollars of federal funds to improve Internet access (The White House, 2022). Nevertheless, it is unclear to what extent the quality of communication infrastructure impacts local economic outcomes and whether it mattered only for the early stages of the Internet in the 1990s and early 2000s or if its impact is still relevant today.

In this paper, we provide causal evidence that modern improvements in the quality of communication infrastructure induce local structural transformation in U.S. counties. To obtain causal estimates, we use cross-sectional regressions at the county level in 2018 in which the quality of Internet offered to businesses is our main treatment, and our outcomes of interest are the counties' short-run GDP, payroll and employment growth, long-run population growth, and GDP and employment sectoral shares. Our first set of findings shows that faster Internet offered to businesses positively impacts short- and long-run growth. Our second set of results shows that better provision of Internet shifts the local economic structure towards high-skilled services and away from other services such as retail, accommodation services, restaurants, and traditional banking. We also find important heterogeneous impacts of better Internet on employment shares within some specific sectors, such as finance, health, support services, retail and wholesale. Lastly, we observe that faster Internet increases local wage inequality.

Our findings suggest that quality improvements in communications infrastructure induce local structural transformation. In particular, faster Internet favors industries that use intensively information and communication technology (ICT) inputs, and that hire intensively workers that use ICT more. Hence, our results are consistent with the Rybczynski theorem from the Hecksher-Ohlin-Vanek (HOV) model (Rybczynski, 1955).[2] We also find that high-skilled workers sort into counties with

[1] Consider regions i, j, and k. Regions i and j are adjacent, while region k is far from both. Let trade costs between two locations be $\tau_{od} = t_o t_{od} t_d, \forall\, o, d \in \{i, j, k\}$ where $o \neq d$. A new road connecting i and j reduces trade costs τ_{ij} mainly through reductions in t_{ij}. Faster Internet in i reduces trade costs with both j and k via lower t_i.

[2] The Rybczynski theorem shows that higher endowments of one factor lead to a more than a proportional ex-

lower communication costs, which leads to the observed growth in sectors that hire these workers intensively. We find that migration plays an important role in this sorting mechanism.

Obtaining causal estimates of the impact of telecommunications infrastructure on local economic outcomes is challenging. On one hand, counties with better amenities or higher productivity attract more college-educated workers and productive establishments (Glaeser et al., 2004). Thus, Internet Service Providers (ISPs) may offer better service in these locations. On the other hand, counties with low competition among ISPs may provide lower-quality Internet, which may disincentivize establishments that need high-quality Internet to locate in these areas.

We circumvent these issues by using an instrumental variable approach. Our instrument is the distance of counties' centroids to the lines connecting ARPANET nodes,[3] a military research network that was the backbone of the Internet in its initial stage during the 1970s.[4] These lines represent the telecommunications equipment that connected ARPANET nodes. To build our instrument, we digitized ARPANET maps using historical government reports. We also talked with Bob Kahn and Vint Cerf, two of the *fathers of the Internet*, who worked on the design of ARPANET and helped us understand some of these maps. The ARPANET spatial structure allows us to analyze the causal impact of modern Internet quality on the local economy. We use ARPANET as our instrument, as we are not interested in the particular historical impacts of ARPANET in local economies.

Historical government reports help us document that the ARPANET structure satisfies the IV assumptions. First, the history of the Internet supports the relevance of our instrument. From 1969 to the early 1980s, ARPANET's physical infrastructure (both the nodes and the lines connecting them) was the backbone of the Internet. Due to path dependence of infrastructure (Duranton et al., 2014; Duranton, 2015), the old Internet backbone is a good predictor of the modern Internet backbone, whose location is not public.[5] Physical closeness to the modern Internet backbone allows ISPs to provide higher quality Internet at a lower cost.[6] Our data support the idea that locations closer to ARPANET lines have faster Internet offered to firms today.

pansion of the output in the sector which uses such factor intensively, and a decline of the output of the sector that does not use such factor intensively (Rybczynski, 1955).

[3] In computer networks, a node is a connection point in a network that is a processing device with an assigned address, as a router, computer terminal, peripheral device, or mobile device, (Encyclopedia.com, 2022).

[4] A backbone of a network is a high-speed network that connects low-speed local networks. A national backbone of the Internet refers to the high-speed network infrastructure that connects local networks in cities, companies, and universities, among others, across the country and the globe.

[5] There are two reasons for this. First, the information belongs to private companies, which are top-tier networks that maintain the Internet backbone equipment and provide service to last-mile Internet service providers (Xfinity, Comcast, etc.). Second, the Internet backbone's specific location is of national security interest. (Wall, 2021).

[6] The modern Internet backbone requires underground fiber optic infrastructure protected by an external layer called raceway or conduit. Installing a fiber network requires underground construction; thus, the closer a county is to an existing fiber network, the lower the underground construction costs are.

The instrument plausibly satisfies the exclusion restriction since the Department of Defense (DoD) decided the location of ARPANET considering military technology needs, contracting relationships between the DoD and academics, and characteristics of computer science departments. Commercial companies did not influence ARPANET. Moreover, we exclude counties with ARPANET nodes from our sample, and our instrument only uses the ARPANET lines. We expect our instrument to satisfy the exogeneity assumption since current productivity and amenities of counties are unlikely to be related to whether ARPANET lines are routed through these counties. This is because a straight line is the least cost way to connect two locations with physical infrastructure (roads, cables, etc.). Our data confirm that the presence of an ARPANET line in a county is uncorrelated with its share of high-skilled services in the 1970s, which also supports the exogeneity assumption. Lastly, our results are robust to excluding counties from six major metropolitan areas, including three California tech hubs (Boston, DC, Los Angeles, NYC, San Francisco, and San Jose).

Our instrument is related to Forman et al. (2012) and Jiang (2022). Forman et al. (2012) uses ARPANET nodes as an instrument for counties' private investment on the Internet to analyze how such investment impacted wages in U.S. counties between 1995 and 2000. Their instrument is weak because nodes were scarce and investment is lumpy. We adjust their instrument in different ways: we use the lines that connected the nodes as an IV, we drop the counties with these nodes, and we use the quality of Internet provision to businesses rather than Internet investment as the main treatment. Our instrument is valid and can be used for other cross-sectional analyses. Similarly, Jiang (2022) uses NSFNET nodes from the late 1980s, combined with the privatization of the Internet in 1995, to analyze how access to the Internet affects the spatial structure of manufacturing firms. Informed by history, we chose ARPANET lines instead of NSFNET nodes in our empirical framework. Historical sources suggest that NSFNET nodes' location is correlated with counties' productivity in the 1970s due to the incentives that the National Science Foundation (NSF) gave to universities who managed the nodes, while ARPANET nodes are not since their location was driven by military interests (Abbate, 2000; DARPA, 1981; Hauben et al., 1998; Leiner et al., 1997). Nevertheless, our approach does not contradict the identification strategy of Jiang (2022).[7]

We analyze two mechanisms: industry linkages and sorting of high-skilled workers with ICT-related occupations. First, better Internet benefits those sectors with a strong dependence on ICT inputs and workers who use them, while the impact on the other sectors is zero or statistically insignificant. Second, we find that faster Internet spurs immigration towards these counties and increases the

[7] Correlation between the location of NSFNET nodes and county productivity does not represent an identification issue for Jiang (2022). First, her variables of interest are outcomes for manufacturing firms, whose location determinants are likely to be unrelated to ICTs before the mid-1990s. Second, her framework requires changes between two spatial equilibria in the internal organization of these firms. Her empirical framework satisfies these assumptions. If researchers were to use her identification strategy to analyze the internal organization of services firms or county-level outcomes, some adjustments would be necessary to address identification issues.

number of workers in occupations related to ICT, such as management, business and finance, office and administrative support, engineering, and computer sciences. Interestingly, the sectors that have a greater abundance of these workers are the same sectors that are more favored by faster Internet speeds. In our heterogeneity analysis, we show that this sorting leads to an increase in earnings inequality, positively affecting the earnings of high-skilled workers, while not impacting the wages of low-skilled workers.

Our work has implications for infrastructure policies intended to reduce the digital gap via subsidies for Internet access can induce changes in the regional economic structure. Many nations use public funds to subsidize Internet access in rural or isolated areas. Some examples include Canada (Government of Canada, 2019), the U.S. (The White House, 2022), Germany (European Commission, 2022), and the U.K. (Hutton, 2022). Our results indicate that these subsidies may favor high-skilled workers in the favored regions.

Our findings relate to three international trade topics. First, our results are in line with the Rybczynski theorem predictions. We find that counties with faster Internet have more college-educated workers and a larger share of workers who are engineers, managers, and computer science professionals. Such counties have higher economic activity in industries that employ intensively workers with a college education or in the aforementioned occupations. Differently, sectors that employ these professionals less intensively have smaller sectoral shares (e.g., wholesale, branch banks, and food services). Second, our empirical results suggest the presence of capital-skill complementarities as the use of better Internet is likely to induce firms to purchase new ICT capital since the use of faster Internet requires newer devices. ICT capital is a complement for high-skilled workers who might become more productive in their tasks. Third, our results show the impact of globalization on local inequality: high-skilled workers benefit more in a county with lower communications costs.

Literature review. We relate to empirical work exploring the impacts of infrastructure on local outcomes (Coşar et al., 2022; Duranton et al., 2014; Duranton, 2015; Gertler et al., 2022). First, Coşar et al. (2022) show that highway upgrades increase trade flows and manufacturing employment. Second, Duranton et al. (2014) find that cities with more highways in the US specialize in the production of heavy goods, while Duranton (2015) documents that major roads induce Colombian cities to trade light goods. Third, Gertler et al. (2022) document that road maintenance raises local welfare in Indonesia. We complement these studies about road infrastructure by analyzing how telecommunications infrastructure quality impacts industry composition and inequality.

Our study relates to classical studies on HOV model tests using aggregate data (Leontief, 1953; Leamer, 1980; Deardorff, 1984; Bowen et al., 1986; Trefler, 1995; Harrigan, 1997; Davis and Weinstein, 2001). Our approach differs in four ways. First, we focus on communication costs that affect regional trade with other regions and the rest of the world. Second, our context varies from cross-national studies since products between *counties* are likely to be competing goods, while this is not necessarily the case for trade between developing and developed nations. For example, a craft beer from the rural county of Hanover, VA, competes with a beer produced in the City of Richmond, VA. Third, we include traded and non-traded services sectors. To some extent, we could argue that many non-traded service sectors can be traded between regions within a country since people travel to nearby locations to acquire them. Fourth, we complement previous work by not including restrictive assumptions on production, technology, or exports in our regional analysis.[8] Our work also differs from studies that test the HOV model predictions based on trade liberalization in developing nations (Atolia, 2007; Esquivel and Rodrıguez-López, 2003) since we analyze a reduction in communication costs in U.S counties.

Furthermore, our work relates to studies on how both technological change and trade increase the use of capital that complements high-skilled workers, thus impacting inequality. This work includes structural models (Burstein et al., 2013; Parro, 2013), reduced-form analysis of trade liberalization in developing nations (Verhoogen, 2008), and historical evidence from the early 1900s in the U.S. (Goldin and Katz, 1998). We add to the previous literature by providing causal estimates of how ICT-related capital impacts local inequality in U.S. regions.

For the infrastructure literature, the closest study to our work is Michaels (2008). He finds that the construction of the US Interstate Highway System increased the demand for skilled labor in skilled-abundant counties. His results are consistent with some predictions of the HOV model. We complement his work by studying a continuous measure of communication infrastructure rather than a single road infrastructure project. Contrarily from us, Michaels (2008) does not find conclusive evidence that highways changed the local industrial composition. Moreover, we find that better infrastructure quality has heterogeneous effects within the same broad sector, as are the cases of finance and health services.

Our paper also has similarities with Akerman et al. (2015), who study the skill complementarity of access to broadband Internet in Norway between 2000-2008. We complement their work in at least four dimensions. First, our research focuses on how Internet quality provision impacts local growth and structural transformation, while their work focuses exclusively on how Internet access affects labor markets. Second, we focus on significantly more advanced stages of Internet technology.[9] Moreover, the period analyzed by Akerman et al. (2015) is before the arrival of

[8] Several tests of the HOV model have attempted to relax many strong theoretical assumptions, but they still require some, such as constant returns of scale, non-joint production, or exogenous prices as in Harrigan (1997); or similar production functions across nations, exports level is expressed as a proportion of the purchasing country's GDP, and factor price equalization as in Davis and Weinstein (2001).

[9] The Internet speeds analyzed by Akerman et al. (2015) can be considered obsolete today. For example, Zoom video calls require a speed of around 550 Kbps, twice the broadband definition in the early 2000s (256 Kbps). The

key Internet products, such as online retail, teleconferencing, and cloud services, which impacted substantially the services sector. Finally, our results are also relevant to the HOV model, not only to capital-skill complementarity.

We relate to the economic geography literature that explores how infrastructure affects specialization at the regional level using structural models (Fajgelbaum and Redding, 2022; Sotelo, 2020; Baldomero-Quintana, 2022). Other studies consider how infrastructure affects welfare and aggregated outcomes leaving the sectoral impacts aside (Alder, 2016; Allen and Arkolakis, 2022; Allen and Atkin, 2016; Asturias et al., 2019; Bonadio, 2016; Donaldson, 2018; Donaldson and Hornbeck, 2016; Faber, 2014). We complement this literature by providing causal evidence that the quality of infrastructure impacts local specialization from a purely empirical standpoint, without making functional form assumptions on production, preferences, or trade costs.

We relate to work in spatial economics on the effects of communication costs and ICT. This includes work on ICT and agglomeration (Charlot and Duranton, 2006; Gaspar and Glaeser, 1998; Glaeser and Ponzetto, 2007; Malecki, 2002; Lin, 2011; Zook, 2002); Internet and real estate prices (Ahlfeldt et al., 2017; Ford et al., 2005a; Dietzel, 2016; Beracha and Wintoki, 2013); and communication and innovation (Carlino et al., 2007; Kantor and Whalley, 2019; Rosenblat and Mobius, 2004). We complement this literature by focusing on the Internet and local economic structure.

Recent work has explored how communication costs impact firms' entry, performance and structure (Arfi and Hikkerova, 2021; Acosta and Lyngemark, 2020; Beem, 2022; Forman and Van Zeebroeck, 2012; DeStefano et al., 2022; Marinoni and Roche, 2022), and trade flows (Fink et al., 2005; Allen, 2014; Freund and Weinhold, 2004; Blum and Goldfarb, 2006; Breinlich and Criscuolo, 2011; Juhász and Steinwender, 2018; Steinwender, 2018; Cristea, 2011). We complement these studies in two ways. First, we document empirically that the quality of communications infrastructure (intensive margin), and not only access (extensive margin), impacts local economic outcomes. Second, we study regional economic specialization, while previous work focuses on trade or firm outcomes.

We share similarities with Forman et al. (2012) and Jiang (2022), but our research questions differ substantially. Forman et al. (2012) focuses on the impacts of private Internet investment on local labor markets in the late 1990s, finding no impacts. Our results differ since we analyze a period of study when the Internet is a highly adopted technology that experienced major changes since the 2000s.[10] Our study is related to Jiang (2022), who finds that the spatial organization of

average Internet speed in 2019 (100 Mbps) was 390 times faster than these older broadband definitions.

[10]Internet speeds have increased exponentially since the 2000s. Connections used in the 1990s were based on dial-up with download and upload speeds of at most 56 Kpbs. The average speeds in US counties in 2018 were between 2 and 671.1 Mbps for download and between 1.1 and 615.7 Mbps for upload. If we focus on the lower bounds, speeds were 17 to 35 times faster in 2018 relative to the 1990s. Moreover, social media and modern search engines changed markets, including housing, retail and labor markets (Dietzel, 2016; Beracha and Wintoki, 2013;

manufacturing firms changed when they accessed the Internet after 1995. Our results complement hers since we find that counties with better Internet have higher activity in some manufacturing and service sub-sectors.

The rest of the paper proceeds as follows. In Section 2, we document the history of the Internet. Such historical context informs our empirical strategy. In Section 3, we describe our data and present descriptive statistics. Section 4 presents our empirical model, including our identification strategy. In Section 5, we present the results of the paper, together with the two mechanisms proposed that can explain such results. Section 6 concludes.

2 Context: The History of Internet

In this section, we document the origins of the Internet. We provide information on ARPANET, the first network to operate as the Internet backbone. We also present facts about the National Sciences Foundation network, NSFNET, which took over the functions of ARPANET in the late 1980s. Our historical context supports the idea that the location of ARPANET nodes and connecting lines is exogenous to county productivity, while NSFNET nodes are not. In addition, we document that ARPANET network was the first backbone. Thus, it is a good predictor of Internet speeds in the U.S., as Figure 1 shows.

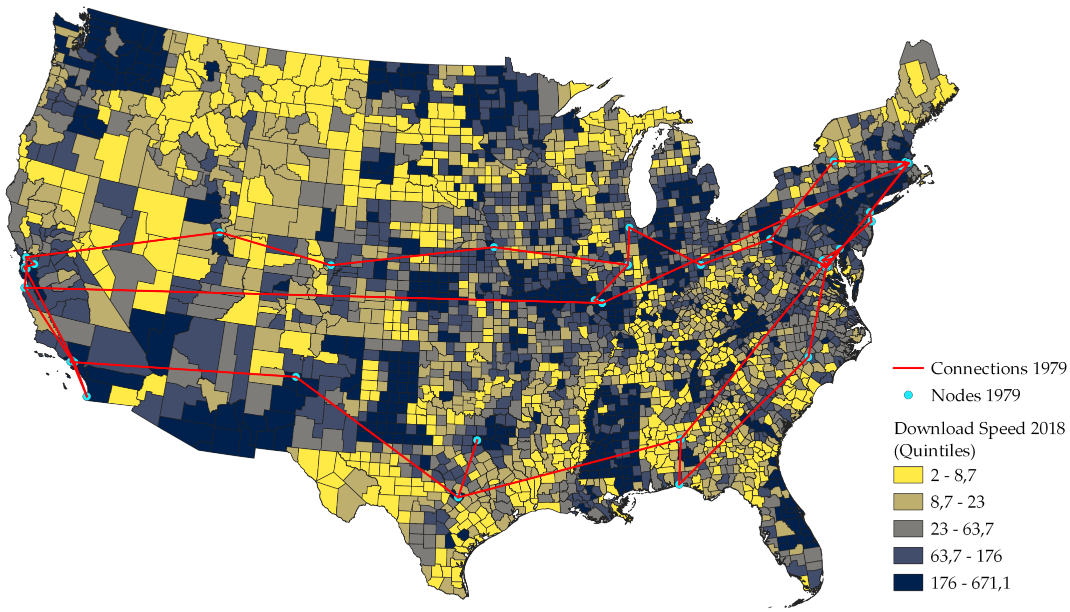
Origin of ARPANET. ARPANET was a research project financed and developed by DARPA, a research office of the DoD. DARPA's objective was to create a network that connected military computers. Two factors drove the financing of the project. First, the DoD had a strong interest in financing research after the Soviet Union launched its first satellite, Sputnik. Second, the DoD wanted to lower administrative costs by allowing its computers to share data. In the early 1960s, the DoD had thousands of computers operating autonomously without any connection, which generated large costs since all data files and software had to be reprogrammed in every device. In addition, military personnel had to be trained to use devices from different manufacturers. These costs doubled the DoD's budget for software creation and maintenance (DARPA, 1981).

