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Digitalization, Cloud Computing, and Innovation in U.S. Businesses

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Contents

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Abstract

This working paper examines differences in the rate of digitalization across industry, firm size class, and location along with how digitalization and cloud computing is associated with different types of innovation. Digitalization—the conversion of text, pictures, video, or sound into a digital form that can be processed by a computer and often referred to as the Fourth Industrial Revolution—has been occurring since the widespread adoption of computers by businesses. The introduction of cloud computing can help to accelerate the digital transition by replacing large capital expenditures on information technology (IT) with IT infrastructure, support, and software as a pay-as-you-go service. The introduction of the cloud may thus reduce the cost of experimenting with new ways of doing business reliant on digitalization, and this phenomenon may be observed in the data on innovation.

Introduction

The Fourth Industrial Revolution—the increasing use of digital information enabling data-driven decision-making—has entered its latest stage of adoption with the discovery that digitalization is also essential for contactless interaction and exchange required by the emergence of COVID-19. The universal need for digitalization extending far beyond the operation of businesses demonstrated the very uneven distribution of digital infrastructure in the form of high-speed broadband. The inability of some school children to participate fully in digital instruction was one revelation from the COVID-19 pandemic that compelled Congress to bridge the current digital divide through large investments in broadband infrastructure included in the Infrastructure Investment and Jobs Act, effective as of 15 November 2021 (Pub.L. 117–58). The Broadband Equity, Access, and Deployment Program authorized $42.45 billion for digital infrastructure investment, prioritizing unserved and underserved regions of the country. In addition to better equalizing digital service provision for households, the legislation will also provide a more level playing field for businesses implementing their digital transition (Whitacre and Biedny 2022).

The 2017 Annual Business Survey (ABS) provides the opportunity to establish a baseline for digitalization of U.S. businesses reliant on the same type of high-speed broadband reliant on availability prior to the substantial broadband investment.[1] In addition to questions on the digitalization of various business functions, the survey also asked about the use of cloud computing services. The cloud makes it possible for businesses to outsource much of the need for in-house information technology (IT) hardware and software, replacing large capital expenditures with a pay-as-you-go service (Etro 2010). The move to the cloud also has implications for the accurate measurement of gross domestic product (GDP) and productivity (Ahmad, Ribarsky, and Reinsdorf 2017; Byrne, Corrado, and Sichel 2018; Reinsdorf and Ribarsky 2019). However, the one critical technical requirement for utilizing Infrastructure as a Service (IaaS) or Software as a Service (SaaS) is high-speed broadband access. An examination of cloud computing use as distinct from the rates of digitalization across geographic categories ranging from central cities to remote rural areas provides a new view of the economic consequences of the digital divide.

The data also provide a much broader view of how the cloud may facilitate some types of innovation more than others. To the extent that more innovative firms may also tend to be earlier adopters of new technology than non-innovators, one would expect some positive association between innovation and cloud computing use. The question examined here is whether some types of innovation have a much stronger association with cloud computing that goes beyond the general innovation orientation of the firm. A critical input to any innovation is the cost of experimentation. Lowering the cost of experimentation for a given type of innovation should increase the incidence of that type of innovation in the population. The discussion considers how costs of various types of experimentation might be lowered by the cloud. The relevance of these possible cost reductions to different types of innovation is examined by estimating innovation incidence rates and the probability of reporting any specific type of innovation as a function of cloud computing use, controlling for industry, firm size, and the degree of rurality. An examination of factors, other than broadband availability, impeding the adoption of cloud computing services use precedes the conclusion, which summarizes differences in adoption rates across space, the association between cloud use and various types of innovation, and the types of follow-on research best able to address the limitations of the analysis.

Summary of the Literature Addressing Digitalization, Cloud Computing, and Innovation

Zolas et al. (2020) also use the 2017 ABS data to investigate cloud computing services use, along with artificial intelligence, robotics, several other advanced technologies, and the digitalization of business information. The analysis examines digitalization of information across specific business functions such as financial, personnel, marketing, customer feedback, supply chain, and production. Digitalization of at least one of these business functions is widespread, observed in more than 90% (75.6% non-imputed) of businesses, with digitalization of financial and personnel information the most common. Digitalization of financial and personnel information were also most likely to be observed together in the same business, with marketing and customer feedback and production and supply chain digitalization also tending to appear together. Financial and personnel information were also the most likely to be intensively digitalized by businesses. The overall picture is one of extensive digitalization of at least some information across the overwhelming majority of U.S. businesses, with older microbusinesses being the only category seemingly lagging in digitalization (Zolas et al. 2020:56).

Of all the advanced technologies examined, only cloud computing demonstrated an intermediate level of adoption with the majority of firms (54% non-imputed), indicating digitalization of at least one business function and also purchase of at least one cloud computing service (Zolas et al. 2020:25). In contrast, the highest adoption rate among other advanced technologies was 6.1% (touchscreens), with artificial intelligence technologies and robotics being under 3% (Zolas et al. 2020:63). However, adoption among larger firms was more prevalent so employment weighted rates (i.e., the probability that one would be employed at a firm using these advanced technologies) increased to 25.4% for touchscreens and close to 10% for robotics and some artificial intelligence technologies. An important finding is that cloud computing used for data analysis is most strongly associated with the adoption of other advanced technologies, reinforcing the idea that data-driven decision-making enabled by these technologies will be reliant on the greater flexibility in IT utilization available in the cloud.

Reflecting the high rate of digitalization of financial functions, the most common use of cloud computing services was for billing. Using cloud services for security, such as a digital firewall, and use for collaboration and file synchronization (e.g., OneDrive or DropBox) were the next most common applications. Data analysis that was most strongly associated with other advanced technologies was the least common cloud computing service used among specified categories, suggesting that the cloud is being used predominantly for outsourcing IT functions such as data storage, server hosting, file sharing, and billing rather than for expanding into new data-intensive technologies. However, 19.5% of all firms do use data analysis cloud computing services, which is much higher than the adoption rates of the other advanced technologies, suggesting that the cloud may play an important role in the diffusion of these advanced technologies.

Zolas et al. (2020:73) provide a preliminary examination of the associations between different cloud computing uses and innovation defined generally as any product or process innovation. Cloud computing uses associated with the outsourcing of IT functions such as billing, storage, and servers demonstrate little association with any innovation. The strongest association with any innovation is for customer feedback, and collaboration or synchronization cloud computing services. The different associations between specific cloud computing uses and any innovation suggest an alternative set of hypotheses; namely, how any cloud computing use is associated with specific types of innovation investigated below.

One topic investigated in the literature is the degree to which the cloud enables experimentation—a critical consideration in assessing how the cloud may facilitate innovation. Ewens, Nanda, and Rhodes-Kropf (2018) investigate experimentation across the business ideas of high-tech start-ups by venture capital firms. The introduction of cloud computing services in 2006 by Amazon Web Services (AWS) and the subsequent decline in prices as more competitors entered the market transformed early-stage funding for start-ups whose business plans were heavily reliant on a digital infrastructure and a strong online presence such as e-commerce websites, social media, and SaaS. Replacing the large, fixed investments in servers, networking gear, and databases with the flexible variable costs available in the cloud allowed venture capital firms to fund many more start-ups in these online sectors with significantly smaller early-stage investments. Ewens, Nanda, and Rhodes-Kropf (2018:422) identify “an increased prevalence of a ‘spray and pray’ investment approach—where investors provide a little funding and limited governance to an increased number of startups that they are more likely to abandon, but where initial experiments significantly inform beliefs about the future potential of the venture.”

The ability of the cloud to inform the potential of digitalization initiatives within the firm is investigated by Jin and McElheran (2017), focusing on young firms in the U.S. manufacturing sector. The examination of young firms allows investigation of one of the primary reasons for their high failure rate: costly learning regarding the productivity of irreversible investments. Using IT service expenditures as a proxy for cloud computing, Jin and McElheran find that such expenditures reduce the annual failure rate of young firm by about 5%, whereas traditional IT investments increase the annual failure rate by roughly the same percentage. In contrast, while IT service expenditures in older firms also reduced the failure rate so did traditional IT investments. Older firms appear to be better able to exploit the specialization and scale advantages of in-house IT investments but also appear to be able to exploit the learning advantages of the cloud as their younger peers do. The reduction in risk associated with new digitalization initiatives afforded by the cloud may translate into more experimentation with new ways of doing business.

The focus on young firms to better exploit digitalization through the cloud extends broadly to all small firms. The potential exclusion of small and medium-sized enterprises (SMEs) from the Fourth Industrial Revolution motivated the Digital for SMEs Global Initiative at the Organisation for Economic Cooperation and Development (OECD) to track digitalization trends and share best practices among member countries. The initiative took on new urgency during the COVID-19 pandemic as digital forms of commerce displaced the person-to-person exchange that is the lifeblood of many small businesses. OECD (2021) provides information on the greater resiliency of digitalized SMEs in responding to the pandemic, factors impeding digitalization in the sector, and the much slower uptake of cloud computing services relative to large businesses. Comparison across member countries demonstrate wide variation in the use of cloud computing services by firms with between 10 and 49 employees. The four Nordic countries (Finland, Sweden, Norway, and Denmark) had at least 60% of SMEs on the cloud while the Canadian share was just over 20% (data from the United States were not provided). The high rate of cloud services use in Nordic countries reflects in part successful efforts in minimizing the digital divide (Lucendo-Monedero, Ruiz-Rodríguez, and González-Relaño 2019). The ABS data provided below will not only be able to fill in the missing U.S. data from the OECD (2021) report but will also provide information on cloud computing services use among microbusinesses (firms with fewer than 10 employees).

Research on cloud computing services use and access to high-speed broadband in the United States has not yet been published at the time of this writing. However, the economic implications of inadequate digital infrastructure in some regions of the United States have garnered much attention (Whitacre, Gallardo, and Strover 2014). Recent research examining the effect of available broadband speed on business start-ups illuminates the potential for the cloud to reduce the need for irreversible investments in digitalization with unknown returns identified by Jin and McElheran (Deller, Whitacre, and Conroy 2021). In fact, the only mention of the cloud in the article pertains to the effect of fast upload speeds increasing the number of business start-ups in some industries (professional, scientific and technical services; health and social services; wholesale trade; finance and real estate) but not others (Other Services including repair/maintenance services and personal services, and Transportation). Inadequate upload speeds in an area would foreclose the opportunity to outsource digital functions critical to the first set of industries, substantially increasing start-up costs through needed IT capital expenditures.

The seriousness of the digital divide across more sparsely populated areas is tracked by the Federal Communications Commission (FCC) Form 477 data on broadband access and adoption. In the report, pertinent to the 2017 ABS data collection, 68.6% of residents in rural areas had access to high-speed internet (defined as 25 Mbps download and 3 Mbps upload from fixed terrestrial and 5 Mbps/1 Mbps from cellular) compared to 97.9% of residents in urban areas (FCC 2018). Broken out by Rural-Urban Continuum Code (RUCC), residents living in completely rural counties (no urban settlement of 2,500) were least likely to have access to high-speed internet (58% to 60%), while residents in the largest nonmetropolitan counties (urban settlements with a population between 20,000 and 50,000) had access rates between

87% and 89% (Rinehart 2018). Access rates in the intermediate nonmetropolitan category (urban settlement with a population between 2,500 and 19,999) were 72% (Rinehart 2018). As broadband access is a necessary condition for cloud computing services use, it is anticipated that completely rural nonmetropolitan counties will demonstrate the lowest adoption rates. However, the extent to which high-speed internet access rates and cloud computing adoption rates mirror each other is an empirical question.

Constructs of Digitalization, Cloud Computing, and Innovation in ABS

In contrast to the analysis of 2017 ABS data by Zolas et al. (2020) that examined distinct business functions that were digitalized and the specific uses of cloud computing services, this analysis considers only the occurrence of digitalization for any business function or the occurrence of any cloud computing use by a firm. Because the focus of this analysis is how digitalization, cloud computing services use, and different types of innovation are related, the combinations of specific functions and uses with innovation quickly becomes intractable. Combining the detailed analysis from Zolas and colleagues (2020) with the summary analysis of the association between cloud computing and innovation should provide a rich source of hypothesis generation. The other difference is that Zolas and colleagues (2020) impute values for digitalization and cloud computing services use for respondents that reply, “Don’t Know” and provide conditional (on function being performed) and unconditional (all firms) adoption rates. The current analysis is limited to unambiguous responses to the digitalization and cloud computing services use questions.

Information on the digitalization of different business functions in the 2017 ABS can be separated into three distinct pairs: (1) digitalization of personnel and financial information; (2) digitalization of marketing and customer feedback information; and (3) digitalization of production and supply chain information (Zolas et al. 2020). The cloud computing services use questions elicit information on services purchased for security or firewalls, servers, data storage and management (e.g., AWS or Microsoft Azure), collaboration and file synchronization (e.g., Dropbox or OneDrive), data analysis, billing and account management, and customer relationship management. Some of the digitalization functions are associated with a distinct cloud computing service, such as the close correspondence between financial information and billing and account management, or customer feedback and customer relationship management. However, most of the cloud computing services have applications across several business functions. The two common attributes of cloud computing services that make them of interest to the study of innovation more generally are the capability for greater coordination by making information easily available throughout the organization and the elasticity of digital resources in the cloud that allow increasing or decreasing them as needed. The examination of digitalization of any business function that is the prerequisite for any use of the cloud provides the most parsimonious way to examine the association between these two common attributes and various types of innovation.