DARPA hired a reputable computer science researcher to build a computer network: Dr. J.C.R. Licklider. He proposed a novel idea at the time: the use of computers to improve human communication (Licklider and Taylor, 1968). In the 1960s, computing firms and most U.S. academics focused on improving the speed of computers to complete tasks, a concept known as batch processing (Hardy, 1980). This situation incentivized Dr. Licklider to shift all research computer research contracts away from private companies and towards academic departments interested mainly in computer network research. Thus, DARPA established DoD contracting relationships with some

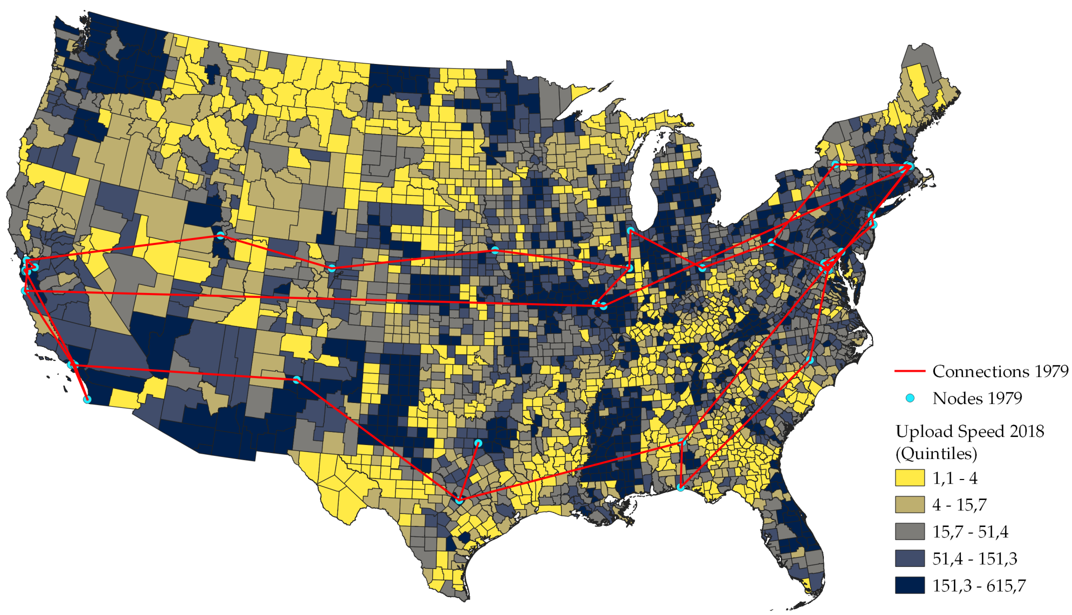
Ford et al., 2005b; Oestmann and Bennöhr, 2015; Cavallo, 2018; Dingel and Neiman, 2020).

Figure 1: ARPANET Connections in 1979 and 2018 Internet Speeds

Panel A: Download Internet speeds offered to businesses



Panel B: Upload Internet speeds offered to businesses



Note: these figures show the mean download and upload speeds offered by Internet service providers to businesses in every U.S. continental county (i.e., different from the Internet service offered to households). Blue counties belong to the top quintile, while yellow counties are in the lowest quintile. The figures also display the ARPANET nodes and lines (which represent the connections between nodes) for April 1979. Source: FCC and Cerf and Khan (1990).

computer research departments at U.S. universities. Consequently, commercial interests played no role in the design and development of ARPANET (DARPA, 1981).

The main idea behind ARPANET and the Internet was to connect independent local networks (DARPA, 1981; Leiner et al., 1997): if one local network was lost, the system continued working. ARPANET demanded novel technological resources: specific software to define a protocol (set of rules for data transmission) and equipment to guarantee the stability and delay of a network (the time for a signal to traverse a network). During the late 1960s, prior to the first ARPANET connection in 1969, DARPA researchers focused on solving these technical issues. Notably, the existing telephone infrastructure was insufficient for ARPANET. [11] The first four ARPANET nodes were connected in 1969. These nodes were research centers with DoD contracts and were chosen due to specific technical expertise.[12] The network was declared fully operational in 1971. Figure A-1 presents the original description of the network as described by Vint Cerf and Bob Kahn (two ARPANET researchers that are part of the list of the *fathers of the Internet*) in 1969.

In the 1970s, ARPANET required DoD's resources and well-coordinated frontier engineering expertise (DARPA, 1981; Hauben et al., 1998; Leiner et al., 1997). Academic researchers solved novel engineering issues frequently. Researchers working on ARPANET collaborated intensively even if they belonged to different universities and their engineering documentation was open (Leiner et al., 1997).[13] Thus, the location of ARPANET nodes also depended on the work style of computer science departments: uncooperative computer science departments were less likely to be a part of ARPANET.

To summarize, three factors influenced the location of ARPANET nodes. First, in the 1970s only universities with DoD contracts were connected to ARPANET (Abbate, 2000). Second, universities with a research agenda focusing on networks were more likely to participate in ARPANET, while computer science departments that focused on batch processing–predominant across U.S. universities–were unlikely to participate in the network (Hauben et al., 1998). Third, collaborative computer science departments were more likely to join the project. Thus, we conclude that the location of ARPANET nodes in the 1970s was driven by factors unique to national defense and computer science departments (DARPA, 1981).

From ARPANET to NSFNET. In the early 1980s, only nodes related to national defense com-

[11]In 1966-1967, an MIT laboratory and the military contractor SDC in Santa Monica, CA, connected two computers using the existing telephone circuit technology. The experiment proved that existing telephone infrastructure was insufficient to establish a good quality network (Hauben et al., 1998; Leiner et al., 1997).

[12]These four nodes correspond to the University of California—Los Angeles, University of California–Santa Barbara, Stanford Research Institute, and the University of Utah.

[13]ARPANET's technical notes about engineering network design were key for the network's success. The notes were open to the public even if the DoD financed the network (Leiner et al., 1997; Hauben et al., 1998). Collaboration and open documentation helped ARPANET researchers to develop fast solutions for engineering issues.

puting research or operations were connected to the Internet. The situation was different in the late 1980s: the backbone was transferred from military to civilian control, and Internet users included universities, private companies, and federal agencies (Abbate, 2000). Five events influenced this change. First, DoD created a separate military computing network in 1983, MILNET. Afterward, ARPANET did not transmit military data, although some military research centers were connected to the network for scientific purposes. Second, NSF founded NSFNET, a national network of regional academic networks. Third, DARPA and NSF collaborated to connect ARPANET and NSFNET. Fourth, NSF encouraged NSFNET regional networks to provide Internet service to commercial companies. Fifth, ARPANET transferred the role as the backbone of the Internet to NSFNET in 1988 and was decommissioned in 1990 (Abbate, 2000; Leiner et al., 1997).

During the 1980s, ARPANET opened its network to more academic centers.[14] DARPA wanted more academics to use the technology and transferred the backbone responsibilities to another group (DARPA, 1981). In 1981, a consortium of universities requested a grant from the NSF to create CSNET, an academic network implemented between 1981 and 1984. In 1981, DARPA signed a cooperative agreement with CSNET to share ARPANET's infrastructure (McKenzie and Walden, 1991; Leiner et al., 1997). To connect to CSNET, NSF agreed to provide resources, but each university or research center would independently manage its internal network.

In 1985 NSF started building NSFNET, a national network that connected regional networks created by universities[15]. NSFNET was built onto the CSNET infrastructure. The new network created a two-tier system: NSFNET regional networks and a national backbone network connecting them. The construction of NSFNET took three years (Abbate, 2000). In 1986, NSF and DARPA made an agreement to guarantee that ARPANET and the regional NSF networks had interoperability (Leiner et al., 1997). Later, in 1987, the NSF reached an agreement to use ARPANET resources to connect regional networks in exchange for sharing ARPANET's operating costs (Abbate, 2000). The NSFNET national network started functions in 1988.

Determinants of the location of NSFNET. The NSFNET regional networks (nodes) were subject to commercial interests due to the incentives imposed by the NSF during its creation. First, the regional networks had to be financially autonomous within three years of receiving funding. Second, NSF encouraged regional networks to find commercial clients (Leiner et al., 1997). Although Federal law prohibited commercial companies to use the NSF national backbone (U.S. Congress,

[14] The Internet is *de facto* a network of local networks. It is divided in three tiers. The upper tier is considered a backbone because it reaches all local networks.

[15] The regional networks were BARRNET for the San Francisco Area, MIDNET in the Midwest, WESNET in the Rocky Mountain region, USAN for those research centers connected to the National Center for Atmospheric Research, NORTHWESTNET in the Northwest, NYSERNET in the New York state area, SESQUINET in Texas, SURANET in the Southeast. NSFNET also connected large computer centers in San Diego, the University of Illinois, and Pittsburgh.

1992), private companies could connect to regional networks (Leiner et al., 1997; McKenzie and Walden, 1991). This scheme was implemented as the NSF had the objective that private firms would create national networks (Leiner et al., 1997). Although commercial networks emerged, no national private backbone appeared until the privatization of NSFNET in 1995.

The NSF financing scheme implied that only universities (or groups of institutions) would create a regional network or node in a region if they had economies of scale. A university could reach economies of scale if it had productive firms nearby, the institution was large, or the college had other institutions nearby. Such factors are plausibly correlated with the productivity of regions. Thus, the presence of NSFNET nodes and local productivity could be correlated.

NSFNET as Internet backbone and its privatization. In the late 1980s, the growth of Internet users made ARPANET's physical infrastructure obsolete as the Internet backbone. Thus, DARPA planned the decommissioning of the network, and NSFNET overtook ARPANET as the Internet backbone (McKenzie and Walden, 1991; Abbate, 2000). The protocol designed by Vint Cerf and Robert Kahn for ARPANET made the transition smooth (TCP/IP). Between 1988 and 1989, DARPA sites transferred their host connections from ARPANET to NSFNET, and in February 1990, ARPANET was officially decommissioned (Abbate, 2000). Independent commercial networks began to grow in the 1980s and 1990s due to the NSFNET regional network services provided to private firms (Abbate, 2000). In 1995, the NSF transferred the NSF national backbone to private companies. Harris and Gerich (1996) documents the technical details of this transition.

The history of the Internet allows us to reach three conclusions, which will be helpful for our empirical strategy. First, ARPANET was not influenced by commercial interests but rather by military ones. Second, the location of nodes was driven by DoD contracts and the research agenda and work philosophies of computer science departments in the 1960s and 1970s. Third, NSFNET regional networks were influenced by commercial interests. Thus, NSFNET nodes are likely to be correlated with local productivity, while ARPANET nodes and the lines connecting them are not.

3 Data

Our data comes from four main sources: the US Census Bureau, the Bureau of Economic Analysis (BEA), the Federal Communications Commission (FCC), and historical maps created by the DARPA office at the DoD. In this subsection, we describe in more detail each of these data sources. Afterward, we show some descriptive statistics for the main variables of interest.

Internet data. To capture the current quality of the Internet offered to businesses, we use data from the FCC for 2014 and 2018.[16] These data come from FCC's Form 477, which must be filled by all broadband providers twice a year to report the list of census blocks in which they offer a particular technology (Federal Communications Commission, 2019). Therefore, the data contain for each census block, a list of all Internet providers, together with the offered technology of transmission to firms (e.g., cable modem, xDSL, fiber, fixed wireless, etc.), the maximum advertised download and upload speeds/bandwidth (for consumers) and the maximum contractual download and upload speeds/bandwidth (for businesses) for each technology.[17] From these data, we keep only those providers and technologies offered to businesses, which we use to compute the mean and median download and upload speeds for each county.

Current Economic Activity. We use employment counts and aggregate payroll by county and sector from the Census Bureau's 2014 and 2018 County Business Patterns (CBP). The CBP includes the number of establishments and employment for every county during the second week of March, as well as the annual payroll. We compute the average wage within counties as the ratio between annual payroll and total employment. The CBP data also contain information by NAICS (North America Industry Classification System) sector, up to 6 digits. However, due to confidentiality restrictions, a data point is only published if it contains at least three establishments. Thus, to minimize the number of missing values arising from these restrictions, we use sectoral data at the 2- and 3-digit NAICS code.[18] For each sector, we compute the share of employment and payroll in each sector within each county. Such shares represent proxies that measure the industrial specialization or composition of a county. We complement these data with information on each county's GDP in 2018 (total and by 2-digit NAICS code) from the BEA and with decadal county-level population between 1900 and 2020 from the US Census Bureau.

ARPANET. For our instrumental variable, we digitized images of decommissioned DoD documents that contained ARPANET maps. In 1990, Vint Cerf and Robert Kahn (Internet pioneers) collected these maps and published them in the Journal of the Association for Computing Machinery (Cerf and Khan, 1990), and are only available in the physical version of the journal. These maps include the abbreviated name and the location of the nodes, and the lines connecting them, which

[16] We use these two years for three reasons. First, the FCC started publishing these data in December 2014; hence we cannot obtain Internet speed measures at the county level from the FCC before this year. Second, when we downloaded the data in early September 2022, some Internet technologies were missing in the 2019 FCC files. Our hypotheses are that there were either changes in their methodology or pending updates in the data. Since we did not find any documented reason for these missing data, we do not use data from 2019. Third, we avoid using data for 2020 as the COVID-19 pandemic substantially altered the demand and supply of the Internet due to the boom of working from home. In addition, the local economic structure was also impacted by the pandemic since some services sectors were negatively impacted and manufacturing industries experienced a boom in 2020-2021, while the opposite occurred in 2021-2022. Thus, we chose 2018 as our base year.

[17] Download speed corresponds to the speed used to download data from a server to a computer in the form of text, files, audio, images, videos, etc. On the other hand, upload speed refers to how fast information can be sent (in the form of text, audio, images, etc.) from a computer to another device connected to the Internet.

[18] The full list of 2-digit NAICS sector is included in Table A-1 in the Appendix.

represent the infrastructure connecting ARPANET nodes. As the name of the nodes is not available in the journal (only their abbreviation), we used DoD historical reports and other historical sources to find the exact address of some of the nodes (Network Information Center, SRI International, 1978; DARPA, 1981; Hauben et al., 1998). We also talked with Vint Cerf and Bob Kahn, who shared their knowledge about the ARPANET network, including the name and location of those nodes whose information was not in historical government reports. Figure 2 shows the original and the digitized maps for 1979. Using the exact location of the nodes and their connecting lines, we compute the minimum distance between each county's centroid and one of the lines, together with an indicator variable that equals 1 if a county contains a node (and 0 otherwise) and another that equals 1 if a line is routed through it.

Descriptive statistics. In Table 1, we present the average and median values for some of the variables of interest. Regarding local sectoral structure, around half of employment and total payroll in the average county is generated in the *Other services* category, which includes *Wholesale and Retail Trade*, *Administration and Support*, *Construction*, *Accommodation and Food Services*, and similar. A third of the counties' employment on average is in *High-skilled services*, which includes *Information Services*, *Management*, *Professional Services*, *Educational Services*, and similar. *Manufacturing* accounts for approximately 15% of the employment on average. For all variables, the mean and the median share of sectoral employment are quite similar. Figures A-3 and A-4 show the spatial distribution of these sectoral shares across the U.S. For the case of Internet quality provision, the average download and upload speeds offered to firms in a US county are 97 and 86 megabits per second (Mbps), respectively. Finally, in 1979 only 1% of counties had an ARPANET node, while 14% had a line going through, and the average county was 192km away from a line.

4 Empirical Model and Identification

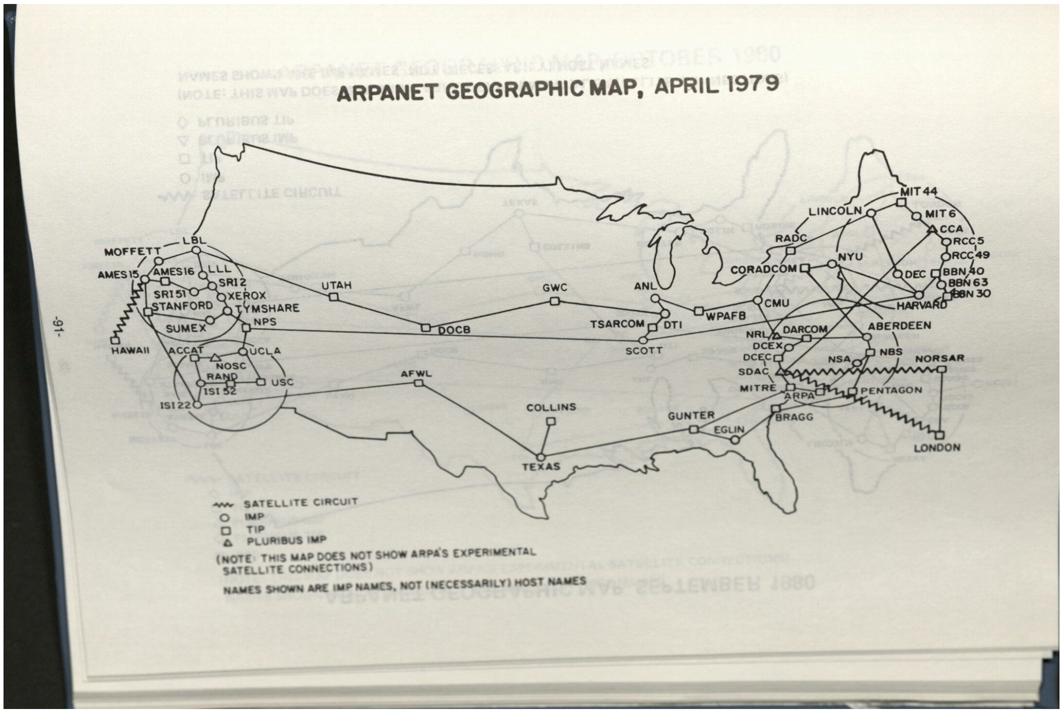
In this section, we discuss the empirical framework we use to estimate the effects of the quality of Internet provision on the current local economic structure. Moreover, we examine the use of ARPANET lines as an instrumental variable, and we assess the assumptions we need to interpret our results as causal. To measure the effects of Internet quality on modern county short-run economic growth and local structural transformation outcomes, we estimate the following model:

$$Y_c = \alpha + \beta\, log(InternetQuality_c) + X_c'\Theta + \epsilon_c \tag{1}$$

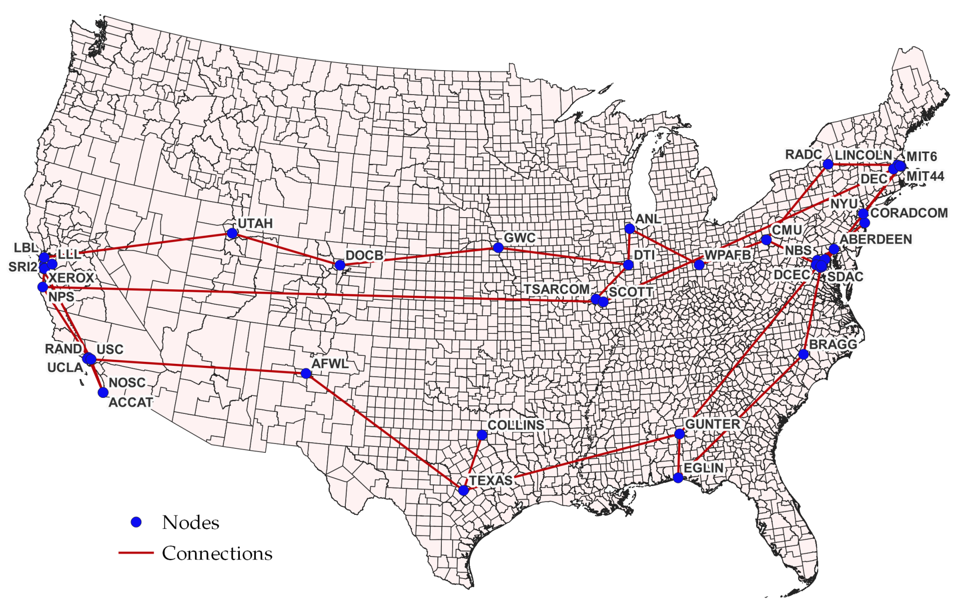
where Y_c is a local economic outcome in county c, such as the 4-year growth rate of real GDP or employment (between 2014 and 2018), the 30-year population growth rate (since 1900 to 2020), or the share of employment in a particular sector in 2018. Moreover, $InternetQuality_c$ is a measure of Internet speed offered to businesses (average download or upload speeds) in county c in 2014 (for

Figure 2: Structure of ARPANET as of 1979

Panel A: Original Map



Panel B: Digitized Map



Note: Panel A displays a scanned image of the ARPA network as of April 1979. The map was created by Vint Cerf and Bob Khan, Internet pioneers. Panel B displays our digitized version of the same map. Source. Cerf and Khan (1990)

Table 1: Descriptive Statistics

Category	Average across Counties	Mean	Median
Current Economic Activity	Share agriculture & mining employees	0.02	0.00
	Share manufacturing employees	0.15	0.12
	Share high-skilled services employees	0.30	0.29
	Share other services employees	0.53	0.52
	Share agriculture & mining payroll	0.04	0.00
	Share manufacturing payroll	0.19	0.16
	Share high-skilled services payroll	0.33	0.32
	Share other services payroll	0.44	0.42
	Total GDP (millions)	109.7	106.2
	Total Employment	40,116	6,557
	Total Payroll (millions)	2,178	248
	Average Wage (thousands)	39.72	37.83
	Growth GDP (4 year)	4.64%	3.95%
	Growth Employment (4 year)	2.99%	3.04%
	Growth Payroll (4 year)	7.54%	7.70%
	Growth Wage (4 year)	4.30%	4.22%
Internet Speeds	Mean download speed offered to firms in 2018 (Mbps)	96.44	38.87
	Mean upload speed offered to firms in 2018 (Mbps)	85.92	27.86
	Mean download speed offered to firms in 2014 (Mbps)	49.72	21.53
	Mean upload speed offered to firms in 2014 (Mbps)	36.73	6.13
ARPANET	Distance to ARPANET lines in 1979 (km)	191.82	119.57
	Had node in 1979	0.01	0.00
	Had connection line in 1979	0.14	0.00

Notes: This table shows the mean and the median of our variables of interest averaging across all counties in the continental US. Variables regarding current economic activity and Internet speeds correspond to 2018. Speeds are measured in Megabits per second (Mbps). High-skilled services include information; finance and insurance; real estate services; professional, scientific and technical services; management of companies and enterprises; educational services; and health care and social assistance. Other services include utilities; construction; wholesale trade; retail trade; transportation and warehousing; administrative and support and waste management and remediation services; arts, entertainment and recreation; accommodation and food services; and other services. GDP growth corresponds to the 4-year growth of the "Real GDP in chained Dollars" series from the BEA. Payroll and wage growth corresponds to the 4-year growth of these variables as given by the 2014 and the 2018 County Business Patterns; the 2014 series were deflated using the national CPI from March 2014.

growth regressions) or in 2018 (for levels); ϵ_c considers the unobserved factors that impact local economic outcomes, such as productivity in county c.[19] In all our specifications, we exclude from our sample any county that had at least one ARPANET node.

The group of control variables (X_c') includes several geographic characteristics, including dummy variables that equal one if the county lies next to the Canadian or Mexican border since the local economy in such counties might depend on these neighboring countries (Hanson, 1996); a dummy variable that equals one if the county lies along the coast of an ocean or a Great Lake; average slope and elevation, and total land and water area, as geography could determine the costs of infrastructure provision. We also include the distance from the county to the centroid of the nearest metropolitan statistical area as a measure of market access as in Michaels (2008); population density as a measure of agglomeration economies; and the population growth rate between 2014 and 2018. Our main parameter of interest is β, which identifies the semi-elasticity of a local economic outcome with respect to the quality of Internet provision across U.S. counties.

The estimation of equation (1) does not yield causal estimates due to the endogeneity between the variables of interest. For instance, counties with higher productivity or better amenities might grow faster and have a larger share of GDP coming from high-skilled services as these counties can attract more productive service establishments and workers. Hence, the willingness to pay for a better Internet in these counties is higher, and ISPs will provide better Internet. Thus, $\hat{\beta}$ would be upward biased. On the other hand, counties with better environmental aesthetic amenities (e.g., rivers, mountains, lakes) might attract more high-skilled workers, which would generate incentives for ISPs to provide high-speed Internet. At the same time, such amenities could make it more difficult to build physical telecommunications infrastructure, thus lowering the quality of local Internet provision. In this case, $\hat{\beta}$ would be downward biased.

To recover the causal estimate, we follow an instrumental variable approach using the spatial structure of ARPANET in 1979 (years before the Internet had commercial viability) as the source of exogenous variation.[20] As we document in Section 2, the decisions about the location of the nodes, and thus the spatial structure of ARPANET, was determined by whether (i) the researchers in academic institutions were contractors for the DoD through its ARPA agency in the 1960s; (ii) the research agenda of the institution was more focused on networks, instead of batch-processing, which was the main paradigm at the time; and (iii) the work style of the computer science departments was of a collaborative nature.

[19] In all the estimations we use Spatial Heteroskedasticity and Autocorrelation Consistent (SHAC) standard errors as proposed by Conley (1999) with a ratio of 28.55km, which correspond to the ratio of a circle that would cover the surface of the median metropolitan statistical area in the U.S.

[20] The first private Internet Service Provider, The World, appeared in 1989.

Hence, due to historical reasons, it is unlikely that the nodes of ARPANET were selected only in counties with the highest productivity levels. Moreover, the presence of a university does not guarantee high levels of productivity. For example, Rust Belt cities that experienced major losses in amenities and productivity have universities e.g., Detroit, Flint, Camden, Youngstown, Toledo, or Dayton. Moreover, we select the status of the network in 1979, when ARPANET only connected DoD contractors, and it was still under military management (Abbate, 2000). This selection guarantees that the structure of ARPANET was more closely related to the research interests of the DoD and the work styles and research agendas of academic departments with which it had contracting relationships. In addition, to avoid remaining concerns, we exclude from our main estimations those counties that had an ARPANET node in 1979. Exploiting the spatial structure of ARPANET, our first stage is defined by

$$log(InternetQuality_c) = a + b \cdot ARPANET_c + X_c'\Gamma + \nu_c \tag{2}$$

where $ARPANET_c$ denotes the log of the minimum distance between county's c centroid and an ARPANET connection line, which were presented in Figure 2. Since government reports and maps do not contain information on the exact location of the physical infrastructure used to connect the nodes, straight lines that mimic the maps of ARPANET (e.g., Figure 2) are our proxy for such physical infrastructure. Given that ARPANET had specific network requirements (reliability and delay) to guarantee interconnection quality between computers, the physical infrastructure connecting the nodes must have been of the highest quality at the time. We estimate different specifications of equation (2) using other instruments, including a dummy variable that equals 1 if a connection line crossed county c, and distance categories to the closest line.

Our identification strategy has a similar logic as Duranton et al. (2014) and Duranton (2015), who use historical routes in the U.S. and Colombia as instruments for the location of modern roads. Due to infrastructure cost reasons, it is easier to build contemporary highways following historical paths. Similarly, it's easier to build the modern Internet backbone on historical ARPANET infrastructure (Abbate, 2000; Leiner et al., 1997; McKenzie and Walden, 1991) because a physical Internet backbone requires an underground optic fiber. In addition, it is cheaper for ISPs to provide high-quality Internet to counties near the modern backbone in the same way that it is cheaper for a construction company to physically connect a county closer to the Interstate Highway System. Since counties closer to ARPANET lines–representing the old Internet backbone–are more likely to be closer to the modern Internet backbone, ISPs are more likely to offer higher Internet speeds in such counties.

A potential concern about our instrumental variable is that the ARPANET connecting lines are located along other types of infrastructure, such as highways or railways. Therefore, we would not be capturing the effect of ARPANET but of these ways. In Figure A-5, we present the maps of the ARPANET network in 1979, together with the primary US roads and the railroad infrastructure in 2019. As the figure shows, there seems to be no correlation between these types of infrastructure.

Our strategy also has similarities to Forman et al. (2012), who use the presence of ARPANET nodes in a county as an instrument for Internet investment by businesses, and to Jiang (2022), who uses the location of NSFNET nodes in a DiD framework. Using only the location of the nodes produces a weak instrument since nodes are scarce (less than 1% of counties had a node). Instead, we use the connection between the nodes as an instrument for the average reported Internet speeds of providers to the FCC within a county, which arguably produces a stronger instrument. We do not consider NSFNET nodes since historical evidence suggests they could be endogenous in a cross-sectional empirical framework that considers geographical areas as the unit of observation.[21] Therefore, we use the ARPANET historical documentation maps from 1979 for our empirical strategy.

We choose 1979, a year when ARPANET had no connections nor shared resources with NSFNET or its predecessor, (Abbate, 2000; McKenzie and Walden, 1991). We consider that our instrumental variable is relevant since ARPANET is the first precursor of the Internet. The main backbone of the Internet relied on ARPANET nodes and lines from the 1970s and 1980s (Leiner et al., 1997). It is likely that modern backbones took advantage of existing underground infrastructure, in the same logic as the path dependence of roads as in Duranton et al. (2014) and Duranton (2015).

As Figure 1 shows, the data support the relevance of our instrument. Counties crossed by ARPANET lines seem to have better Internet quality as of 2018, both download and upload speeds. We formally test the relevance of our instrument by estimating different specifications of equation (2) using OLS. In particular, Table 2 validates the previous results, even after including the vector of control variables. Notice that those counties that had an ARPANET node in 1979 have Internet speeds that on average double those in counties without a node (Panel A); however, less than 1% of counties had a node, which would render a weak instrument as in Forman et al. (2012). Similarly, counties that had an ARPANET connection line in 1979 have download and upload speeds that are 27% and 38% higher in 2018, respectively, relative to counties without a line (Panel B). Notably, counties farther away from a 1979 ARPANET line have lower Internet speeds (Panel C). In particular, a 10% increase in distance is correlated with speeds that are between 1.3% and 1.8% lower. This negative relationship with distance holds if we consider distance categories instead of a continuous measure (Panel D). These results support the relevance of our instrumental

[21] NSF encouraged local NSFNET regional networks to provide service to private companies. Due to increasing returns to scale, only some universities created NSFNET regional networks. Most likely, the ones where there was an abundance of private companies that needed advanced telecommunications services in the 1980s, which would threaten causal identification in county-level cross-sectional regressions. Nonetheless, NSFNET nodes can be used as IV for firm-level outcomes like the ones in Jiang (2022).

variable.[22]

The structure of ARPANET as an instrumental variable satisfies the exclusion restriction. In other words, ARPANET impacts the local economic structure in U.S. counties exclusively through modern Internet speeds. Based on the history of the network, it is unlikely that the nodes chosen by the DoD through contractor processes, academic research agendas (interested in network research or not), and research work styles in the 1960s (collaborative or uncooperative) are related to productivity or amenities in counties today. Moreover, the presence of a university does not guarantee high levels of productivity and amenities (e.g., Detroit, MI, Camden, NJ). The agenda and collaboration style of computer science departments depend on their internal dynamics, and their contracting relationships depend on professional networks. Moreover, national defense computing research locations were decided purely based on the interests of DARPA and the DoD. Lastly, to guarantee that the exclusion restriction is satisfied, we drop from our samples any counties with ARPANET nodes.

Our instrumental variable is unlikely to be correlated with omitted variables that influence local economic structure; that is, it satisfies the exogeneity assumption. Using ARPANET lines connecting the nodes instead of the nodes themselves supports this assumption. Even if there are remaining concerns that the ARPANET nodes are located in counties with high amenities or productivity, the lines that connect them are likely to be exogenous to such unobserved factors. For example, an ARPANET line connects the Argonne National Laboratory in Argonne, IL, to the Wright-Patterson Air Force Base in Green County, OH. Such line passes over several Indiana counties, including Wabash County. Even under the strong assumption that military nodes in Argonne, IL, or Green County, OH, were selected due to the high productivity of the counties, the line passing over Wabash County, IN, is exogenous to the productivity of these counties with nodes. The lines themselves predict the location of the ARPANET backbone, which itself predicts the geographical layout of the equipment that forms the modern Internet backbone. In Table A-4, we show that even though the location of the nodes in 1979 is strongly correlated with the share of employment in high-skilled and business services in the 1970s, whether a county is crossed by a connection line is not correlated by such shares.

Our last concern for identification is whether our strategy satisfies the Stable Unit Treatment Value Assumption (SUTVA). In our case, SUTVA implies that potential outcomes for a given county respond only to its own Internet quality and are unrelated to the treatment status of other counties. Due to engineering-related reasons, the local provision of the Internet does not directly

[22] These results are robust if we use the 1988 structure of ARPANET instead of the 1979 structure or if we use Internet speeds in 2014 instead of speeds in 2018. Both sets of results are presented in Table A-2 and Table A-3, respectively.

Table 2: **OLS Estimates**. The Impact of ARPANET on Current Internet Speeds Offered to Businesses

***Panel A**: County has a node*	Mean download speed		Mean upload speed	
	(1)	(2)	(3)	(4)
Had node in 1979	1.314***	0.900***	1.605***	1.083***
	(0.154)	(0.183)	(0.166)	(0.196)
Constant	3.599***	3.881***	3.236***	3.593**
	(0.039)	(1.315)	(0.046)	(1.478)
***Panel B**: County has a line*	Mean download speed		Mean upload speed	
	(1)	(2)	(3)	(4)
Had connection line in 1979	0.352***	0.271***	0.468***	0.380***
	(0.079)	(0.078)	(0.090)	(0.089)
Constant	3.551***	3.504**	3.174***	3.127**
	(0.041)	(1.362)	(0.048)	(1.532)
***Panel C**: Distance to a line*	Mean download speed		Mean upload speed	
	(1)	(2)	(3)	(4)
Distance to Line in 1979	-0.168***	-0.132***	-0.213***	-0.184***
	(0.026)	(0.026)	(0.029)	(0.030)
Constant	5.540***	3.590***	5.691***	3.247**
	(0.299)	(1.388)	(0.344)	(1.564)
***Panel D**: Distance to a line*	Mean download speed		Mean upload speed	
(Categories)	(1)	(2)	(3)	(4)
Has a line	0.638***	0.543***	0.812***	0.743***
	(0.108)	(0.108)	(0.122)	(0.121)
No line and $dist \in (0km, 73.4km]$	0.604***	0.544***	0.733***	0.717***
	(0.106)	(0.110)	(0.121)	(0.123)
No line and $dist \in (73.4km, 151.5km]$	0.386***	0.358***	0.484***	0.498***
	(0.103)	(0.104)	(0.117)	(0.117)
No line and $dist \in (151.5km, 290.8km]$	0.152	0.157	0.159	0.202*
	(0.103)	(0.102)	(0.118)	(0.116)
Constant	3.266***	1.448	2.830***	0.385
	(0.076)	(1.388)	(0.084)	(1.540)
Observations	3,077	3,072	3,077	3,072
Controls		X		X

Notes: This table shows the impact of ARPANET in 1979 structure on modern Internet speed offered to businesses by county. We display the impact on the mean download and the mean upload speeds. The dependent variables are a dummy variable that equals 1 if a county has a node (Panel A); a dummy variable that equals 1 if a county has a connection line (Panel B); the log of the distance between the country's centroid and a connection line (Panel C); and distance quartiles from a connection line (Panel D), where counties between 290.8km and 1,118km belong to the omitted category. Panels B, C and D do not include counties with a node in 1979 (32) and the number of observations corresponds to these panels. Controls include geographic and economic characteristics. SHAC-adjusted standard errors (Conley, 1999) are in parenthesis, with a radius of 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

influence another county's provision because ISPs are in charge of the last mile and can differentiate the Internet service quality at granular levels.[23] Such targeting capacity by ISPs dissipates concerns about SUTVA violations.

5 Results

In this section, we present the main results of the paper. In particular, we show the impact that better provision of the Internet has on local economic activity. Moreover, we show its impacts on local structural transformation. Finally, we present the results regarding the two main proposed mechanisms behind such impact, together with the impact of internet quality on earnings inequality within counties.

5.1 Internet Quality and Short-Run Local Economic Growth

To study the effect of a better provision of the Internet on local economic growth, we start by estimating equation (1) using as dependent variables the 4-year growth rate (between 2014 and 2018) of the county's real GDP, total annual payroll, total employment, and average wages. We estimate such equations using two-stage least squares (2SLS), where, in the first stage, we estimate equation (2) using the (log) mean Internet speeds offered to businesses in 2014 as a function of the (log) distance between a country's centroid and an ARPANET connection line in 1979. In Table 3, we present the results of such estimation, using download speeds in Panel A and upload speeds in Panel B. We report two types of standard errors: robust, and spatial heteroskedasticity and autocorrelation consistent standard errors (Conley, 1999), together with the first-stage Kleibergen-Paap F-test for weak instruments (Kleibergen and Paap, 2006).

We highlight three results from Table 3. First, better Internet has a slight positive effect on economic growth as shown in column 1. In particular, doubling Internet speeds can lead to an increase of 2.1 to 3.7 percentage points (pp) in the 4-year GDP growth rate, which is a relevant magnitude if we consider that the interquartile range (IQR) for this rate is 14.8 percentage points. Although robust to different specifications, it is worth noticing that this estimate is somewhat imprecise. Second, notice in column 3 that there is a positive and significant effect on short-run employment growth: doubling the quality of the Internet increases the 4-year employment growth by 2.8 to

[23] The provision of Internet has some similarities to electricity or water, cases in which the provider decides the quality of the service in the last mile; hence the quality of the service provision can be targeted (counties, neighborhoods, blocks, buildings, etc.). For example, quality can vary across tracts within the same city or even across neighborhoods within the same county. Some illustrative cases are Detroit (Wayne County) today or Chattanooga (Hamilton County) in the past, cities where national commercial ISPs did not provide high-speed Internet in specific neighborhoods, even though the rest of the city had access to broadband services. The importance of the last mile has been documented in detail by journalists, economists and non-profits (Lobo et al., 2008; Peñarroyo et al., 2022; Thornton and Mars, 2022).

Table 3: **2SLS Estimates**. Effect of Better Internet Speed Offered to Businesses on Local Economic Aggregates

Panel A: Download Speed	Growth rate of			
	GDP	Annual Payroll	Employment	Average Wage
	(1)	(2)	(3)	(4)
Log(Mean Download Speed	0.037*	0.024	0.049***	-0.028**
Offered to Businesses)	(0.021)	(0.018)	(0.016)	(0.011)
	[0.022]	[0.019]	[0.017]	[0.012]
Constant	0.074	0.211	0.281***	-0.052
	(0.174)	(0.131)	(0.096)	(0.081)
	[0.182]	[0.142]	[0.111]	[0.084]
FS F-Test	44.446	46.000	45.192	45.192
Panel B: Upload Speed	Growth rate of			
	GDP	Annual Payroll	Employment	Average Wage
	(1)	(2)	(3)	(4)
Log(Mean Upload Speed	0.021*	0.013	0.028***	-0.016**
Offered to Businesses)	(0.012)	(0.010)	(0.009)	(0.006)
	[0.012]	[0.011]	[0.009]	[0.007]
Constant	0.166	0.271**	0.404***	-0.123
	(0.169)	(0.125)	(0.090)	(0.076)
	[0.176]	[0.139]	[0.106]	[0.079]
FS F-Test	56.421	58.614	57.594	57.594
Observations	3,022	3,047	3,037	3,037
Controls	X	X	X	X

Notes: This table shows the results of regressions of different local economic outcomes on current Internet offered to businesses (both mean download and upload speeds). We use as an instrument the county centroid's distance to an ARPANET connection line in 1979. We include geographic and economic controls in our first stage. Average wages are measured as the ratio between total payroll and total employment. Regressions do not include counties with ARPANET nodes in 1979. The FS F-Test corresponds to the Kleibergen & Paap F-test for weak instruments. Robust standard errors are in parentheses and SHAC-adjusted standard errors (Conley, 1999) are in brackets, with p-values * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The radius for SHAC errors is set at 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution.

4.9 pp, which has an IQR of 12.5. That is, faster Internet leads to job growth and employment reallocation towards those regions with better access to it.

Third, since the growth rate of total payroll does not change (column 2), results from column 4 suggest that faster Internet leads to a reduction in the growth rate of wages–though not necessarily a decrease in wage levels. In particular, doubling Internet speeds offered to firms decreases the growth rate of wages by 1.6 to 2.8 pp. In principle, these results seem to differ from Forman et al. (2012), who find a null impact of better Internet on average wages. We do not consider that both sets of results contradict each other, as Forman et al. (2012) analyze the effects of firms' Internet investments on county wage levels during the five-year period when the adoption of the technology was in its initial stages. Differently, we evaluate the quality of Internet provision on growth rates 20 years after, in a period when the technology was already widely adopted. The short-run impacts on wage growth might occur if better Internet leads to a positive labor supply shock in a county without substantially affecting labor demand.