The self-reported innovation measures examined in this report include any product innovation, product innovation that was new to a firm’s market indicating novelty, business practice innovation, and marketing innovation. All of the innovation questions in the 2017 ABS comply with the third edition of the *Oslo Manual* (OECD and Eurostat 2005) and represent positive measures of innovation. An innovation requires a significant change from previous products, processes, or methods but does not require that the change has been “successful” in terms of increased product sales, improved efficiency, or other beneficial outcomes required of a normative measure of innovation. From this perspective, the innovation measures are aptly suited to examining whether the lower costs of experimentation presumed by transforming many IT functions into a service rather than requiring large capital expenditures does in fact lead to significant changes in products, processes, or methods.

There are several ways that cloud computing services use might enable product innovation within firms. The findings from Zolas and colleagues (2020) that cloud computing services related to customer feedback and collaboration or synchronization were associated with any type of innovation suggest some possible mechanisms. Better tracking of market trends through data-intensive customer feedback applications might boost innovations that are new to the business as firms learn of valued features in competitors’ products (Erevelles, Fukawa, and Swayne 2015). Customer feedback applications facilitating a continuous flow of user experience data to the firm may provide a source of innovation and design ideas (Verganti, Vendraminelli, and Iansiti 2020). Data analysis cloud computing services that reduce the initial cost for artificial intelligence and machine learning applications may enable truly novel new-to-market innovations in highly complex processes such as drug discovery (Chan et al. 2019). The two factors working against the adoption of cloud computing services by firms pursuing product innovation are lingering concerns regarding the security of storing valuable proprietary information on the cloud and the more generic character of cloud computing services relative to more specialized, in-house IT capabilities (Jin and McElheran 2017). The strength of the association between cloud computing services use and product innovation is an empirical question.

Priors on the association between cloud computing services use and business practice innovation are stronger given that increasing use of data to drive decisions is at the center of much of this innovation. The examples of business practice innovation supplied to respondents in the ABS include “first time use of supply chain management, business re-engineering, knowledge management, lean production, quality management, etc.” The demands put on documentation and tight version control for many of these initiatives would favor adoption of turnkey applications in the cloud. The advantages of scale and specialization that may accrue to in-house IT applications cannot be dismissed (Jin and McElheran 2017), but even large firms may benefit from the lower cost of exploring the efficacy of various business practice innovations through the cloud.

The possible synergies between richer market information and product innovation were discussed above. However, the ABS also includes explicit marketing innovation questions related to new (1) aesthetic design or packaging, (2) methods or techniques for product promotion, (3) methods for product placement or sales channels, or (4) methods of pricing. An affirmative response to any of these questions is classified as a marketing innovation in the analysis below. Evaluating the efficacy of marketing innovations is likely to be data intensive, requiring numerous point-of-sale comparisons, and controlling for potentially confounding factors (Erevelles, Fukawa, and Swayne 2015). It is reasonable to assume that firms without the means for effectively evaluating marketing innovations would be less likely to engage in such innovation. If the cloud makes such evaluation tools more affordable for a larger number of firms, then cloud computing services use would likely increase the rate of marketing innovation.

The rates of digitalization and cloud computing services use by industry, firm size, and location are examined before investigating the association between cloud computing services use and innovation.

Digitalization and Cloud Computing Services Use

Table 1 examines the incidence of digitalization by two-digit North American Industry Classification System (NAICS) code industry along with the conditional (i.e., among firms that indicated IT function use) adoption rate of cloud computing by industry. Information (NAICS 51) had the highest incidence of both digitalization and cloud computer, with digitalization in more than 80% of firms and cloud computing services use in more than 60% of firms. The share of agriculture, forestry, fishing, and hunting (NAICS 11) firms reporting cloud computing services use was less than half that of professional, scientific, and technical services (NAICS 54) or NAICS 51. Differences in the incidence of digitalization across industries is considerably smaller. The largest percentage point differences between digitalization and cloud computing services use within an industry are found in mining (NAICS 21), durable manufacturing (NAICS 33), and NAICS 11. However, even in these industries the adoption of cloud computer services ranges from a little under a third to less than half. Given the much more recent introduction of the cloud relative to the introduction of personal computers enabling widespread digitalization, cloud adoption rates across all industries appear to have been robust.

TABLE 1

Digitalization and cloud computing, by industry

(Percent and standard error)

		Digitalization		Cloud computing	
Industry	NAICS code	Percent	Standard error of mean	Percent	Standard error of mean
Agriculture, forestry, fishing and hunting	11	63.49	2.46	30.26	3.83
Mining	21	70.90	2.80	37.05	3.67
Utilities	22	71.61	9.31	43.76	6.70
Construction	23	66.88	1.24	39.73	1.60
Food and fiber manufacturing	31	74.45	4.39	47.32	4.57
Nondurable manufacturing	32	79.48	3.19	48.74	3.92
Durable manufacturing	33	79.15	2.42	45.88	3.68
Wholesale trade	42	73.62	1.22	48.53	1.44
Retail trade	44	59.63	2.28	34.55	2.22
Retail trade	45	68.79	1.37	43.43	1.67
Transportation and warehousing	48	63.12	3.37	36.82	3.44
Transportation and warehousing	49	68.26	6.16	44.01	5.69
Information	51	83.47	1.10	65.68	1.67
Finance and insurance	52	75.17	1.20	52.04	1.32
Real estate rental and leasing	53	71.29	1.11	49.21	1.28
Professional, scientific, and technical services	54	80.62	1.14	60.79	1.18
Management of companies and enterprises	55	76.36	1.88	45.72	3.00
Administration and support and waste management and remediation services	56	70.86	1.34	46.16	1.56
Educational services	61	78.73	1.39	58.77	1.50
Health care and social assistance	62	72.64	0.73	52.77	0.59
Arts, entertainment, and recreation	71	74.99	1.56	48.9	1.58
Accommodation and food services	72	59.73	0.98	32.41	1.14
Other services (except public administration)	81	58.42	1.22	33.42	1.25

NAICS = North American Industry Classification System.

Note(s):
The titles for NAICS 31–33, which are assigned the label of "Manufacturing" in the 2017 NAICS Manual, are modified here to provide more information for the reader. Information on the detailed retail industries in NAICS 44 and NAICS 45 is available at https://www.naics.com/what-is-naics-sector-44-45-full-description-and-statistics/. Information on the detailed Transportation and Warehousing industries in NAICS 48 and NAICS 49 is available at https://www.naics.com/naics-code-description/?code=48-49.

Source(s):
National Center for Science and Engineering Statistics and Census Bureau, 2018 Annual Business Survey: Data Year 2017.

Table 2 presents a similar analysis broken out by firm size category, both for all firms in the sample and limited to single-unit firms. The incidence of digitalization and cloud computing services use is statistically lower in both microbusiness categories (1–4 and 5–9 employees) relative to larger firms, either among single-unit firms or among all firms.[2] The point estimates of digitalization and cloud computing services use incidence also tend to increase with firm size, but these differences are not statistically significant (i.e., point estimate comparisons are within the margin of error). The concern that digitalization and cloud computing services use among small businesses (10–49 employees) lags significantly behind larger businesses, as expressed in OECD 2021, appears to be less applicable to the U.S. case.[3] That same report did not investigate digitalization and cloud computing services use in microbusinesses, which do appear to lag in the U.S. case. In terms of international comparison, small business (10–49 employees) incidence of cloud computing services use is similar to a number of Western European countries (Belgium, Netherlands, Italy, and the United Kingdom) but lower than the Nordic countries (Norway, Sweden, Finland, and Denmark).

TABLE 2

Digitalization and cloud computing for all firms and single-unit firms, by firm size class

(Percent and standard error)

	Digitalization		Cloud computing	
Employment size	Percent	Standard error of mean	Percent	Standard error of mean
All firms				
1–4	64.58	0.28	40.52	0.24
5–9	71.96	0.52	47.27	0.59
10–19	77.03	0.88	52.21	1.21
20–49	80.80	1.97	55.89	3.08
50–99	84.96	2.93	61.75	3.54
100–249	86.58	2.91	63.21	3.98
250–499	86.32	1.75	62.98	4.38
500–999	83.94	14.83	58.83	12.81
1,000 or more	79.18	13.81	54.62	f
Single-unit firms				
1–4	64.57	0.28	40.51	0.23
5–9	71.95	0.52	47.27	0.58
10–19	77.02	0.88	52.20	1.21
20–49	80.58	2.00	55.73	3.21
50–99	84.51	3.62	61.87	3.97
100–249	86.08	5.23	63.54	7.15
250–499	86.20	3.48	63.64	12.05
500–999	84.76	f	63.78	f
1,000 or more	81.94	f	61.28	f

f = standard error is more than 50% of mean.

Source(s):
National Center for Science and Engineering Statistics and Census Bureau, 2018 Annual Business Survey: Data Year 2017.

Table 3 uses the single-unit firm sample to provide precise geographic information on digitalization and cloud computing use using the Economic Research Service's RUCC (Economic Research Service 2013).[4] The high rates of cloud computing services use in the Nordic countries have been attributed to their relative success in bridging the digital divide. In the U.S. case, the differences in digitalization rates across the Rural-Urban Continuum are much smaller than the difference in cloud computing services use rates, reinforcing findings on the U.S. digital divide (FCC 2018; Rinehart 2018). Digitalization rates in the largest metropolitan county category are not statistically different than rates in four out of the six nonmetropolitan county categories. In comparison, cloud computing services use rates in the largest metropolitan county category is statistically larger than rates in all but one (i.e., RUCC 5) of the nonmetropolitan county categories. Digitalization rates in the largest metropolitan county category are approximately 8 percentage points higher than in the completely rural nonmetropolitan county category, but 15 percentage points higher with respect to cloud computing services use rates. These results suggest that adoption of cloud computing services use has been slower in nonmetropolitan counties than expected if digitalization is the sole determinant of adoption. Other factors likely matter and some of these will be considered below.

TABLE 3

Digitalization and cloud computing for single-unit firms, by settlement size category

(Percent and standard error)

Rural-urban continuum code	Settlement size description	Digitalization				Cloud computing			
		Percent		Standard error of mean		Percent		Standard error of mean	
1	Counties in a metropolitan area with a population of 1 million or more	69.55		1.39		47.34		1.49	
2	Counties in a metropolitan area with a population of 250,000 to 1 million	70.42		1.42		44.88		1.65	
3	Counties in a metropolitan area with a population of fewer than 250,000	69.9		1.31		42.58		1.47	
4	Counties with an urban population of 20,000 or more adjacent to a metropolitan area	67.99		1.14		39.05	*	1.28	
5	Counties with an urban population of 20,000 or more not adjacent to a metropolitan area	69.42		1.38		41.17		1.79	
6	Counties with an urban population of 2,500 to 19,999 adjacent to a metropolitan area	63.83	*	1.05		35.41	*	1.08	
7	Counties with an urban population of 2,500 to 19,999 not adjacent to a metropolitan area	65.53		1.26		36.31	*	1.45	
8	Counties that are completely rural (urban population fewer than 2,500) adjacent to a metropolitan area	62.88		1.76		32.98	*	1.77	
9	Counties that are completely rural (urban population fewer than 2,500) not adjacent to a metropolitan area	61.04	*	1.57		32.58	*	1.89	

* = estimate is significantly different than rural-urban continuum code 1 estimate at the 0.05 level.

Note(s):
Settlement size categories are the rural-urban continuum codes constructed by the Economic Research Service using official Office of Management and Budget designations of metropolitan and nonmetropolitan counties (https://www.ers.usda.gov/data-products/rural-urban-continuum-codes.aspx). More information on the rural-urban continuum codes available here: https://www.ers.usda.gov/data-products/rural-urban-continuum-codes.aspx. These estimates are derived from companies with only a single location and may differ from the published innovation counts and estimates based on single- and multi-unit firms (Kindlon 2021). Limiting analysis to single-unit firms eliminates the potential headquarters' bias resulting from attributing innovation to the reporting location of multi-unit firms and reduces potential measurement error resulting from attributing company reports of innovation to all branch locations. The statistics allow inferences regarding the population of single-unit firms but do not allow inferences regarding the population of all firms.

Source(s):
National Center for Science and Engineering Statistics and Census Bureau, 2018 Annual Business Survey: Data Year 2017.