Results from Table 3 are key to understanding how Internet quality affects local economies in the short run. We observe increases in GDP growth but a deceleration in wage growth. This might imply that regional growth is likely to be driven by increases in capital productivity rather than labor productivity, which is consistent with the Internet making computers and other ICT devices more productive. Interestingly, this fact is consistent with one of the original objectives of ARPANET: to make military computers more productive.

Moreover, the first stage KP F-statistic for weak instruments shows a value of around 45 in Panel A and around 58 in Panel B. Thus, the distance to an ARPANET line in 1979 is not a weak instrument for current Internet speeds. Moreover, our results are robust to specifications where we (i) further restrict the spatial correlation patterns of the error term (Table A-5); (ii) use the 1988 ARPANET structure as our instrumental variable (Table A-6); (iii) include all counties in the continental US (Table A-7); (iv) exclude 6 Metropolitan Areas with a large concentration of nodes (Table A-8);[24] (v) use median download speed as a measure for Internet quality (Table A-7). We also estimate equation (1) using OLS to grasp the direction of the original bias. As can be seen in Table A-9, coefficients from the OLS estimation are negative and some of them are significantly different from zero; that is, they are lower than those in Table 3. This comparison suggests that ignoring the endogeneity problem of these regressions would lead to downward biased estimators, as hypothesized in Section 4.

5.2 Internet Quality and Long-Run Local Economic Growth

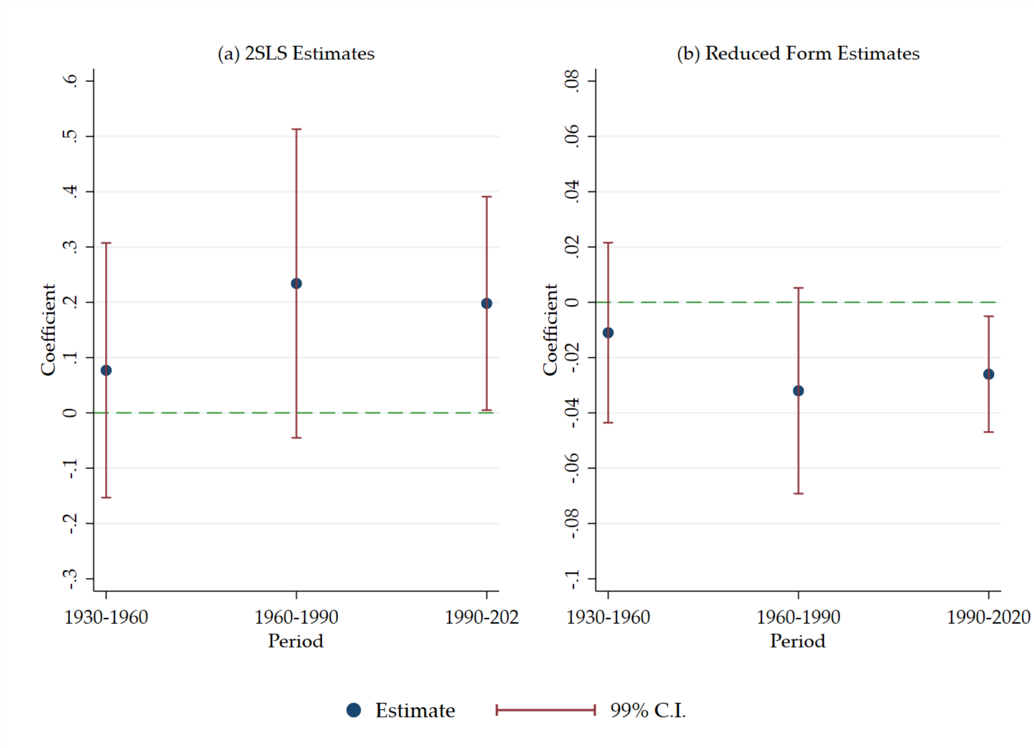
To study the impacts of the Internet on long-run economic growth, we estimate equation (1) using 30-year population growth rates as the dependent variable for the periods 1930-1960, 1960-1990, and 1990-2020. Our treatment is the average Internet speeds offered to businesses in 2018 instrumented by the distance of the county's centroid to an ARPANET connecting line in 1979. Notice that, in this specification, our treatment is in fact the change in Internet quality in the long run, from 1990 to 2018, as Internet speeds offered to firms in 1990 were zero across all counties. Although firms could access regional NSFNET networks, they could not access the national network since it was

[24] From this specification, we exclude the following metropolitan areas: Boston-Cambridge-Newton, Los Angeles-Long Beach-Anaheim, New York-Newark-Jersey City, San Francisco-Oakland-Hayward, San Jose-Sunnyvale-Santa Clara, and Washington-Arlington-Alexandria.

privatized in 1995. Moreover, we use county population growth as our dependent variable since from a historical perspective such variable is a good indicator of its long-run growth for regions.

We present the resulting estimates for the regressions for each respective period in Panel A from Figure 3. We highlight three results. First, faster Internet speeds had a positive effect on local economic growth between 1990 and 2020. Second, our results suggest that counties that have expanded their Internet twice as much in net terms (a difference of 100% in today's speeds) experienced population growth rates of almost 20 percentage points larger between 1990 and 2020. Such estimates are realistic as the average population growth in this period across U.S. counties was 22%, and its IQR was around 40 percentage points. Third, the impacts of modern high-quality Internet in 1930-1960 are not statistically significant. Since this period lies before the creation of ARPANET, it serves as a good placebo test for our results.

Figure 3: Impact of Internet Speed on Long-Run Growth



Note: these figures show the causal effect of better Internet provision on long-run population growth at the county level. In Figure (a), we measure Internet provision as download speeds offered to businesses and instrument it with the distance to an ARPANET line in 1979, together with geographic and economic characteristics. In Figure (b), we regress population growth directly on the instrumental variable (i.e., the reduced form). We show the coefficients and the 99% confidence intervals. Regressions do not include counties with ARPANET nodes in 1979. SHAC-adjusted standard errors (Conley, 1999) are reported in parenthesis, with a radius of 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution.

Similarly, in Panel B from the same figure, we present the reduced form results of this regression;

that is, we regress population growth directly on the distance from a county's centroid to an ARPANET connecting line in 1979 (our IV). These estimates are negative, which suggests that counties farther from the 1979 ARPANET lines experienced less population growth between 1990 and 2020. Noticeably, the impact of ARPANET lines on population growth is not statistically significant for the periods 1930-1960 and 1960-1990.

5.3 Internet Quality and Local Structural Transformation

Besides growth, we would like to understand if and how a better provision of communications infrastructure alters the sectoral economic structure of counties; that is if it leads to local structural transformation. Since research has already shown that better communication infrastructure can lead to better transmission of ideas (Carlino et al., 2007), it would be natural to conclude that better communication infrastructure favors local activity in sectors where ideas are key for the growth of the sector.

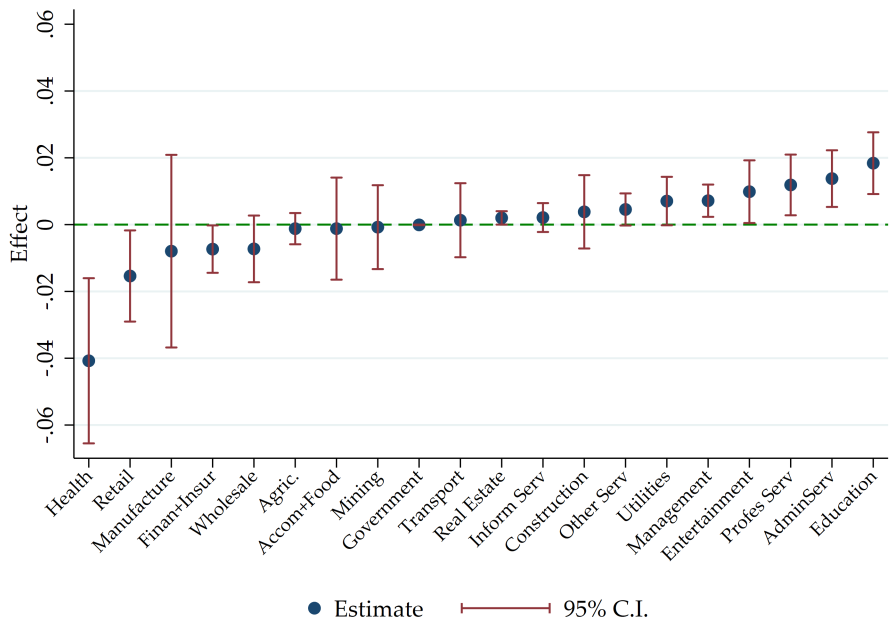
To explore local structural transformation, we estimate equation (1) using as dependent variable the share of employment and the share of GDP in each sector within a county in 2018, the quality of the Internet in 2018 as our variable of interest, and the (log) distance to an ARPANET connection line in 1979 as its instrument. We start by analyzing these shares at the 2-digit NAICS sector. We present the results of these regressions in Figure 4, where we show the point estimates and their 95% confidence intervals. The horizontal axis of this figure presents the 2-digit NAICS sector codes sorted by the size of the point estimate; the full name of each sector can be found in Table A-1.

Results from Panel A in Figure 4 show that faster Internet download speeds have a positive impact on the employment shares of five 2-digit sectors: (i) *Educational Services*; (ii) *Administrative, Support, Waste Management, and Remediation Services*; (iii) *Professional, Scientific, and Technical Services*; (iv) *Arts, Entertainment, and Recreation*; and (v) *Management of Companies and Enterprises.* In addition, it also has a small but significant positive effect on *Real Estate and Rental and Leasing*, and *Utilities.* Notice that these positive effects are concentrated in the sectors denominated *Skilled-Scalable Services* by Eckert et al. (2020), or *Prime Services* by Ahlfeldt et al. (2020). As discussed in these papers, such services are intensive in high-skilled workers and information services and have been responsible for the relatively faster growth of larger cities in the past two decades.

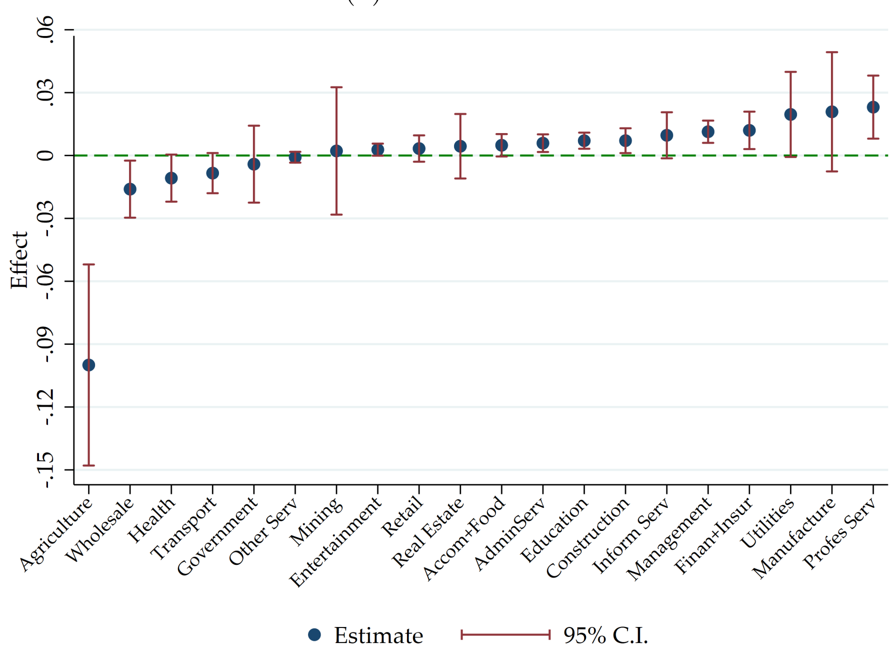
On the other hand, faster download speeds affect negatively employment shares in three aggregate sectors: (i) *Health Care and Social Assistance*; (ii) *Retail Trade*; and (iii) *Finance and Insurance.* These effects are statistically significant at the 95% confidence level. Notice that these three sectors can be found in almost every town and city across the U.S., which could suggest that regions with worse quality Internet might have only service firms to serve the local market (e.g., physician

Figure 4: Internet and Local Structural Transformation

(a) Employment Shares



(b) GDP Shares



Note: these figures show the 2SLS estimates that measure the causal impact of better Internet provision (measured as faster download speeds offered by Internet providers to businesses) on the share of employment or GDP on 2-digit NAICS sectors. We use as an instrumental variable the distance to an ARPANET line in 1979, together with geographic and economic characteristics. The horizontal axis shows the sectors sorted by the size of the estimate. The full sector names are shown in Table A-1.

practices, social assistance offices, physical banks, retail stores). It is possible that in rural and low-populated counties establishments such as retail stores, physician practices, and government social assistance offices might be major employers. Hence, the arrival of firms that use ICT is more likely to impact the share of employment in such sectors. Moreover, we find heterogeneous impacts of better Internet on *Healthcare and Social Assistance* and *Finance and Insurance* when we consider the 3-digit NAICS sub-sectors in these groups of industries (see table 5 for more details). In addition, the effect on *Manufacturing* (31) also appears to have a negative point estimate, but it is quite imprecisely estimated, which could be explained by the heterogeneous effects of Internet quality on different manufacturing sub-sectors. This sectoral ranking is robust to using (i) payroll shares instead of employment shares as our dependent variable (Figure A-6); (ii) upload speeds as the measure of Internet quality (Figure A-7); or (iii) the 1988 ARPANET structure for our IV strategy (Figure A-8).

For more specific magnitudes, consider the point estimate for *Professional, Scientific, and Technical Services* ($\hat{\beta} = 0.012$), and the median county, which has an average download speed of 39 Mbps and 2.6% of employment in this sector. Our estimates suggest that, if this county improves its Internet quality to 135 Mbps (a 350%, equivalent to the county in the 75th percentile), this county could see an increase in the relative importance of this sector of 4.2 pp, going from 2.6% to 6.8% of the total county-level employment. Contrarily, consider the point estimate for *Retail Trade* ($\hat{\beta} = -0.015$). If this same median county experiences a 350% increase in download speeds, it could see a reduction in the relative importance of retail employment of 5.3pp, going from 15.4% to 10.1%.

In Panel B from Figure 4, we present the results of the same estimations but using sectoral GDP shares as the main dependent variables. In this case, the positive effects for high-skilled services hold: four of the five services in this category are in the top 6 of the sectors positively affected by better Internet quality, including *Finance and Insurance*. However, we would like to note two important differences compared to the previous figure. First, manufacturing appears to be positively affected in this case, but its confidence intervals remain quite broad and the effects are not significant. Second, there is a sizeable negative effect of Internet quality on the relative importance of Agriculture. We also observe negative impacts on *Wholesale Trade*; *Health Care and Social Assistance*; and *Transportation and Warehousing*.

To disentangle the impacts of better Internet provision on sectoral outcomes at the county level, we re-estimated the model using employment shares for each one of the 92 NAICS sectors at the 3-digit level. Given the large dimensionality of these results, we report them separately for Agriculture, Mining, and Manufacturing sub-sectors in Table 4, and for all Services sub-sectors in Table 5. Moreover, we categorize all 3-digit sectors depending on whether their point estimate is significant at the 95% confidence level, positive or negative. We display the table with the estimates and the standard errors for each sub-sector in the online appendix.[25]

Table 4: **Direction of 2SLS Estimates**. Impact of Internet Speed Offered to Businesses on Agriculture and Manufacturing Subsectors

Positive Impacts (95%)	**Zero or Statistically Insignificant Impacts**	**Negative Impacts (95%)**
313 - Textile Mills	113 Forestry & Logging	211 - Oil & Gas Extraction
332 - Fabricated Metal Product Manufacturing	114 - Fishing, Hunting, Trapping	321 - Wood Product Manufact.
335 - Electrical Equipment, Appliance, & Component Manufact.	115 - Support Activities for Agriculture & Forestry	
339 - Miscellaneous Manufacturing	212 - Mining (except Oil & Gas)	
	213 - Support Act. for Mining	
	221 - Utilities	
	236 - Construction of Buildings	
	237 - Heavy & Civil Engineering Construction	
	238 - Specialty Trade Contractors	
	311 - Food Manufacturing	
	312 - Beverage & Tobacco Product Manufacturing	
	314 - Textile Product Mills	
	315 - Apparel Manufacturing	
	316 - Leather & Allied Product Manufacturing	
	322 - Paper Manufacturing	
	323 - Printing & Related Support Activities	
	324 - Petroleum & Coal Products Manufacturing	
	325 - Chemical Manufacturing	
	326 - Plastics & Rubber Products Manufacturing	
	327 - Nonmetallic Mineral Product Manufacturing	
	331 - Primary Metal Manufact.	
	333 - Machinery Manufacturing	
	334 - Computer & Electronic Product Manufacturing	
	336 - Transportation Equipment Manufacturing	
	337 - Furniture & Related Product Manufacturing	

Notes: We classify the NAICS 3-digit sub-sectors according to 2SLS estimates. The estimates are obtained by a regression of the share of employment in each sector on the quality of Internet provision (measured as higher download speeds offered by Internet providers to businesses). The IV is the distance of a county to an ARPANET line in 1979. We include geographic economic characteristics in the first stage. The classification depends on whether the 2SLS estimate was significant at the 95% confidence level. Regressions do not include counties with ARPANET nodes in 1979. Exact estimates are provided on request.

With respect to manufacturing, we highlight two findings. First, only *Wood Product Manufacturing* is negatively and significantly affected by higher Internet quality. On the other hand, only four

[25] The sub-sectors Crop Production (111), Animal Production (112), Rail Transportation (482), Postal Service (491), Internet Publishing and Broadcasting (516), and Private Households (814) are not included in the CBP.

sub-sectors are positively impacted. In particular, the following manufacturing 3-digit NAICS sub-sectors are positively impacted by better download speeds: *Textile Mills*; *Fabricated Metal Product Manufacturing*; *Electrical Equipment, Appliance, and Component Manufacturing*; and *Miscellaneous Manufacturing.* These impacts could be explained by the fact that better communication technologies benefit industries with just-in-time manufacturing. Differently, none of the agricultural or mining 3-digit NAICS sub-sectors is positively affected by better Internet. In particular, the effect on all of them is null, except for activities belonging to *Oil and Gas Extraction* which requires good quality communications, particularly for drilling activities.

For the case of services, our findings show interesting patterns. First, within information services, the most favored sub-sectors are the ones related to Internet and communication: *Telecommunications*, and *Internet service providers, Web search data processing services.* Second, the disaggregated impacts on *Finance and Insurance* and *Healthcare and Social Assistance* are illustrative of the local structural change generated by the Internet. At the aggregate level we found evidence that better Internet quality has a negative impact on these two sectors, as shown in Figure 4.

However, when we consider 3-digit NAICS sub-sectors, we find that the reduction in the employment share of *Finance and Insurance* is driven by *Credit Intermediation and Related Activities*, which experiences a significant negative impact. This sub-sector includes commercial banking and all its branches located across the country, from the largest cities to the most rural towns. Differently, the impact of better Internet provision on *Securities, Commodity Contracts, and Other Financial Investments* is positive and statistically significant. This sub-sector includes trading and other high-tech finance activities. Similarly, the negative impact of faster Internet on *Healthcare and Social Assistance* comes from the impacts on *Social Assistance* and *Ambulatory Healthcare Services.* These results contrast with the null impacts on *Nursing* and *Residential Care Facilities*, and the positive and significant impacts on *Hospitals.*

Third, within the 2-digit NAICS sector 56 that corresponds to *Administrative and Support and Waste Management and Remediation Services* the impacts are also heterogeneous across sub-sectors. While *Administrative and Support Services* is positively affected by higher Internet speeds, *Waste Management and Remediation Services* is not impacted. Fourth, we also find heterogeneity within the 2-digit NAICS sub-sectors *Retail Trade* and *Wholesale Trade.* Some sub-sectors, such as *Wholesale Electronic Markets, Agents & Brokers* or *Warehousing and Storage*, are positively affected by better Internet provision. Contrarily, sub-sectors like *Merchant wholesalers of non-durable goods*, *Gasoline stations*, *Truck transportation*, and *Food Services and Drinking Places*, face a negative impact.