Innovation by Cloud Computing Services Use Status

Table 4 compares the incidence of product innovation, business practice innovation, and marketing innovation by cloud computing services use status and 2-digit NAICS code industry.[5] Product innovation is further broken out by any product innovation (either new-to-the-business or new-to-the-market) and new-to-the-market product innovation. In every industry the incidence of every type of innovation is higher among cloud computing services users relative to nonusers. This result is not surprising if one assumes that more innovative firms will be more likely to adopt new technologies, such as the cloud that was first introduced by AWS in 2006. What is less clear is the extent to which the cloud may enable different types of innovation either by lowering the cost of experimentation for new ways of doing business or by increasing the quantity and quality of information incorporated in new product ideas or for assessing innovation initiatives.[6] However, comparing the magnitude of increase in innovation incidence of cloud computing services users across innovation types does provide some clues. Across industries, the share of cloud computing services users reporting any product innovation on average is less than twice as large (1.82) as that of firms not using cloud computing services at the point estimate. This is also the case with respect to new-to-market product innovation (1.76). The share of cloud computing services users reporting business practice innovation is more than twice as large (2.34) as that of firms not using cloud computing services. The same phenomenon characterizes marketing innovation (2.38). However, when comparing upper- and lower-bound robust estimates of these ratios, the characterization of the product innovation ratios being less than 2 and the business practice and marketing innovation ratios being more than 2 is not supported. That is, robust upper-bound estimates for product innovation are more than 2, and robust lower-bound estimates for business practice and marketing innovation are less than 2. Industries such as finance and insurance (NAICS 52) where cloud computing services use appears to have a weaker association with product innovation still have a strong association with marketing innovation. If one were able to compare cloud computing services users and nonusers with identical innovation orientations, the expectation would be that cloud computing services use would be most likely to explain higher rates of business practice or marketing innovation.

TABLE 4

Incidence of various types of innovation by users and nonusers, by industry

(Percent and ratio)

Industry	NAICS code	Any product innovation			New-to-market product innovation			Business practice innovation			Marketing innovation		
		Using cloud	Not using cloud	Ratio	Using cloud	Not using cloud	Ratio	Using cloud	Not using cloud	Ratio	Using cloud	Not using cloud	Ratio
Agriculture, forestry, fishing and hunting	11	15.76	7.71	2.04	6.59	2.64	2.50	15.52	7.34	2.11	18.01	7.21	2.50
Mining	21	11.95	6.30	1.90	4.52	3.13	1.44	13.64	5.83	2.34	13.75	4.90	2.81
Utilities	22	20.44	7.37	2.77	7.26	3.10	2.34	19.62	9.25	2.12	27.50	6.61	4.16
Construction	23	16.48	9.65	1.71	5.62	3.55	1.58	18.84	7.55	2.50	23.08	9.56	2.41
Food and fiber manufacturing	31	46.55	26.77	1.74	26.03	16.16	1.61	33.54	13.97	2.40	56.41	27.51	2.05
Nondurable manufacturing	32	34.79	20.42	1.70	18.10	10.68	1.69	28.72	13.27	2.16	41.93	19.61	2.14
Durable manufacturing	33	38.02	23.34	1.63	23.78	13.71	1.73	32.40	15.05	2.15	38.31	18.78	2.04
Wholesale trade	42	34.45	21.80	1.58	20.70	13.19	1.57	23.96	9.96	2.41	38.67	17.25	2.24
Retail trade	44	27.94	17.79	1.57	14.78	8.88	1.66	20.63	8.46	2.44	40.39	18.34	2.20
Retail trade	45	36.43	22.69	1.61	20.48	12.37	1.66	23.16	9.18	2.52	46.71	21.24	2.20
Transportation and warehousing	48	16.08	7.94	2.03	5.15	2.42	2.13	21.20	8.48	2.50	21.90	8.74	2.51
Transportation and warehousing	49	20.15	9.60	2.10	8.28	4.57	1.81	26.29	11.20	2.35	26.01	9.85	2.64
Information	51	44.57	25.63	1.74	24.81	14.32	1.73	25.83	12.04	2.15	46.87	22.64	2.07
Finance and insurance	52	24.79	16.30	1.52	9.06	6.81	1.33	22.16	11.28	1.96	27.90	14.13	1.97

TABLE 4

Incidence of various types of innovation by users and nonusers, by industry

(Percent and ratio)

Industry	NAICS code	Any product innovation			New-to-market product innovation			Business practice innovation			Marketing innovation		
		Using cloud	Not using cloud	Ratio	Using cloud	Not using cloud	Ratio	Using cloud	Not using cloud	Ratio	Using cloud	Not using cloud	Ratio
Real estate rental and leasing	53	15.56	7.71	2.02	5.43	2.59	2.10	18.84	7.85	2.40	27.69	11.40	2.43
Professional, scientific, and technical services	54	27.56	15.15	1.82	11.42	6.33	1.80	22.96	9.55	2.40	29.09	11.84	2.46
Management of companies and enterprises	55	14.28	6.69	2.13	4.45	3.93	1.13	22.46	7.96	2.82	26.14	9.65	2.71
Administration and support and waste management and remediation services	56	23.20	12.55	1.85	8.15	4.38	1.86	21.67	8.98	2.41	29.82	12.23	2.44
Educational services	61	40.30	25.52	1.58	20.34	12.44	1.64	24.69	10.62	2.32	43.27	22.36	1.94
Health care and social assistance	62	24.71	14.97	1.65	8.95	5.27	1.70	21.23	9.92	2.14	26.39	11.76	2.24
Arts, entertainment, and recreation	71	30.94	17.52	1.77	15.78	8.41	1.88	20.46	8.45	2.42	40.24	18.48	2.18
Accommodation and food services	72	23.02	13.13	1.75	11.46	6.62	1.73	23.61	10.12	2.33	42.35	20.03	2.11
Other services (except public administration)	81	24.16	13.95	1.73	10.96	5.89	1.86	21.08	8.26	2.55	34.48	15.19	2.27

NAICS = North American Industry Classification System.

Note(s):
The titles for NAICS 31–33, which are assigned the label of "Manufacturing" in the 2017 NAICS Manual, are modified here to provide more information for the reader. Information on the detailed retail trade industries in NAICS 44 and NAICS 45 is available at https://www.naics.com/what-is-naics-sector-44-45-full-description-and-statistics/. Information on the detailed Transportation and Warehousing industries in NAICS 48 and NAICS 49 is available at https://www.naics.com/naics-code-description/?code=48-49.

Source(s):
National Center for Science and Engineering Statistics and Census Bureau, 2018 Annual Business Survey: Data Year 2017.

Table 5 compares the incidence of any product innovation and new-to-market product innovation, business practice innovation, and marketing innovation by cloud computing services use status and firm size category. The general trend from table 4 is repeated with the share of cloud computing services users reporting business practice or marketing innovation being significantly higher than nonusers.[7] The share of cloud computing services users reporting product innovation is somewhat higher than nonusers.[8] The major difference with table 4 is that the magnitude of the effect on business practice and marketing innovation—both in absolute terms and relative to product innovation—appears to diminish down the table as firm size increases. The smallest size class (1–4 employees) makes up a plurality of the business population and is thus most representative of the average relationships identified in table 4. The share of cloud computing services users in this size class reporting business practice and marketing innovation is more than twice that of nonusers for both point and robust estimates. The share of cloud computer users reporting either type of product innovation is also higher than nonusers, but the ratio is less than that for business practice or marketing innovation. For the largest business size class, the point estimates suggest these same ratios decline for all types of innovation considered; however, they are not estimated with enough precision to make a definitive statement regarding their relative magnitude. These suggestive findings at the point estimates are consistent with the idea that the cloud may have a larger impact on smaller firms that are less able to choose between large capital expenditures on IT and purchase of IT services (Jin and McElheran 2017).

TABLE 5

Incidence of various types of innovation by cloud adopters and non-adopters, by firm size

(Percent and ratio)

Employment size	Any product innovation			New-to-market product innovation			Business practice innovation			Marketing innovation		
	Using cloud	Not using cloud	Ratio	Using cloud	Not using cloud	Ratio	Using cloud	Not using cloud	Ratio	Using cloud	Not using cloud	Ratio
1–4	25.12	13.83	1.82	10.88	6.08	1.79	18.18	7.43	2.45	28.77	12.24	2.35
5–9	26.44	15.58	1.70	11.98	7.05	1.70	23.72	10.67	2.22	33.90	16.90	2.01
10–19	26.76	15.96	1.68	12.58	7.84	1.60	26.40	12.29	2.15	35.94	18.72	1.92
20–49	26.09	15.55	1.68	12.60	7.87	1.60	28.30	14.21	1.99	36.79	19.95	1.84
50–99	25.53	16.74	1.53	12.23	8.65	1.41	29.87	16.50	1.81	37.87	22.14	1.71
100–249	26.96	17.10	1.58	13.71	8.64	1.59	33.05	17.76	1.86	38.11	23.04	1.65
250–499	28.34	19.47	1.46	14.21	11.35	1.25	35.16	20.86	1.69	39.55	26.93	1.47
500–999	27.75	18.89	1.47	13.97	9.98	1.40	33.73	18.59	1.81	39.58	24.89	1.59
1,000 or more	34.31	24.64	1.39	19.28	15.88	1.21	39.90	27.54	1.45	47.56	31.03	1.53

Source(s):
National Center for Science and Engineering Statistics and Census Bureau, 2018 Annual Business Survey: Data Year 2017.

Table 6 compares the incidence of product innovation and new-to-market product innovation, business practice innovation, and marketing innovation by cloud computing services use status and settlement size category for single-unit firms. The pattern identified in table 4 is replicated throughout the settlement size category where the share of cloud computing services users reporting any product innovation or new-to-market product innovation at the point estimates are less than twice as high as nonusers, and the share of cloud computer services users reporting business practice or marketing innovation is more than twice that of nonusers. As was the case with table 4, robust upper-bound estimates of the product innovation ratio are above 2 and robust lower-bound estimates of business practice and marketing innovation are below 2. The most striking similarity across settlement size categories occurs in the new-to-market product innovation columns. New-to-market product innovation is the rarest type of innovation reported in the ABS and requires bringing new ideas to the market for the first time. The innovation rates are very similar by cloud computing services use status across the settlement hierarchy. The observed metropolitan advantage in new-to-market innovation appears to be due mostly to a larger percentage of cloud computing services users that innovate at close to twice the rate of nonusers (Wojan 2022). This does not necessarily imply that new-to-market innovation rates would equalize with the equalization of metropolitan and nonmetropolitan cloud computing services use as causality has not been determined. But this finding does raise questions regarding the extent to which the digital divide may have impeded innovation, with implications for investment in high-speed broadband as a possible policy lever for expanding the geography of innovation (National Science Board 2020).

TABLE 6

Incidence of various types of innovation by cloud adopters and non-adopters for single-unit firms, by settlement size category

(Percent, ratio, and standard error)

Rural-urban continuum code	Settlement size description	Any product innovation			New-to-market product innovation			Business practice innovation			Marketing innovation			Cloud computing services use	
		Using cloud	Not using cloud	Ratio	Using cloud	Not using cloud	Ratio	Using cloud	Not using cloud	Ratio	Using cloud	Not using cloud	Ratio	Using cloud	Standard error
1	Counties in a metropolitan area with a population of 1 million or more	26.38	14.79	1.78	11.76	6.66	1.77	22.69	9.44	2.40	32.46	14.73	2.20	47.34	1.49

TABLE 6

Incidence of various types of innovation by cloud adopters and non-adopters for single-unit firms, by settlement size category

(Percent, ratio, and standard error)

Rural-urban continuum code	Settlement size description	Any product innovation			New-to-market product innovation			Business practice innovation			Marketing innovation			Cloud computing services use	
		Using cloud	Not using cloud	Ratio	Using cloud	Not using cloud	Ratio	Using cloud	Not using cloud	Ratio	Using cloud	Not using cloud	Ratio	Using cloud	Standard error
2	Counties in a metropolitan area with a population of 250,000 to 1 million	25.49	14.58	1.75	11.56	6.67	1.73	21.71	9.45	2.30	31.93	14.69	2.17	44.88	1.65
3	Counties in a metropolitan area with a population of fewer than 250,000	25.08	14.82	1.69	11.22	6.81	1.65	21.16	8.99	2.35	31.66	14.46	2.19	42.58	1.47
4	Counties with an urban population of 20,000 or more adjacent to a metropolitan area	23.84	13.93	1.71	11.18	6.20	1.80	19.79	7.98	2.48	30.11	14.06	2.14	39.04	1.28
5	Counties with an urban population of 20,000 or more not adjacent to a metropolitan area	26.73	13.92	1.92	11.86	6.86	1.73	20.33	9.02	2.25	31.64	14.79	2.14	41.16	1.79
6	Counties with an urban population of 2,500 to 19,999 adjacent to a metropolitan area	22.89	13.35	1.71	10.14	6.15	1.65	19.01	8.05	2.36	28.52	12.79	2.23	35.41	1.08
7	Counties with an urban population of 2,500 to 19,999 not adjacent to a metropolitan area	24.07	13.81	1.74	11.87	6.50	1.83	19.05	7.92	2.41	28.77	12.88	2.23	36.30	1.45
8	Counties that are completely rural (urban population fewer than 2,500) adjacent to a metropolitan area	23.16	12.12	1.91	9.49	6.06	1.57	18.58	7.64	2.43	28.48	11.72	2.43	32.98	1.77
9	Counties that are completely rural (urban population fewer than 2,500) not adjacent to a metropolitan area	23.73	14.92	1.59	10.86	5.98	1.82	19.47	7.38	2.64	30.74	12.70	2.42	32.58	1.89