Table 5: **Direction of 2SLS Estimates**. Impact of Internet Speed on Services Subsectors

Positive Impacts (95%)	**Zero or Statistically Insignificant Impacts**	**Negative Impacts (95%)**
425 - Wholesale Electronic Markets & Agents & Brokers	423 - Merchant Wholesalers, Durable Goods	424 - Merchant Wholesalers, Nondurable Goods
442 - Furniture & Home Furnishings Stores	441 - Motor Vehicle & Parts Dealers	447 - Gasoline Stations
448 - Clothing & Clothing Accessories Stores	443 - Electronics & Appliances Stores	484 - Truck Transportation
451 - Sporting Goods, Hobby, Book, & Music Stores	444 - Building Material & Garden Equipment & Supplies Dealers	522 - Credit Intermediation & Related Activities
485 - Transit & Ground Passenger Transportation	445 - Food & Beverage Stores	621 - Ambulatory Health Care Services
493 - Warehousing & Storage	446 - Health & Personal Care St.	624 - Social Assistance
517 - Telecommunications	452 - General Merchandise Stores	722 - Food & Drinking Services
518 - ISPs, Web Search Portals, and Data Processing Services	453 - Miscellaneous Store Retailers	
519 - Other Information Services	454 - Nonstore Retailers	
523 - Securities, Commodity Contracts & Other Financial Invest.	481 - Air Transportation	
532 - Rental & Leasing Services	483 - Water Transportation	
551 - Management of Companies & Enterprises	486 - Pipeline Transportation	
561 - Administrative & Support Services	487 - Scenic & Sightseeing Transportation	
611 - Educational Services	488 - Support Activities for Transportation	
622 - Hospitals	511 - Publishing (except Internet)	
711 - Performing Arts, Spectator Sports, & Related Industries	512 - Motion Picture & Sound Recording Industries	
812 - Personal & Laundry Services	515 - Broadcasting (exc. Internet)	
	521 - Monetary Authorities	
	524 - Insurance Carriers & Related Activities	
	525 - Funds, Trusts, & Other Financial Vehicles	
	531 - Real Estate	
	533 - Lessors of Nonfinancial Intangible Assets	
	541 - Professional, Scientific, & Technical Services	
	562 - Waste Management & Remediation Services	
	623 - Nursing & Residential Care Facilities	
	712 - Museums, Historical Sites, & Similar Institutions	
	713 - Amusement, Gambling, & Recreation Industries	
	721 - Accommodation	
	811 - Repair & Maintenance	
	813 - Religious, Grantmaking, Civic, Professional, & Similar	

Notes: We classify the NAICS 3-digit sub-sectors according to 2SLS estimates. The estimates are obtained by a regression of the share of employment in each sector on the quality of Internet provision (measured as higher download speeds offered by Internet providers to businesses). The IV is the distance of a county to an ARPANET line in 1979. We include geographic economic characteristics in the first stage. The classification depends on whether the 2SLS estimate was significant at the 95% confidence level. Regressions do not include counties with ARPANET nodes in 1979. Exact estimates are provided on request.

5.4 Mechanism 1: Input-Output Linkages

We explore input-output linkages as a potential mechanism for the observed changes in local structural transformation. Specifically, we consider the case of industries that purchase a significant amount of inputs from ICT sectors in the economy. If ISPs offer higher quality Internet across counties, this can increase the quality and quantity of the inputs purchased from ICT industries. One example is audiovisual communication via the Internet. If firms can have access to higher-quality Internet, they are more likely to purchase Skype or Zoom for their business communications, which is an improvement relative to mobile phone calls. A second example is data storage services. High-speed Internet allows firms to purchase relatively inexpensive cloud services, which are cheaper compared to purchasing servers and hiring computer technicians just to obtain data storage capacity.

We use the input-output accounts from the Bureau of Economic Analysis to quantify the dependence of every sector on Information and Communication Technologies. Specifically, we use the "Total Requirements Table" that shows the inputs that are required directly and indirectly to deliver a dollar of output to final uses. First, we select the 2-digit NAICS sectors *Broadcasting and Telecommunication* and *Information Services and Data Processing Services* as the main sectors representing ICT technologies. Second, we rank sectors depending on their absolute dependence and relative dependence on ICT inputs as per the "Total Requirements Table".[26] Third, we rank sectors in quartiles depending on these measures, with quartile 1 containing those sectors at the top quartile of the distribution.

We estimate the effect of faster Internet on the share of employment at the county level in all sectors within the same quartile. Our findings show that the share of employment in those sectors with higher dependence on inputs related to ICT sectors is more sensitive to improvements in Internet quality, as shown in Table 6. In fact, when we consider the absolute dependence on ICT inputs, we observe an increasing effect across quartiles, ranging from a null effect in quartile 4 to a positive impact in quartile 1 ($\hat{\beta} = 0.047$). Following the same interpretation as in Section 5.3, the latter coefficient represents an increase of 16.5pp in the share of employment in sectors belonging to this category, following an increase of 350% in the average Internet speed offered to businesses within a county (the difference between the counties in the percentiles 50th and 75th of the Internet speed distribution across U.S. counties). Our results are robust to using absolute or relative relevance, or download or upload speeds. They are also robust to using payroll shares instead of employment, as shown in Table A-10. Moreover, we use a different ranking based on tertiles or deciles, instead

[26]For absolute dependence, we use the coefficients from the total requirements table. For example to produce \$1 of *Computer and electronic products* we need \$0.0297021 of direct and indirect inputs from *Broadcasting and telecommunications*. For relative dependence, we estimate the ratio of the value of inputs coming from ICT sectors with respect to the total value of inputs.

Table 6: **2SLS Estimates, Heterogeneity Analysis**. Impacts of Internet Speeds on Sectors due to Industry Linkages with ICT-related Industries - Dependent Variable: Employment Shares

Panel A	Absolute relevance of ICT-inputs			
	Quartile 4	Quartile 3	Quartile 2	Quartile 1
	(1)	(2)	(3)	(4)
Log(Mean download speed Offered to Businesses)	-0.004	0.013	-0.061**	0.047**
	(0.008)	(0.015)	(0.025)	(0.020)
Constant	-0.036	0.037	1.265***	-0.110
	(0.064)	(0.102)	(0.274)	(0.145)
Panel B	Absolute relevance of ICT-inputs			
	Quartile 4	Quartile 3	Quartile 2	Quartile 1
	(1)	(2)	(3)	(4)
Log(Mean upload speed Offered to Businesses)	-0.003	0.009	-0.044**	0.034**
	(0.006)	(0.010)	(0.017)	(0.014)
Constant	-0.041	0.054	1.187***	-0.049
	(0.060)	(0.093)	(0.257)	(0.143)
Panel C	Relative relevance of ICT-inputs			
	Quartile 4	Quartile 3	Quartile 2	Quartile 1
	(1)	(2)	(3)	(4)
Log(Mean download speed Offered to Businesses)	0.002	-0.031	-0.026	0.050**
	(0.009)	(0.020)	(0.019)	(0.022)
Constant	0.049	0.259	0.890***	-0.041
	(0.071)	(0.175)	(0.177)	(0.168)
Panel D	Relative relevance of ICT-inputs			
	Quartile 4	Quartile 3	Quartile 2	Quartile 1
	(1)	(2)	(3)	(4)
Log(Mean upload speed Offered to Businesses)	0.002	-0.022	-0.019	0.036**
	(0.007)	(0.014)	(0.014)	(0.016)
Constant	0.052	0.220	0.856***	0.023
	(0.066)	(0.170)	(0.167)	(0.166)
Observations	3,054	3,054	3,054	3,054
Controls	X	X	X	X

Notes: Quartile 1 are sectors with high dependence on ICT inputs. Quartile 4 are sectors with low dependence. This table shows the results of estimating a regression of employment shares within different sectoral categories on the quality of Internet offered to businesses in 2018 (either the average download or upload speed), instrumented with the distance of a county centroid to an ARPANET line in 1979. We include geographic and economic controls in the first stage. Sectoral categories are due to industry linkages. We split the sectors into quartiles defined by rankings built using the absolute or relative dependence of a 2-digit NAICS sector on ICT-related inputs. We compute such quartiles using input-output tables from the BEA. Regressions do not include counties with ARPANET nodes in 1979. SHAC-adjusted standard errors (Conley, 1999) are reported in parenthesis, with a radius of 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

of quartiles, and the findings remain similar (Table A-11). Thus, we conclude that our results are driven by industry linkages between industries sensitive to Internet quality and ICT-related inputs.

5.5 Mechanism 2: Sorting of Workers in ICT Related Occupations

Local structural transformation could be driven by an inflow of workers in occupations that might benefit from the use of ICTs, as the Rybczynski theorem would predict. For instance, firms in sectors that benefit the most from higher Internet quality, such as business and administrative services, could decide to locate in places with a relatively higher abundance of workers in ICT-driven occupations, e.g., computer scientists and administrative support workers. This can lead to a virtuous cycle in which these growing sectors end up attracting more ICT-driven workers. We do implement two empirical exercises to test this hypothesis. First, we analyze whether higher Internet quality leads to the sorting of workers who are associated with ICT capital. Second, we explore whether Internet speeds lead to more migration.

For the empirical exercise related to sorting, we use data from the 5-year American Community Survey for 2013-2017. The dataset contains the number of workers in different occupation categories for each county (Manson et al., 2022). For each location, we compute the total number and the share of workers in occupations that are more prone to using the Internet. In particular, we include management, business, and financial occupations, computer and mathematical occupations, architecture and engineering occupations, and office and administrative support occupations. Using these data, we estimate regressions equivalent to those in Section 5.3, that is, we regress the log (and the share) of workers in ICT-driven occupations on current Internet speeds offered to businesses, instrumented with the county distance to an ARPANET connection line.

The results of these regressions suggest that better Internet provision in a county increases the number of workers in occupations that might benefit from the use of ICTs. In particular, estimates from Panel A in Table 7 imply that a 1% increase in download speeds leads to a 1.7% increase in the total number of workers in ICT-intensive occupations. These results also hold if, instead of occupations, we consider workers with educational attainment higher than a bachelor's degree: a master's, a professional school or a doctorate degree. Results from Panel B suggest that a 1% increase in download speeds leads to a 2% increase in the total number of workers with more than a bachelor's degree. Better Internet also increases the relative importance of both types of workers within a county, as we show in column (1) of both panels. Table A-12 shows that these results are robust when we use upload speeds to measure the quality of Internet provision offered to businesses.

These results are consistent with the Rybczynski theorem from the HOV model: higher endowments of one factor lead to a more than proportional expansion of the output in the sector that uses such factor intensively, and a decline in the output of the other sector. In our case, since the higher quality

Table 7: **2SLS Estimates**. The Impact of Internet on the prevalence of ICT-intensive workers

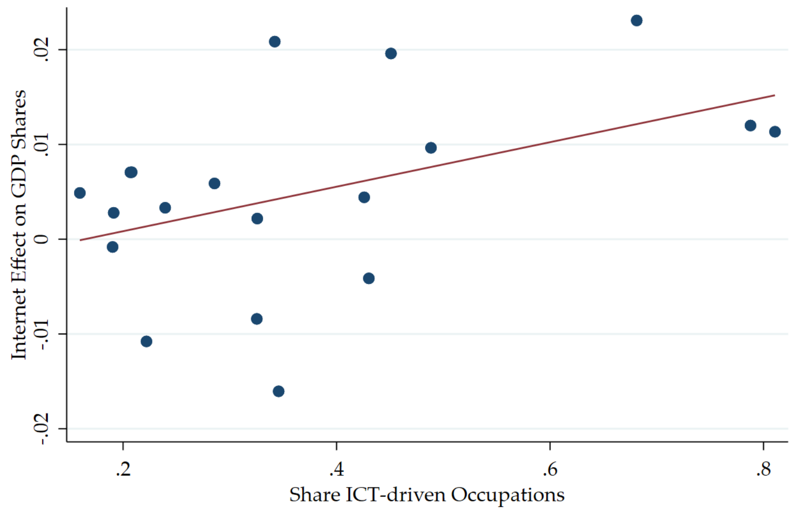
Panel A: Workers in ICT related occupations		
	Share (1)	Logs (2)
Log (Mean Download Speed	0.013*	1.664***
Offered to Businesses)	(0.007)	(0.312)
Constant	0.119**	-1.623
	(0.053)	(2.339)
Panel B: Workers with more than a Bachelor's Degree		
	Share (1)	Logs (2)
Log (Mean Download Speed	0.034***	1.977***
Offered to Businesses)	(0.007)	(0.372)
Constant	0.176***	-0.604
	(0.057)	(2.760)
Observations	3,072	3,071
Controls	X	X

Notes: This table shows the results of regressions studying the impact of mean download speeds on the prevalence of ICT-intensive (Panel A) or high-skilled workers (Panel B), both using shares and logs. We use as instrumental variable the distance of a country centroid to an ARPANET connection line in 1979. We include geographic and economic controls in the first stage. Data for the dependent variables come from the NHGIS 2013-2017 5-year ACS (NHGIS code: AH04 and AH3S). Regressions do not include counties with ARPANET nodes in 1979. SHAC-adjusted standard errors (Conley, 1999) are reported in parenthesis, with a radius of 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

of the Internet increases the number of workers who use ICTs more frequently, the sectors that expand are those that hire these workers more intensively. To support our argument, in Figure 5 we show the correlation between the size of the estimates that measure the impacts of better Internet speeds on GDP sectoral shares (from Figure 4) and the share of ICT-related occupations for 2-digits NAICS sector. This correlation is positive, hence sectors that employ more ICT-related workers see a larger expansion of their output share due to the provision of faster Internet.

We also test for the presence of capital-skill complementarities for the particular case of computer equipment. We estimate correlations at the county level between a proxy of a county's use of computer equipment and its share of ICT-related workers, and average Internet download speeds offered to businesses. Since we do not have data on the sales or use of computers, we use the county's total payroll in two 4-digit sectors – *Electronics and Appliance Stores* and *Professional and Commercial Equipment and Supplies Merchant Wholesalers* – as proxies for the use or sales of home and office computers, respectively. We show the results of these correlations in Figure 6. In the top panel, we observe that counties with a larger share of workers in ICT-driven occupations have more activity in those sectors related to the retail and wholesale of computers and electronic

Figure 5: Estimates of the Impact of Faster Internet on Sectoral Economic Activity vs. Share of ICT-Related Occupations



Note: This figure shows the correlation between the 2SLS estimates that measure the causal impact of better Internet provision (i.e., faster download speeds offered by ISPs to businesses) on the share of GDP on 2-digit NAICS sectors (from Figure 4) and the share of workers in ICT-related occupations for each sector: management, business, and financial occupations, computer and mathematical occupations, architecture and engineering occupations, and office and administrative support occupations. The figure excludes the estimates for agriculture.

equipment. Similarly, the bottom panel shows that Internet speeds in a county are positively correlated with the size of these sub-sectors. These results point to the presence of capital-skill complementarity in counties with better communications infrastructure.

To complement the empirical analysis related to sorting, we test whether higher Internet speeds spur higher migration towards better-connected places. For doing so, we use data from Winkler et al. (2013), who provide reliable estimates of net migration for all U.S. counties each decade from 1950 to 2010. Using our identification strategy, we regress the number of net migrants and the net migration rate on the quality of Internet offered to businesses.

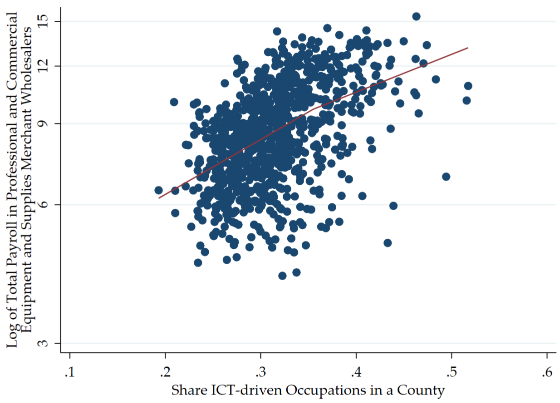
Our estimates are presented in Table A-13. We find that counties with better quality Internet provision have a higher net migration rate. These results are robust to using either download or upload speed as our treatment, or the rate or number of migrants as our dependent variable. These results are consistent with our story that counties with better Internet infrastructure attract more workers with either college degrees or working in tasks associated with ICT capital.

5.6 Internet Quality and Inequality

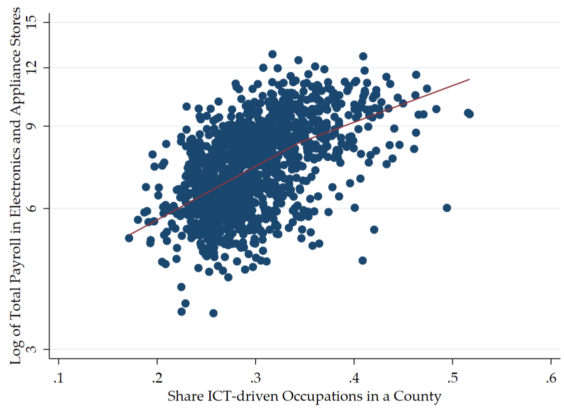
Our previous findings show that better Internet rises the share of high-skilled workers in a county. If the demand for these types of workers is increasing, it is possible that Internet speeds could affect

Figure 6: Use of PC in a County (Proxy), Workers in ICT-driven Occupations and Internet Speeds

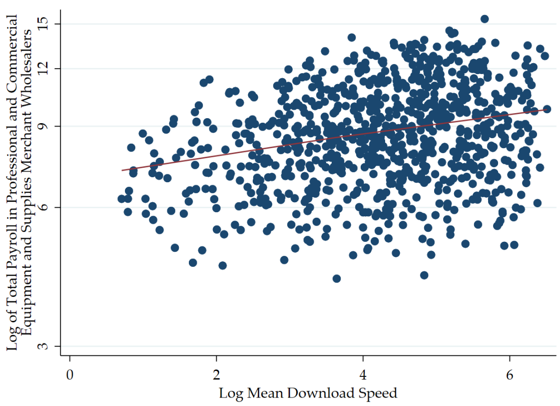
(a) Use Office PC (Proxy) vs. ICT Workers



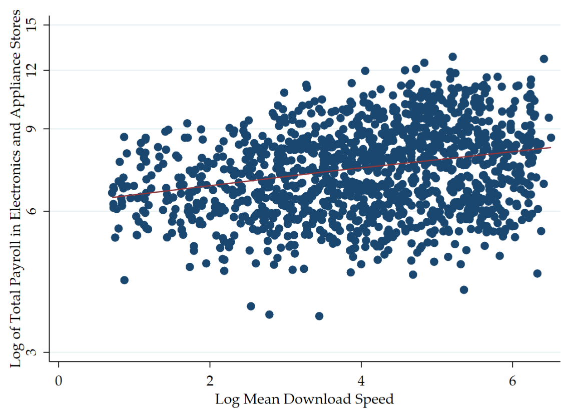
(b) Use Home PC (Proxy) vs. ICT Workers



(c) Use Office PC (Proxy) vs. Internet Speed



(d) Use Home PC (Proxy) vs. Internet Speed



Note: These figures show the correlation between the use of personal computers, the share of workers in ICT-related occupations in a county, and Internet quality (measured as the mean download speed offered by ISPs to firms). We use as a proxy for "Use of Office PC" in a county the total payroll of the sub-sector *Electronics and Appliance Stores* (NAICS code 4232), and for "Use of Home PC" in a county the total payroll of the sub-sector *Professional and Commercial Equipment and Supplies Merchant Wholesalers* (NAICS code 4431). Due to confidentiality restrictions, the CBP data only reports this information for 893 counties for NAICS code 4234, and for 1322 counties for NAICS code 4431.

local inequality through a relative increase in the wages of high-skilled workers. To formally test this hypothesis, we retrieve data from the 5-year 2015-2019 ACS on the median yearly earnings by educational attainment at the county level (Manson et al., 2022). Using these data, we compute average wage for workers in 3 distinct categories: individuals with less than a bachelor's degree,[27] with a bachelor's degree, or with a graduate or a professional degree. Afterward, we estimate the same regression as in Table 7 but using the log of earnings as the main dependent variable.