Note(s):
Settlement size categories are the RUCCs constructed by the Economic Research Service using official Office of Management and Budget designations of metropolitan and nonmetropolitan counties (https://www.ers.usda.gov/data-products/rural-urban-continuum-codes.aspx). More information on the rural-urban continuum codes available here: https://www.ers.usda.gov/data-products/rural-urban-continuum-codes.aspx. These estimates are derived from companies with only a single location and may differ from the published innovation counts and estimates based on single- and multi-unit firms (Kindlon 2021). Limiting analysis to single-unit firms eliminates the potential headquarters' bias resulting from attributing innovation to the reporting location of multi-unit firms and reduces potential measurement error resulting from attributing company reports of innovation to all branch locations. The statistics allow inferences regarding the population of single-unit firms but do not allow inferences regarding the population of all firms.

Source(s):
National Center for Science and Engineering Statistics and Census Bureau, 2018 Annual Business Survey: Data Year 2017.

Table 7 provides preliminary estimates of the likelihood that single-unit firms located in metropolitan counties use the cloud relative to single-unit firms in wholly rural nonmetropolitan counties not adjacent to a metropolitan area, controlling for industry and firm size. It is possible that the much slower adoption of cloud computer services in the most rural counties indicated in table 3 and table 6 is a function of the types of businesses located there. Logistic regression allows controlling for the different adoption rates by industry and firm size to provide a more accurate estimate of how likely a metropolitan firm would be to use the cloud compared with an otherwise similar rural peer. The odds ratio suggests that a single-unit firm in the largest urban county category (RUCC 1) would be 45% more likely to use the cloud than a firm in the same industry and size class in the most rural county category (RUCC 9). This difference in cloud computing services use is nearly identical to the differences presented in table 3 and table 6. The implication is that differences in industrial structure and the size distribution of firms does not explain any of the metropolitan–nonmetropolitan difference in cloud computing services use. Rejecting these possible explanations does not confirm that the observed differences are due to the digital divide, but it does narrow the range of alternative explanations.

TABLE 7

Logistic regression of cloud computing status, by settlement size category

(Odds ratio and 95% Wald confidence interval)

Variable	Settlement size description	Effect	Odds ratio	95% Wald confidence limits	
RUCC 1	Counties in a metropolitan area with a population of 1 million or more	1 vs. 9	1.453	1.423	1.484
RUCC 2	Counties in a metropolitan area with a population of 250,000 to 1 million	2 vs. 9	1.355	1.326	1.384
RUCC 3	Counties in a metropolitan area with a population of fewer than 250,000	3 vs. 9	1.267	1.24	1.296
RUCC 4	Counties with an urban population of 20,000 or more adjacent to a metropolitan area	4 vs. 9	1.152	1.126	1.179
RUCC 5	Counties with an urban population of 20,000 or more not adjacent to a metropolitan area	5 vs. 9	1.232	1.201	1.264
RUCC 6	Counties with an urban population of 2,500 to 19,999 adjacent to a metropolitan area	6 vs. 9	1.033	1.009	1.057
RUCC 7	Counties with an urban population of 2,500 to 19,999 not adjacent to a metropolitan area	7 vs. 9	1.071	1.045	1.096
RUCC 8	Counties that are completely rural (urban population fewer than 2,500) adjacent to a metropolitan area	8 vs. 9	0.992	0.96	1.025
(RUCC 9 excluded category)	Counties that are completely rural (urban population fewer than 2,500) not adjacent to a metropolitan area				

RUCC = rural-urban continuum code.

Note(s):
Industry and firm size fixed effects not reported. Settlement size categories are the RUCCs constructed by the Economic Research Service using official Office of Management and Budget designations of metropolitan and nonmetropolitan counties (https://www.ers.usda.gov/data-products/rural-urban-continuum-codes.aspx). These estimates are derived from companies with only a single location. Limiting analysis to single-unit firms eliminates the potential headquarters' bias resulting from attributing innovation to the reporting location of multi-unit firms and reduces potential measurement error resulting from attributing company reports of innovation to all branch locations. The statistics allow inferences regarding the population of single-unit firms but do not allow inferences regarding the population of all firms.

Source(s):
National Center for Science and Engineering Statistics and Census Bureau, 2018 Annual Business Survey: Data Year 2017.

Table 8 presents results from applying the logistic regression model to the likelihood that cloud computing services users reported any of the four types of innovation, controlling for industry, firm size, and settlement size for single-unit firms. The results are qualitatively identical to the results presented in table 4 and table 6: cloud users are less than twice as likely to report product innovation and more than twice as likely to report business practice or marketing innovation relative to nonusers. However, the magnitude of the effect appears to be even larger for both marketing and business practice innovation. In fact, both odds ratio estimates are closer to 3 than to 2. These estimates can be thought to represent the naïve effect of cloud computing services use on innovation, abstracting from the role that the innovation orientation of a firm may play in the decision to use the cloud. Before discussing the limitations of this analysis and how they might be addressed, information from the 2019 ABS on impediments to adopting cloud computing services are briefly discussed.

TABLE 8

Logistic regression of various types of innovation

(Odds ratio and 95% Wald confidence limit)

Variable	Product innovation			New-to-market innovation			Business practice innovation			Marketing innovation		
	Odds ratio	95% Wald confidence limits		Odds ratio	95% Wald confidence limits		Odds ratio	95% Wald confidence limits		Odds ratio	95% Wald confidence limits	
Any cloud computing service	1.945	1.935	1.955	1.787	1.774	1.799	2.538	2.524	2.552	2.798	2.784	2.811

Note(s):
Settlement size defined by rural-urban continuum code category, industry, and firm size fixed effects not reported. More information on the RUCCs available here: https://www.ers.usda.gov/data-products/rural-urban-continuum-codes.aspx.

Source(s):
National Center for Science and Engineering Statistics and Census Bureau, 2018 Annual Business Survey: Data Year 2017.