Table 8: 2SLS Estimates. The Impact of Internet Speed Offered to Businesses on the Earnings of Workers by Educational Attainment

Panel A	Earnings of Workers with		
	Less than Bachelor's (1)	Bachelor's (2)	Graduate or Professional (3)
Log (Mean Download Speed Offered to Businesses)	0.031	0.157***	0.165***
	(0.020)	(0.035)	(0.038)
Constant	9.622***	10.285***	10.733***
	(0.199)	(0.271)	(0.268)
Panel B	Earnings of Workers with		
	Less than Bachelor's (1)	Bachelor's (2)	Graduate or Professional (3)
Log (Mean Upload Speed Offered to Businesses)	0.022	0.112***	0.116***
	(0.014)	(0.022)	(0.023)
Constant	9.661***	10.492***	10.919***
	(0.188)	(0.230)	(0.229)
Observations	3,071	3,048	3,001
Controls	X	X	X

Notes: This table shows the results of regressions studying the impact of internet speeds on the earnings of workers by educational attainment. Internet speeds are measured with mean download speeds (Panel A) or mean upload speeds (Panel B) offered by Internet service providers to businesses in the county. The instrument is the county centroid's distance to an ARPANET connection line in 1979. We include geographic and economic controls in the first stage. Data for the dependent variables come from the NHGIS 2015-2019 5-year ACS (NHGIS code: AMFR). Regressions do not include counties with ARPANET nodes in 1979. SHAC-adjusted standard errors (Conley, 1999) are reported in parenthesis, with a radius of 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Results from Table 8 show that better quality of Internet offered to businesses leads to an increase in the earnings of workers with at least a bachelor's degree: a 1% increase in the quality of Internet increases median earnings by between 0.11% to 0.17%. On the other hand, better Internet seems

[27]This category includes individuals with less than or with a high school degree (including equivalencies), some college, or an associate's degree.

to have a small–but insignificant– effect on the earnings of individuals with less than a bachelor's degree. Thus, our results show that the reduction in communication costs, induced by better Internet provision, leads to a rise in local inequality. These results are in line with previous findings on how reductions in trade costs can increase local inequality (Hanson, 1996; Goldberg and Pavcnik, 2007; Topalova, 2010; Verhoogen, 2008).

6 Conclusions

Higher quality communication infrastructure can have major impacts on local economic outcomes. Different from other types of infrastructure, better communications infrastructure can increase the transmission speed of ideas between individuals at relatively low costs. Moreover, the reduction in trade costs derived from better communications infrastructure is different compared to the decrease in trade costs caused by roads or railroads. Research has also shown that improvements in communications access can lead to more innovation, entrepreneurship, larger firms, higher housing prices and higher trade flows. However, their effects on local economies and local structural transformation remained understudied.

In this paper, we document how differences in the quality of communication infrastructure influence the structural transformation of local economies, their short- and long-run economic growth, and their wage inequality. In particular, we use economic and Internet provision data for all counties in the United States for 2018, to explore the relationship between better these variables. For identification, we use the distance from each county to one of the lines connecting ARPANET nodes, a network that was the precursor of the Internet and later became the backbone of the Internet in its initial stage. These connection lines represent the actual telecommunications equipment installed to connect the old network nodes. We obtain such information from historical government reports documenting the early history of the Internet and combine them with different geographic and economic characteristics.

Our estimates suggest that if a county improves the Internet it provides to businesses, its short-run GDP and employment growth increase, as well as its long-run population growth. Moreover, better Internet favors local GDP and employment in high-skilled services, such as management, information, professional services, and educational services. Nonetheless, better Internet also leads to a decrease in the relative importance of other sectors, such as retail, food services, health services, and financial services. Even though the negative effect on financial and health services might seem puzzling, they appear natural when we explore a more disaggregated sectoral structure. Specifically, better Internet reduces the county share of employment in *Credit Intermediation and Related Activities*, which mostly includes physical banks, while it increases employment in those subsectors related to high-tech financial products. Similarly, faster Internet reduces the local share of employment in social assistance and ambulatory healthcare services but increases the employment shares of *Hospitals*.

Two mechanisms explain our results. First, we find that industry linkages account for some of the observed changes in local structural transformation. Specifically, we show that faster Internet favors sectors that purchase a higher amount of inputs from ICT-related industries. Second, we find that better Internet induces migration and sorting of high-skilled workers and workers in ICT-driven occupations towards these better-connected regions. Thus, our results are consistent with the Rybczynski theorem from the Heckscher-Ohlin-Vanek model and with the presence of capital-skill complementarity. Lastly, we show that reductions in communication costs induced by the better provision of the Internet increase local wage inequality. That is, subsidies to improve the quality of the Internet may favor high-skilled workers relatively more.

Our results have implications for public expenditures on infrastructure, as they suggest that higher Internet quality explains regional development and local inequality. Advanced and middle-income economies have spent public resources on regional Internet subsidies like Canada (Government of Canada, 2019), the United States (The White House, 2022), Germany (European Commission, 2022), United Kingdom (Hutton, 2022), Colombia (Gobierno de Colombia, 2022) or Brazil (Governo Federal do Brasil, 2020). The motivation behind these policies has been to reduce the technology education gap and bring more development to the farther away regions. Nevertheless, such subsidies might lead to unintended consequences regarding local industry structure and inequality.

Three issues are beyond the scope of this paper as they would require a different econometric model and data. First, our empirical strategy does not allow us to study whether Internet improvements are zero-sum. That is, whether counties with faster Internet are becoming more intensive in high-skilled services at the expense of other counties. Such a question would require dynamic panel data and an exogenous rollout of high-quality Internet service. Second, our paper does not explain whether local structural transformation occurs due to the expansion of existing businesses or changes in the location decisions of services firms. These issues are addressed by Jiang (2022) for manufacturing establishments. Third, our paper does not study the impact of the Internet and connectivity on inequality and convergence across regions. From our point of view, these three topics require further research.

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Quality of Communications Infrastructure, Local Structural Transformation, and Inequality

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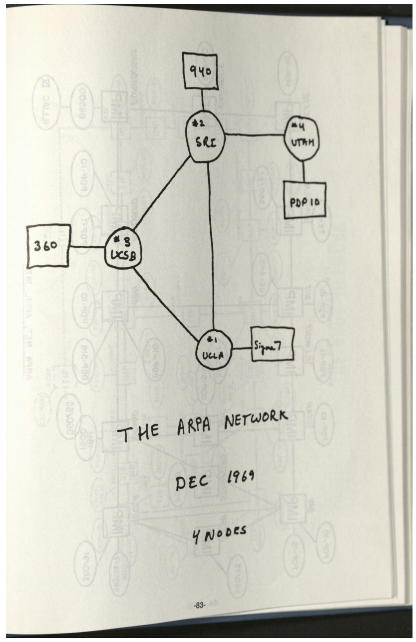
Luis Baldomero-Quintana, William & Mary

Appendix
(for online publication)

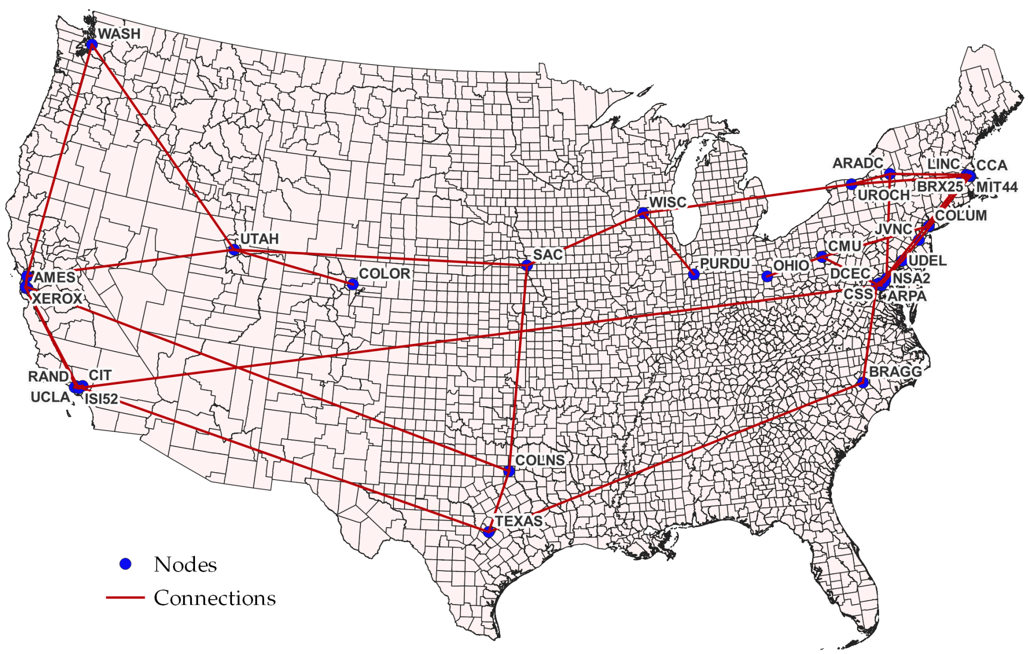
A1 Extra Figures and Tables

Figure A-1: Original description of ARPANET nodes in December 1969



Source: Cerf and Khan (1990)

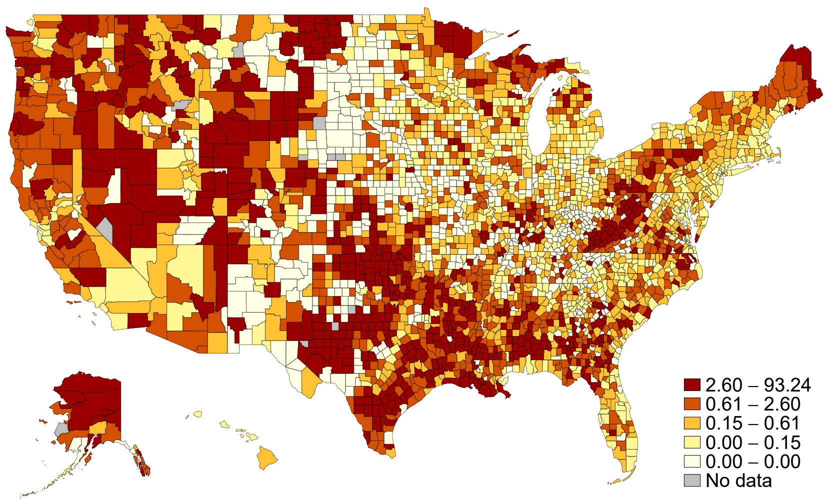
Figure A-2: ARPANET - 1988, Digitized Map



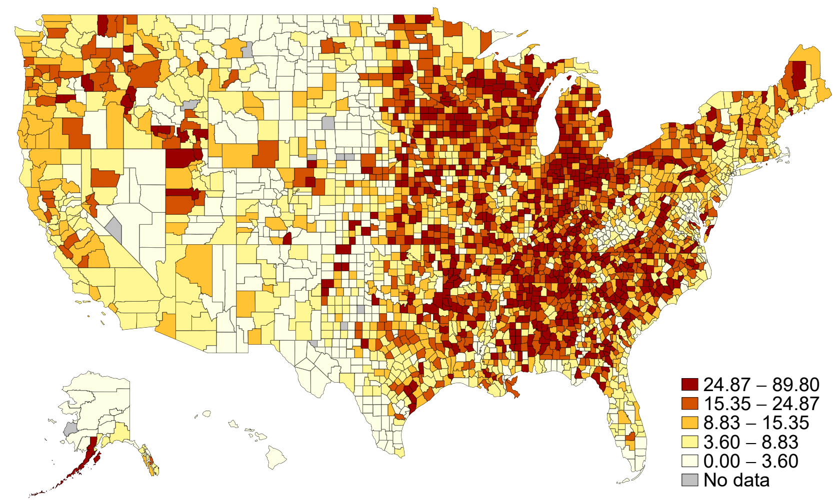
Note: This figure shows a digitized map of the ARPA network as of April 1988 extracted from Cerf and Khan (1990).

Figure A-3: Employment Shares by Aggregate Sectors

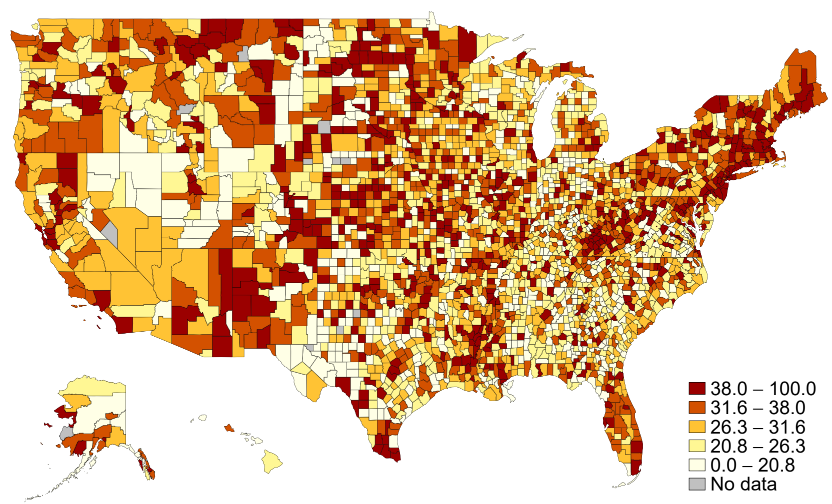
(a) Agriculture and Mining



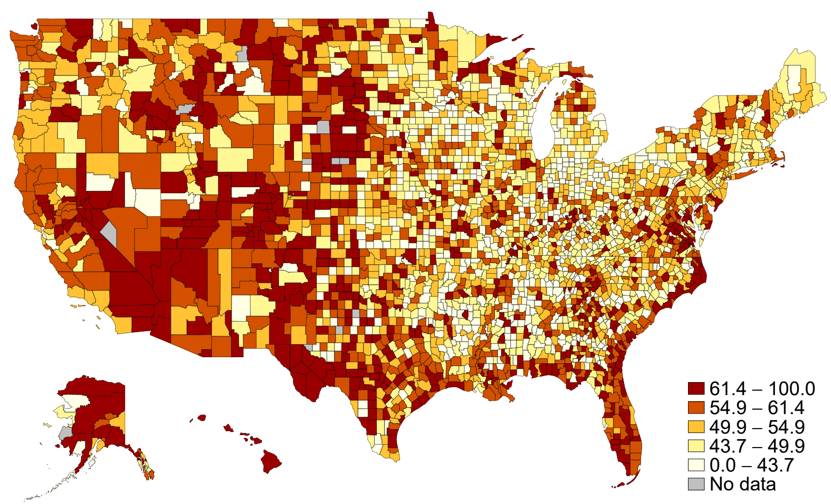
(b) Manufacturing



(c) High Skilled Services



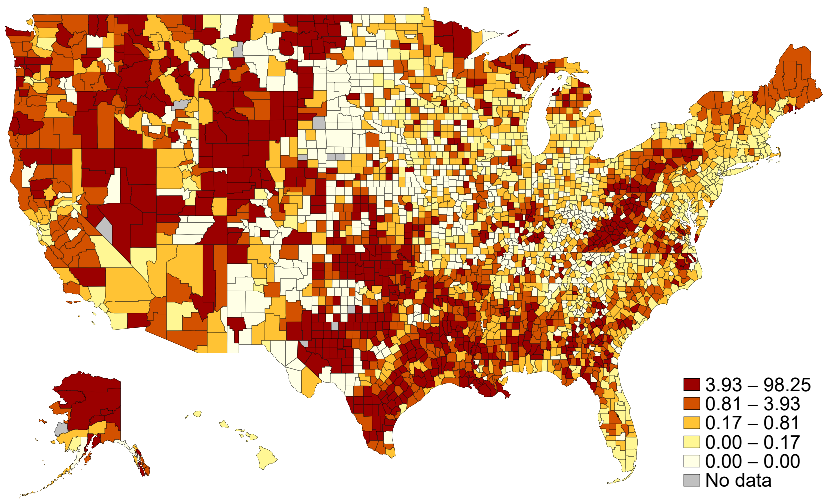
(d) Other Services



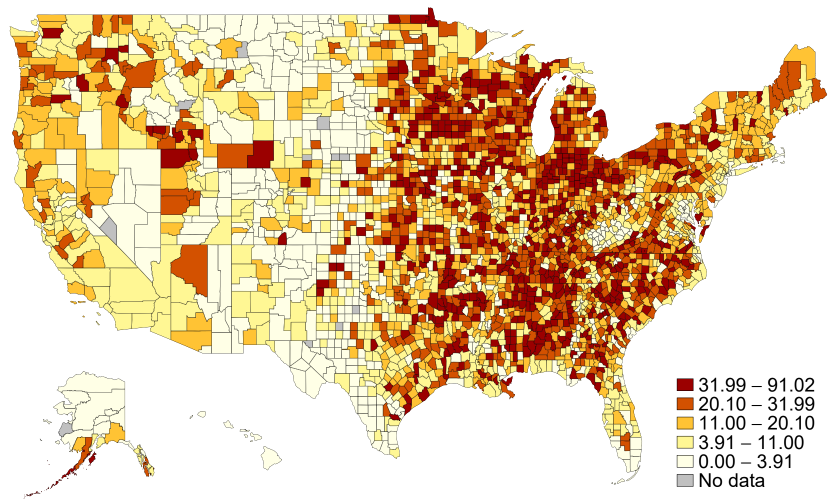
Note: these maps show the shares of employment in each county by quintiles using data from the 2018 County Business Patterns.

Figure A-4: Payroll Shares by Aggregate Sectors

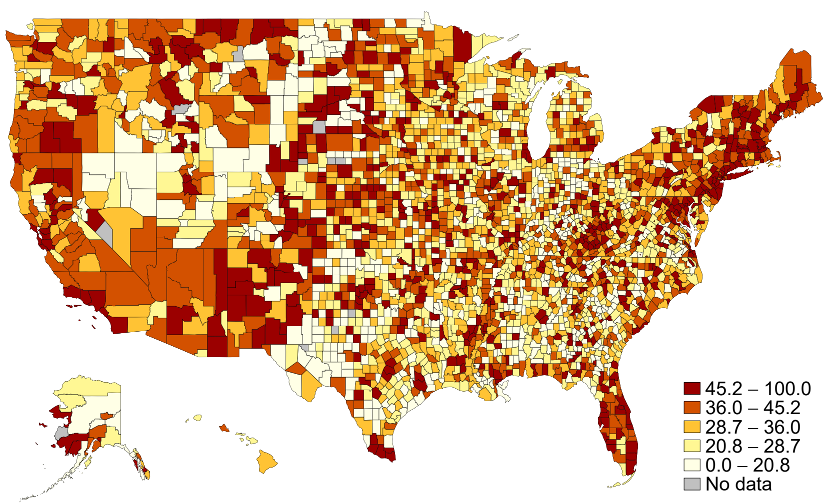
(a) Agriculture and Mining



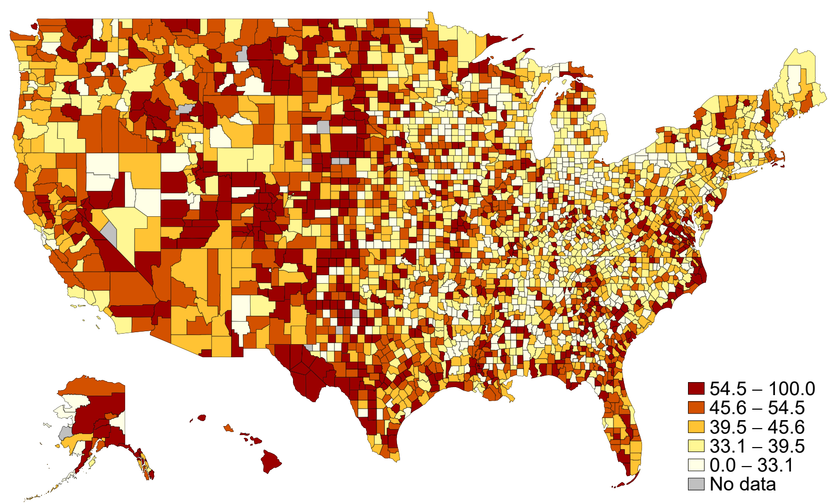
(b) Manufacturing



(c) High Skilled Services



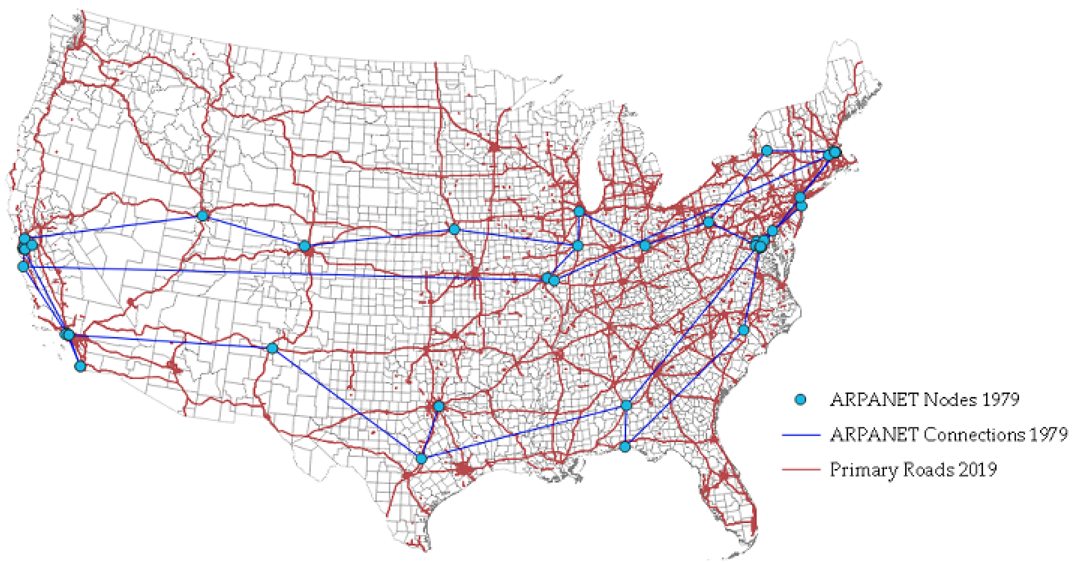
(d) Other Services



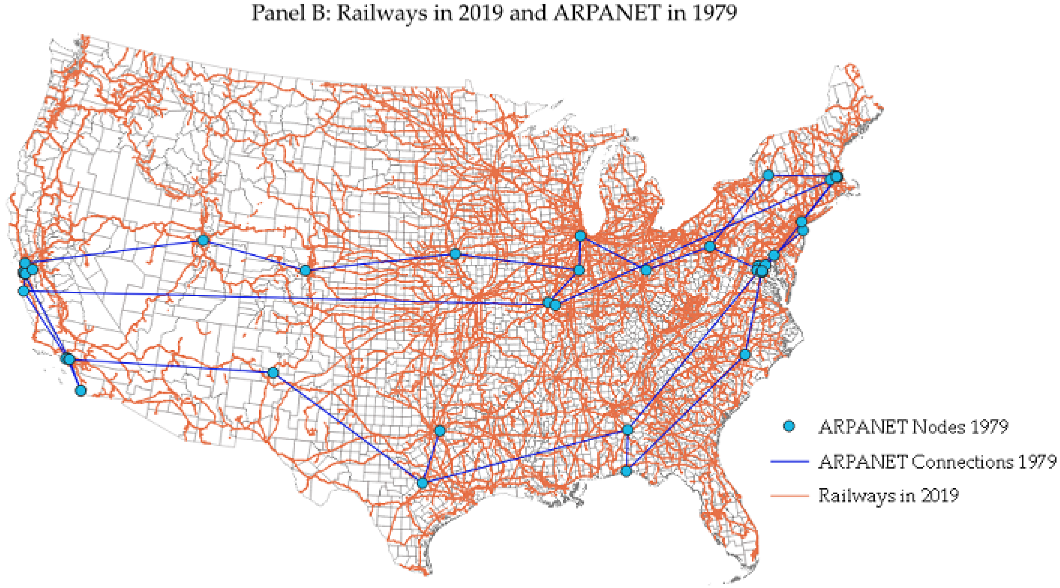
Note: these maps show the shares of aggregate payroll in each county by quintiles using data from the 2018 County Business Patterns.

Figure A-5: ARPANET Connections in 1979 and 2019 Transport Infrastructure

Panel A: Primary Roads in 2019 and ARPANET in 1979

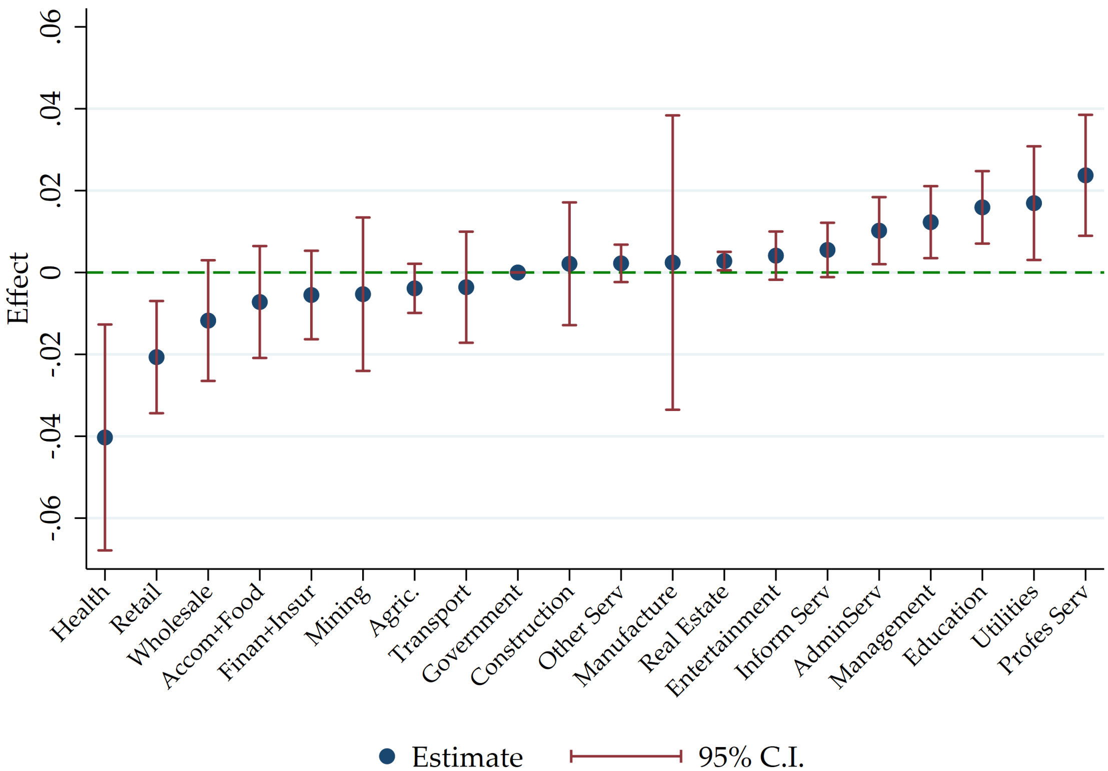


Panel B: Railways in 2019 and ARPANET in 1979



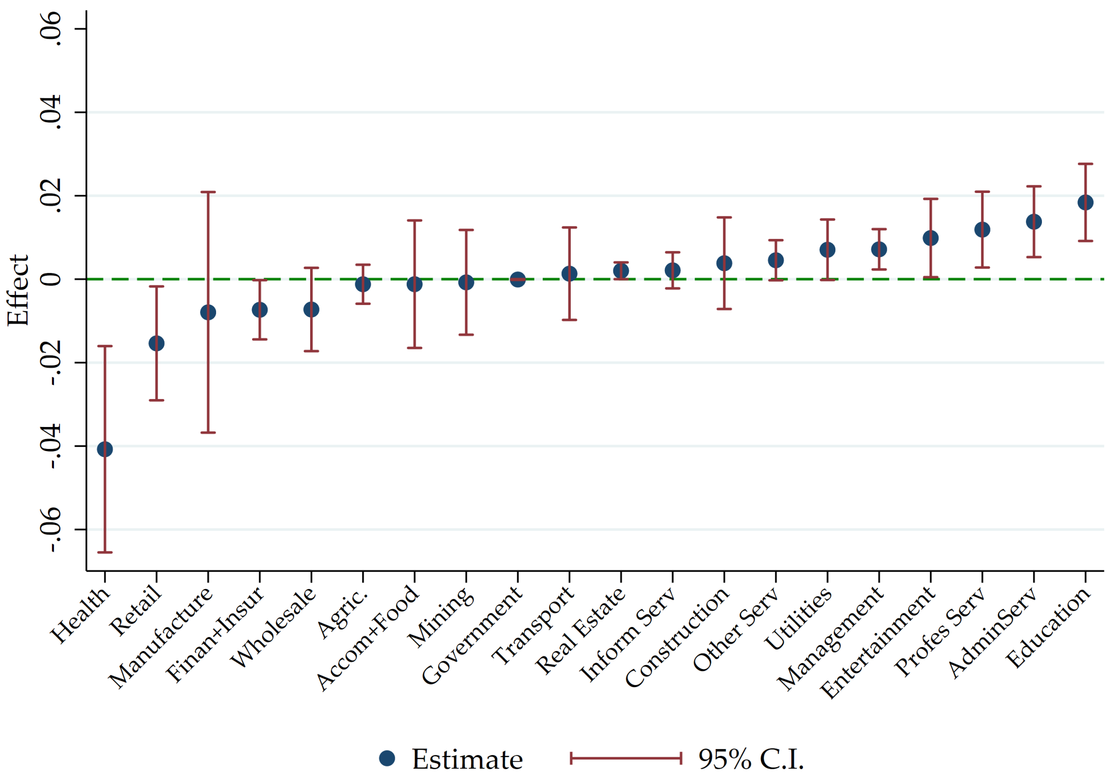
Note: these maps display the digitized ARPANET structure in 1979 together with the US Primary Roads in 2019 (Panel A) or the Railways in 2019 (Panel B). Sources: Cerf and Khan (1990) and US Data Catalog.

Figure A-6: Internet and Local Structural Transformation - Impact of Download Speeds Offered to Businesses on Payroll Sectoral Shares



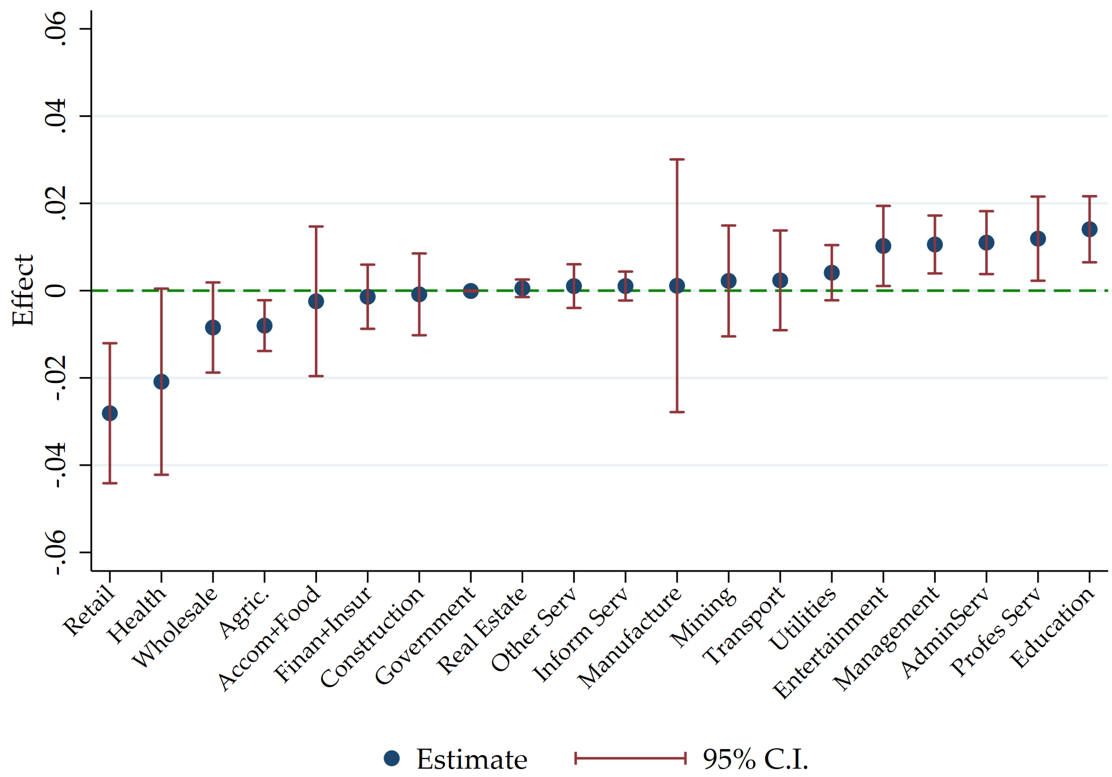
Note: This figure shows the causal effect of better Internet provision (measured as higher download speeds offered to businesses) on the share of payroll of 2-digit NAICS sectors, estimated using the distance to an ARPANET line in 1979 as an instrument, together with geographic and economic characteristics. The horizontal axis shows the sectors sorted by the size of the estimate. *Health* is the NAICS code 62 that includes both health and social assistance services. *Other Serv* is the NAICS code 81 and it considers services not classified in other 2-digit NAICS codes such as personal care, religious organizations, automotive and electronic repair, non-profits, funeral homes, etc. The full sector names are shown in Table A-1.

Figure A-7: Internet and Local Structural Transformation - Impact of Upload Speeds Offered to Businesses on Sectoral Employment Shares



Note: This figure shows the causal effect of better Internet provision (measured as higher upload speeds offered to businesses) on the share of employment of 2-digit NAICS sectors, estimated using the distance to an ARPANET line in 1979 as an instrument, together with geographic and economic characteristics. The horizontal axis shows the sectors sorted by the size of the estimate. *Health* is the NAICS code 62 that includes both health and social assistance services. *Other Serv* is the NAICS code 81 and it considers services not classified in other 2-digit NAICS codes such as personal care, religious organizations, automotive and electronic repair, non-profits, funeral homes, etc. The full sector names are shown in Table A-1.

Figure A-8: Internet and Local Structural Transformation - Impact of Internet Speed Offered to Businesses on Employment Shares - Alternative IV: ARPANET structure 1988



Note: This figure shows the causal effect of better Internet provision (measured as higher download speeds offered to businesses) on the share of employment of 2-digit NAICS sectors, estimated using the distance to an ARPANET line in 1988 as an instrument, together with geographic and economic characteristics. The horizontal axis shows the sectors sorted by the size of the estimate. *Health* is the NAICS code 62 that includes both health and social assistance services. *Other Serv* is the NAICS code 81 and it considers services not classified in other 2-digit NAICS codes such as personal care, religious organizations, automotive and electronic repair, non-profits, funeral homes, etc. The full sector names are shown in Table A-1.

Table A-1: List of NAICS 2-Digit Sectors

Sector	Description
11	Agriculture, Forestry, Fishing and Hunting
21	Mining, Quarrying, and Oil and Gas Extraction
22	Utilities
23	Construction
31-33	Manufacturing
42	Wholesale Trade
44-45	Retail Trade
48-49	Transportation and Warehousing
51	Information
52	Finance and Insurance
53	Real Estate and Rental and Leasing
54	Professional, Scientific, and Technical Services
55	Management of Companies and Enterprises
56	Administrative and Support and Waste Management and Remediation Services
61	Educational Services
62	Health Care and Social Assistance
71	Arts, Entertainment, and Recreation
72	Accommodation and Food Services
81	Other Services (except Public Administration)

Notes: This table shows the codes and description for the 2-digit NAICS classification.

Table A-2: **OLS Estimates**. The Impact of ARPANET in 1988 on Modern Internet Speeds Offered to Businesses

***Panel A**: County has a node*	Mean download speed		Mean upload speed	
	(1)	(2)	(3)	(4)
Had node in 1988	1.434***	0.932***	1.738***	1.104***
	(0.161)	(0.177)	(0.171)	(0.189)
Constant	3.600***	3.947***	3.238***	3.670**
	(0.039)	(1.314)	(0.046)	(1.478)
***Panel B**: County has a line*	Mean download speed		Mean upload speed	
	(1)	(2)	(3)	(4)
Had connection line in 1988	0.265***	0.205***	0.356***	0.280***
	(0.081)	(0.079)	(0.093)	(0.090)
Constant	3.561***	3.571***	3.185***	3.229**
	(0.042)	(1.351)	(0.049)	(1.518)
***Panel C**: Distance to a line*	Mean download speed		Mean upload speed	
	(1)	(2)	(3)	(4)
Distance to Line in 1988	-0.161***	-0.123***	-0.219***	-0.182***
	(0.026)	(0.026)	(0.030)	(0.030)
Constant	5.433***	4.302***	5.735***	4.326***
	(0.293)	(1.369)	(0.340)	(1.526)
***Panel D**: Distance to a line*	Mean download speed		Mean upload speed	
(Categories)	(1)	(2)	(3)	(4)
Has a line	0.737***	0.673***	0.988***	0.937***
	(0.106)	(0.105)	(0.122)	(0.120)
No line and $dist \in (0km, 72.2km]$	0.708***	0.646***	0.974***	0.942***
	(0.097)	(0.098)	(0.110)	(0.110)
No line and $dist \in (72.2km, 131.3km]$	0.654***	0.647***	0.873***	0.903***
	(0.097)	(0.097)	(0.111)	(0.111)
No line and $dist \in (131.3km, 224.7km]$	0.528***	0.561***	0.682***	0.754***
	(0.099)	(0.097)	(0.114)	(0.112)
Constant	3.088***	1.641	2.553***	0.513
	(0.074)	(1.338)	(0.086)	(1.504)
Observations	3,083	3,079	3,083	3,079
Controls		X		X

Notes: This table shows the impact of ARPANET in 1988 structure on today's internet, both the mean download and the mean upload speeds offered to businesses. The dependent variables are a dummy variable that equals 1 if a county has a node (Panel A); a dummy variable that equals 1 if a county has a connection line (Panel B); the log of the distance between the country's centroid and a connection line (Panel C); and distance quartiles from a connection line (Panel D), where counties between 290.8km and 1,118km belong to the omitted category. Panels B, C and D do not include counties with a node in 1988 (26) and the number of observations corresponds to these panels. Controls include geographic and economic characteristics. SHAC-adjusted standard errors (Conley, 1999) are in parenthesis, with a radius of 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A-3: **OLS Estimates**. The Impact of ARPANET on 2014 Internet Speeds Offered to Businesses

***Panel A**: County has a node*	Mean download speed		Mean upload speed	
	(1)	(2)	(3)	(4)
Had node in 1979	1.080***	0.737***	1.697***	1.194***
	(0.160)	(0.155)	(0.209)	(0.204)
Constant	3.261***	3.115***	2.262***	1.026
	(0.026)	(0.793)	(0.042)	(1.275)
***Panel B**: County has a line*	Mean download speed		Mean upload speed	
	(1)	(2)	(3)	(4)
Had connection line in 1979	0.295***	0.227***	0.515***	0.394***
	(0.058)	(0.056)	(0.088)	(0.086)
Constant	3.221***	2.752***	2.193***	0.374
	(0.027)	(0.817)	(0.044)	(1.290)
***Panel C**: Distance to a line*	Mean download speed		Mean upload speed	
	(1)	(2)	(3)	(4)
Distance to Line in 1979	-0.137***	-0.117***	-0.226***	-0.208***
	(0.017)	(0.017)	(0.026)	(0.027)
Constant	4.844***	2.830***	4.865***	0.513
	(0.196)	(0.806)	(0.302)	(1.270)
***Panel D**: Distance to a line*	Mean download speed		Mean upload speed	
(Categories)	(1)	(2)	(3)	(4)
Has a line	0.487***	0.435***	0.841***	0.786***
	(0.073)	(0.070)	(0.109)	(0.109)
No line and $dist \in (0km, 73.4km]$	0.452***	0.427***	0.729***	0.759***
	(0.068)	(0.068)	(0.103)	(0.106)
No line and $dist \in (73.4km, 151.5km]$	0.185***	0.201***	0.353***	0.432***
	(0.066)	(0.066)	(0.100)	(0.102)
No line and $dist \in (151.5km, 290.8km]$	0.133**	0.187***	0.219**	0.347***
	(0.064)	(0.061)	(0.098)	(0.095)
Constant	3.029***	1.211	1.867***	-2.475*
	(0.046)	(0.843)	(0.069)	(1.340)
Observations	3,077	3,072	3,077	3,072
Controls		X		X

Notes: This table shows the impact of ARPANET in 1979 structure on Internet speeds offered to businesses in 2014 by county. We display the impact on the mean download and the mean upload speeds. The dependent variables are a dummy variable that equals 1 if a county has a node (Panel A); a dummy variable that equals 1 if a county has a connection line (Panel B); the log of the distance between the country's centroid and a connection line (Panel C); and distance quartiles from a connection line (Panel D), where counties between 290.8km and 1,118km belong to the omitted category. Panels B, C and D do not include counties with a node in 1979 (32) and the number of observations corresponds to these panels. Controls include geographic and economic characteristics. SHAC-adjusted standard errors (Conley, 1999) are in parenthesis, with a radius of 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A-4: Correlation between 1979 ARPANET Structure and 1970 Employment Shares

	Node in 1979	Node in 1979	Connection line in 1979	Connection line in 1979
	(1)	(2)	(3)	(4)
Share of high-skilled services in 1970	0.713***		0.568*	
	(0.188)		(0.299)	
Share of business services in 1970		1.311***		0.488
		(0.386)		(0.523)
Constant	-0.039	-0.016	-0.206	-0.222
	(0.131)	(0.133)	(0.247)	(0.250)
Observations	3,097	3,097	3,065	3,065
Controls	X	X	X	X

Notes: This table shows the correlation between the location of ARPANET nodes and connection lines in 1979 with the shares of workers in high-skilled services or in business services, controlling for the vector of geographic and economic characteristics. Regressions from columns 3 and 4 do not include counties with nodes. SHAC-adjusted standard errors (Conley, 1999) are in parenthesis, with a radius of 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A-5: **2SLS Estimates**. Effect of Better Internet Speed Offered to Businesses on Local Economic Aggregates
Other Standard Errors

Panel A: SHAC p75	Growth rate of			
	GDP	Annual Payroll	Employment	Average Wage
	(1)	(2)	(3)	(4)
Log(Mean Download Speed	0.037*	0.024	0.049***	-0.028**
Offered to Businesses)	(0.021)	(0.018)	(0.016)	(0.011)
	[0.022]	[0.020]	[0.017]	[0.012]
Constant	0.074	0.211	0.281***	-0.052
	(0.174)	(0.131)	(0.096)	(0.081)
	[0.184]	[0.149]	[0.120]	[0.085]
FS F-Test	37.14	38.45	37.79	37.79
Panel B: SHAC p90	Growth rate of			
	GDP	Annual Payroll	Employment	Average Wage
	(1)	(2)	(3)	(4)
Log(Mean Download Speed	0.037	0.024	0.049***	-0.028**
Offered to Businesses)	(0.021)	(0.018)	(0.016)	(0.011)
	[0.023]	[0.020]	[0.018]	[0.013]
Constant	0.074	0.211	0.281***	-0.052
	(0.174)	(0.131)	(0.096)	(0.081)
	[0.189]	[0.158]	[0.134]	[0.085]
FS F-Test	29.98	30.92	30.45	30.45
Observations	3,022	3,047	3,037	3,037
Controls	X	X	X	X

Notes: This table shows the results of regressions of different local economic outcomes on current Internet (both mean download and upload speeds offered to businesses). We use the county centroid's distance to an ARPANET connection line in 1979 as an instrument. We include geographic and economic controls in our first stage. Average wages are measured as the ratio between total payroll and total employment. Regressions do not include counties with ARPANET nodes in 1979. The FS F-Test corresponds to the Kleibergen & Paap F-test for weak instruments. Robust standard errors are in parentheses and SHAC-adjusted standard errors (Conley, 1999) are in brackets, with p-values * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. In Panel A, the radius for SHAC errors is set at 41.61km, corresponding to the radius of the metropolitan area in the 75th percentile of the distribution. In Panel B, the radius is 59.37km, corresponding to the 90th percentile.

Table A-6: **2SLS Estimates**. Effect of Better Internet Speeds Offered to Business on Local Economic Aggregates - Alternate IV: 1988 ARPANET Structure

Panel A	Growth rate of			
	GDP	Annual Payroll	Employment	Average Wage
	(1)	(2)	(3)	(4)
Log(Mean Download Speed	0.088***	0.026*	0.033***	-0.010
Offered to Businesses)	(0.024)	(0.014)	(0.013)	(0.009)
	[0.026]	[0.015]	[0.013]	[0.009]
Constant	-0.032	0.204	0.321***	-0.099
	(0.191)	(0.128)	(0.091)	(0.076)
	[0.204]	[0.141]	[0.105]	[0.078]
F test	59.503	63.202	61.823	61.823
Panel B	Growth rate of			
	GDP	Annual Payroll	Employment	Average Wage
	(1)	(2)	(3)	(4)
Log(Mean Upload Speed	0.045***	0.014*	0.017***	-0.005
Offered to Businesses)	(0.012)	(0.007)	(0.006)	(0.005)
	[0.013]	[0.008]	[0.007]	[0.005]
Constant	0.182	0.271**	0.405***	-0.125*
	(0.175)	(0.125)	(0.086)	(0.074)
	[0.184]	[0.139]	[0.101]	[0.076]
F test	94.073	99.958	98.477	98.477
Observations	3,022	3,047	3,037	3,037
Controls	X	X	X	X

Notes: This table shows the results of regressions of different local economic outcomes on current internet (both mean download and upload speeds), using the county centroid's distance to an ARPANET connection line in 1988 as an instrument. We include geographic and economic controls in our first stage. Average wages are measured as the ratio between total payroll and total employment. Regressions do not include counties with ARPANET nodes in 1979. The FS F-Test corresponds to the Kleibergen & Paap F-test for weak instruments. Robust standard errors are in parentheses and SHAC-adjusted standard errors (Conley, 1999) are in brackets, with p-values * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The radius for SHAC errors is set at 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution.

Table A-7: **2SLS Estimates**. Effect of Higher Internet Speed Offered to Businesses on Local Economic Aggregates

Panel A: All Counties		Growth rate of		
Download Speed	GDP	Annual Payroll	Employment	Average Wage
	(1)	(2)	(3)	(4)
Log(Mean Download Speed	0.039**	0.024	0.044***	-0.022**
Offered to Businesses)	(0.019)	(0.016)	(0.014)	(0.010)
Constant	0.043	0.189	0.269**	-0.065
	(0.177)	(0.137)	(0.105)	(0.080)
FS F-Test	57.729	59.717	58.813	58.813
Panel A: All Counties		Growth rate of		
Upload Speed	GDP	Annual Payroll	Employment	Average Wage
	(1)	(2)	(3)	(4)
Log(Mean Upload Speed	0.022**	0.014	0.025***	-0.013**
Offered to Businesses)	(0.011)	(0.009)	(0.008)	(0.006)
Constant	0.138	0.250*	0.380***	-0.120
	(0.172)	(0.135)	(0.101)	(0.075)
FS F-Test	71.895	74.773	73.640	73.640
Observations	3,053	3,079	3,069	3,069
Panel C: Base Sample		Growth rate of		
Median Speed	GDP	Annual Payroll	Employment	Average Wage
	(1)	(2)	(3)	(4)
Log(Median Download Speed	0.160	0.102	0.209**	-0.120*
Offered to Businesses)	(0.113)	(0.091)	(0.102)	(0.063)
Constant	-0.319	-0.037	-0.234	0.243
	(0.378)	(0.297)	(0.329)	(0.211)
FS F-Test	6.657	7.067	7.081	7.081
Observations	3,022	3,047	3,037	3,037
Controls	X	X	X	X

Notes: This table shows the results of regressions of different local economic outcomes on current Internet speeds offered to businesses, using the county centroid's distance to an ARPANET connection line in 1979 as an instrument. We include geographic and economic controls in the first stage. Average wages are measured as the ratio between total payroll and total employment. Regressions from Panel A and B include all counties in the US, even if they had a node in 1979. Regressions from Panel C use the baseline sample and the median download speed as a measure of internet speed. The FS F-Test corresponds to the Kleibergen & Paap F-test for weak instruments. Robust standard errors are in parentheses and SHAC-adjusted standard errors (Conley, 1999) are in brackets, with p-values * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The radius for SHAC errors is set at 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution.

Table A-8: **2SLS Estimates**. Effect of Better Internet Speeds Offered to Businesses on Local Economic Aggregates

Panel A: Download Speed	Growth rate of			
	GDP	Annual Payroll	Employment	Average Wage
	(1)	(2)	(3)	(4)
Log(Mean Download Speed	0.047*	0.043**	0.065***	-0.026**
Offered to Businesses)	(0.026)	(0.021)	(0.019)	(0.013)
Constant	0.128	0.368***	0.440***	-0.058
	(0.179)	(0.133)	(0.105)	(0.082)
FS F-Test	34.936	38.724	37.960	37.960
Panel B: Upload Speed	Growth rate of			
	GDP	Annual Payroll	Employment	Average Wage
	(1)	(2)	(3)	(4)
Log(Mean Upload Speed	0.026*	0.024**	0.036***	-0.014**
Offered to Businesses)	(0.014)	(0.012)	(0.010)	(0.007)
Constant	0.232	0.467***	0.591***	-0.118
	(0.184)	(0.132)	(0.103)	(0.083)
FS F-Test	46.703	51.357	50.369	50.369
Observations	2,996	3,014	3,004	3,004
Controls	X	X	X	X

Notes: This table shows the results of regressions of different local economic outcomes on current internet (both mean download and upload speeds), using the county centroid's distance to an ARPANET connection line in 1979 as an instrument. We include geographic and economic controls in our first stage. Average wages are measured as the ratio between total payroll and total employment. Regressions do not include counties in six MSAs that have a relatively high concentration of nodes in 1979: Boston-Cambridge-Newton, Los Angeles-Long Beach-Anaheim, New York-Newark-Jersey City, San Francisco-Oakland-Hayward, San Jose-Sunnyvale-Santa Clara, and Washington-Arlington-Alexandria. The FS F-Test corresponds to the Kleibergen & Paap F-test for weak instruments. SHAC-adjusted standard errors (Conley, 1999) are in parentheses, with p-values * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The radius for SHAC errors is set at 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution.

Table A-9: **OLS Estimates**. Effect of Better Internet Speeds Offered to Businesses on Local Economic Aggregates

Panel A: Download Speed	Growth rate of			
	GDP	Annual Payroll	Employment	Average Wage
	(1)	(2)	(3)	(4)
Log(Mean Download Speed	-0.002	-0.006**	-0.003*	-0.002
Offered to Businesses)	(0.005)	(0.003)	(0.002)	(0.002)
Constant	0.155	0.288**	0.416***	-0.119
	(0.173)	(0.136)	(0.097)	(0.075)
Panel B: Upload Speed	Growth rate of			
	GDP	Annual Payroll	Employment	Average Wage
	(1)	(2)	(3)	(4)
Log(Mean Upload Speed	-0.001	-0.004**	-0.003**	-0.002**
Offered to Businesses)	(0.003)	(0.002)	(0.001)	(0.001)
Constant	0.150	0.274**	0.408***	-0.125
	(0.174)	(0.137)	(0.097)	(0.076)
Observations	3,022	3,047	3,037	3,037
Controls	X	X	X	X

Notes: This table shows the results of regressions of different local economic outcomes on current internet (both mean download and upload speeds), using OLS and controlling for geographic and economic characteristics. Average wages are measured as the ratio between total payroll and total employment. Regressions do not include counties with ARPANET nodes in 1979. SHAC-adjusted standard errors (Conley, 1999) are in parentheses, with p-values * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The radius for SHAC errors is set at 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution.

Table A-10: **2SLS Estimates, Heterogeneity Analysis**. Importance of Internet within Sector (by Quartiles) - Dependent Variable: Payroll Shares

Panel A	Absolute relevance of ICT-inputs			
	Quartile 4	Quatrile 3	Quartile 2	Quartile 1
	(1)	(2)	(3)	(4)
Log(Mean download speed	-0.004	0.044*	-0.114**	0.036
Offered to Businesses)	(0.011)	(0.023)	(0.050)	(0.029)
Constant	-0.068	-0.023	1.101**	-0.040
	(0.091)	(0.159)	(0.503)	(0.203)
Panel B	Absolute relevance of ICT-inputs			
	Quartile 4	Quatrile 3	Quartile 2	Quartile 1
	(1)	(2)	(3)	(4)
Log(Mean upload speed	-0.003	0.032**	-0.081**	0.025
Offered to Businesses)	(0.008)	(0.016)	(0.035)	(0.020)
Constant	-0.072	0.033	0.955*	0.006
	(0.086)	(0.141)	(0.510)	(0.204)
Panel C	Relative relevance of ICT-inputs			
	Quartile 4	Quatrile 3	Quartile 2	Quartile 1
	(1)	(2)	(3)	(4)
Log(Mean download speed	0.393	-0.082*	-0.012	0.050
Offered to Businesses)	(0.494)	(0.046)	(0.026)	(0.033)
Constant	2.133	0.001	0.830***	0.067
	(4.592)	(0.404)	(0.265)	(0.234)
Panel D	Relative relevance of ICT-inputs			
	Quartile 4	Quatrile 3	Quartile 2	Quartile 1
	(1)	(2)	(3)	(4)
Log(Mean upload speed	0.280	-0.058*	-0.008	0.035
Offered to Businesses)	(0.351)	(0.032)	(0.018)	(0.023)
Constant	2.637	-0.104	0.816***	0.131
	(4.279)	(0.428)	(0.248)	(0.234)
Observations	3,054	3,054	3,054	3,054
Controls	X	X	X	X

Notes: This table shows the results of estimating a regression of payroll shares within different sectoral categories on the quality of Internet in 2018 (either the average download or upload speed), instrumented with the county centroid's distance to an ARPANET line in 1979. We include geographic and economic controls in the first stage. Sectoral categories are given by quartile aggregations given different rankings built using the absolute or relative dependence of a 2-digit NAICS sector on ICT-related inputs, which was computed using input-output tables from the BEA. Regressions do not include counties with ARPANET nodes in 1979. SHAC-adjusted standard errors (Conley, 1999) are reported in parenthesis, with a radius of 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A-11: **2SLS Estimates, Heterogeneity Analysis**. Importance of Internet within Sector (other classifications) - Dependent Variable: Employment Shares

Panel A	Absolute relevance of ICT-inputs (employment)					
	Tertile 3	Tertile 2	Tertile 1	Decile 10	Decile 5	Decile 1
	(1)	(2)	(3)	(4)	(5)	(4)
Log(Mean download speed	-0.010	0.011	-0.003	0.005	0.003	0.071***
Offered to Businesses)	(0.010)	(0.021)	(0.025)	(0.006)	(0.009)	(0.017)
Constant	0.250***	0.222	0.753***	0.128**	0.116	0.104
	(0.072)	(0.169)	(0.218)	(0.053)	(0.072)	(0.113)
Panel B	Relative relevance of ICT-inputs (employment)					
	Tertile 3	Tertile 2	Tertile 1	Decile 10	Decile 5	Decile 1
	(1)	(2)	(3)	(4)	(5)	(4)
Log(Mean download speed	-0.015	0.002	0.009	-0.000	-0.025	0.071***
Offered to Businesses)	(0.011)	(0.020)	(0.025)	(0.005)	(0.019)	(0.017)
Constant	0.025	0.407**	0.724***	0.092**	0.268	0.104
	(0.082)	(0.171)	(0.211)	(0.042)	(0.171)	(0.113)
Panel C	Absolute relevance of ICT-inputs (annual payroll)					
	Tertile 3	Tertile 2	Tertile 1	Decile 10	Decile 5	Decile 1
	(1)	(2)	(3)	(4)	(5)	(4)
Log(Mean download speed	-0.015	-0.012	0.003	0.008	0.017	0.073***
Offered to Businesses)	(0.013)	(0.045)	(0.035)	(0.008)	(0.012)	(0.018)
Constant	0.397***	-0.148	0.827***	0.175**	0.141	0.140
	(0.099)	(0.385)	(0.311)	(0.080)	(0.097)	(0.128)
Panel D	Relative relevance of ICT-inputs (annual payroll)					
	Tertile 3	Tertile 2	Tertile 1	Decile 10	Decile 5	Decile 1
	(1)	(2)	(3)	(4)	(5)	(4)
Log(Mean download speed	-0.015	-0.029	0.007	0.001	-0.078*	0.073***
Offered to Businesses)	(0.015)	(0.045)	(0.035)	(0.007)	(0.045)	(0.018)
Constant	-0.016	0.167	0.818***	0.106*	0.090	0.141
	(0.110)	(0.392)	(0.306)	(0.056)	(0.400)	(0.128)
Observations	3,054	3,054	3,054	3,054	3,054	3,054
Controls	X	X	X	X	X	X

Notes: This table shows the results of estimating a regression of employment shares within different sectoral categories on the quality of Internet in 2018 (either the average download or upload speed offered to businesses). Our instrument is the county centroid's distance to an ARPANET line in 1979. We include geographic and economic controls in the first stage. Sectoral categories are given by deciles or tertiles aggregations given different rankings built using the absolute or relative dependence of a 2-digit NAICS sector on ICT-related inputs. Decile or tertile 1 is high dependence, and decile 10 or tertile 3 is low dependence. We compute the absolute and relative dependence using input-output tables from the BEA. Regressions do not include counties with ARPANET nodes in 1979. SHAC-adjusted standard errors (Conley, 1999) are reported in parenthesis, with a radius of 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A-12: **2SLS Estimates**. The Impact of Internet on the prevalence of ICT-intensive workers, Upload Speeds

Panel A: Workers in ICT related occupations		
	Share (1)	Logs (2)
Log (Mean Upload Speed	0.009*	1.195***
Offered to Businesses)	(0.005)	(0.185)
Constant	0.135**	0.468
	(0.053)	(1.816)
Panel B: Workers with more than a Bachelor's Degree		
	Share (1)	Logs (2)
Log (Mean Upload Speed	0.024***	1.420***
Offered to Businesses)	(0.005)	(0.220)
Constant	0.218***	1.870
	(0.052)	(2.128)
Observations	3,072	3,071
Controls	X	X

Notes: This table shows the results of regressions studying the impact of mean upload speeds on the prevalence of ICT-intensive (Panel A) or high-skilled workers (Panel B), both using shares and logs. We use as IV the county centroid's distance to an ARPANET connection line in 1979. We include geographic and economic controls in the first stage. Data for the dependent variables come from the NHGIS 2013-2017 5-year ACS (NHGIS code: AH04 and AH3S). Regressions do not include counties with ARPANET nodes in 1979. SHAC-adjusted standard errors (Conley, 1999) are reported in parenthesis, with a radius of 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A-13: **2SLS Estimates**. The Impact of Internet on Net Migration

Panel A	Net Migration Rate (1)	Net Migrants (2)
Log (Mean Download Speed Offered to Firms)	3.38***	5,972*
	(1.11)	(3,134)
Constant	30.79***	-188,951***
	(10.82)	(54,172)
FS F-Test	28.48	
Panel B	Net Migration Rate (1)	Net Migrants (2)
Log (Mean Upload Speed Offered to Firms)	2.47***	4,365*
	(0.77)	(2,244)
Constant	34.78***	-181,898***
	(10.07)	(52,039)
FS F-Test	41.17	
Observations	3,009	3,009
Controls	X	X

Notes: This table shows the results of regressions studying the impact of mean download and upload speeds offered to firms on net migration, both totals and rates. We use as instrumental variable the distance of a country centroid to an ARPANET connection line in 1979. We include geographic and economic controls in the first stage. Migration data comes from Winkler et al. (2013). Regressions do not include counties with ARPANET nodes in 1979. SHAC-adjusted standard errors (Conley, 1999) are reported in parenthesis, with a radius of 28.55km, corresponding to the radius of the metropolitan area in the median of the distribution. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$