Impediments to Adopting Cloud Computing Services

Table 9 summarizes responses from several questions included in the 2019 ABS that asked businesses about impediments to adopting cloud computing services. The survey did not ask if lack of access to high-speed broadband was an impediment. A majority of firms (54.26%) indicated that there were no factors that adversely affected adoption of the technology. Three out of 10 firms reported that the technology was not relevant to their business. The two responses answered affirmatively by significantly more than 1% of businesses included concerns about the costs of cloud computing services (6.92%) and its security (4.14%). Impediments related to inadequate or insufficient data, human resources, or financial capital were rarely noted. By means of comparison, if the 33% of nonmetropolitan firms likely to have had inadequate broadband in 2017 had been asked about this as a possible impediment to adopting cloud computing services in ABS, that would amount to roughly 5% of U.S. businesses.

TABLE 9

Factors adversely affecting adoption and utilization of cloud computing services

(Percent and standard error)

Factor	Percent	Standard error of mean
This technology was too expensive	6.92	0.06
The technology was not mature	1.07	0.03
Lacked access to required data	0.76	0.02
Required data not reliable	0.53	0.03
Lacked access to required human capital and talent	1.03	0.05
Laws and regulations	0.96	0.05
Concerns regarding safety and security (physical security and/or cybersecurity)	4.14	0.12
Lacked access to capital	1.35	0.05
Technology not applicable to this business	30.39	0.39
No factors adversely affected the adoption of this technology	54.26	0.27

Source(s):
National Center for Science and Engineering Statistics and Census Bureau, 2019 Annual Business Survey: Data Year 2018.

Conclusions and Limitations of the Analysis

Information collected through the 2017 ABS provides new insights on the digitalization of U.S. businesses, the uptake of cloud computing services, and the association of cloud computing services with various types of innovation. The information on cloud computing services is particularly valuable at this time when the rapid digitalization of activities inside and outside of businesses due to the COVID-19 pandemic has demonstrated deficiencies in the nation's digital infrastructure. The findings presented here are consistent with a slower uptake of cloud computing services in those regions of the country most likely to be underserved by adequate high-speed broadband. However, the information available in the 2017 ABS is not able to confirm that the slower uptake is not due to alternative explanations. Linking the 2017 ABS to FCC Form 477 data would allow testing if the slower rate of adoption by nonmetropolitan firms persists in places with access to high-speed broadband. Future analysis of ABS data after the implementation of the Broadband Equity, Access, and Deployment Program—directed to bridging the regional digital divide—would also inform the extent to which inadequate digital infrastructure delayed adoption of cloud computing services. The current analysis provides a valuable baseline for future work.

The current analysis also identified a very strong association with cloud computing services use and product, business practice, and marketing innovation. However, additional research is required to determine the extent to which the cloud enables the various types of innovation versus adoption of cloud computing services merely serving as an indicator of an extant innovation orientation. Moving from the current naïve association to testing causal relationships between the cloud and innovation could be pursued in several ways. Testing if cloud computing services use merely signals a strong innovation orientation could be done using propensity score matching (Li 2013). If firms using the cloud are matched to nonusers on characteristics strongly associated with innovation orientation, then the association between cloud computing services use and innovation would be net of innovation orientation explained by the matching variables. Alternatively, if the innovation orientation of firms is believed to be largely unobservable, then modeling the association between cloud computing services use and innovation as an endogenous treatment could control for this source of endogeneity (Vella and Verbeek 1999).

The strong association between various types of innovation and any cloud computing services use opens additional questions regarding the association of specific cloud computing services on adoption of particular advanced technologies and their association with specific types of innovation. Zolas et al. (2020) demonstrated that replacing in-house IT for some universal business functions, such as billing, with services from the cloud have little association with innovation. Data from the 2017 ABS would support a deeper dive into how specific cloud computing services are being used to augment data-driven management through advanced technologies and how this may be facilitating different types of innovation.

References

Ahmad N, Ribarsky J, Reinsdorf M. 2017. *Can Potential Mismeasurement of the Digital Economy Explain the Post-Crisis Slowdown in GDP and Productivity Growth?* OECD Statistics Working Papers, No. 2017/09. Paris: OECD Publishing. Available at https://doi.org/10.1787/a8e751b7-en.

Byrne D, Corrado C, Sichel DE. 2018. *The Rise of Cloud Computing: Minding Your P's, Q's and K's*. NBER Working Paper No. 25188. Cambridge, MA: National Bureau for Economic Research. Available at https://www.nber.org/papers/w25188.

Chan SHC, Shan H, Dahoun T, Vogel H, Yuan S. 2019. Advancing Drug Discovery via Artificial Intelligence. *Trends in Pharmacological Sciences*, 40(8):592–604. Available at https://doi.org/10.1016/j.tips.2019.06.004.

Deller S, Whitacre B, Conroy T. 2021. Rural Broadband Speeds and Business Startup Rates. *American Journal of Agricultural Economics* 104(3):999–1025. Available at https://doi.org/10.1111/ajae.12259.

Economic Research Service, U.S. Department of Agriculture. 2020. *Rural-Urban Continuum Codes*. Available at https://www.ers.usda.gov/data-products/rural-urban-continuum-codes.aspx.

Erevelles S, Fukawa N, Swayne L. 2016. Big Data Consumer Analytics and the Transformation of Marketing. *Journal of Business Research* 69(2):897–904. Available at https://doi.org/10.1016/J.JBUSRES.2015.07.001.

Etro F. 2010. The Economic Consequences of the Diffusion of Cloud Computing. In Dutta S, Mia I, editors, The Global Information Technology Report 2009–2010*:* ICT for Sustainability, pp. 107–112. Geneva: World Economic Forum. Available at https://www3.weforum.org/docs/WEF_GITR_Report_2010.pdf.

Ewens M, Nanda R, Rhodes-Kropf M. 2018. Cost of Experimentation and the Evolution of Venture Capital. *Journal of Financial Economics* 128(3):422–442. Available at https://doi.org/10.1016/j.jfineco.2018.03.001.

Federal Communications Commission (FCC). 2018. *2018 Broadband Deployment Report*. Available at https://www.fcc.gov/reports-research/reports/broadband-progress-reports/2018-broadband-deployment-report.

Haug KC, Kretschmer T, Strobel T. 2016. Cloud Adaptiveness within Industry Sectors–Measurement and Observations. *Telecommunications Policy* 40(4):291–306. Available at https://doi.org/10.1016/j.telpol.2015.08.003.

Jin W, McElheran KS. 2017. *Economies Before Scale: Learning, Survival, and Performance of Young Plants in the Age of Cloud Computing*. Rotman School of Management Working Paper No. 3112901. Available at SSRN: https://ssrn.com/abstract=3112901 or http://dx.doi.org/10.2139/ssrn.3112901.

Kindlon A; National Center for Science and Engineering Statistics (NCSES). 2021. *First Comprehensive Innovation Survey for the United States: Data from the 2017 Annual Business Survey*. NSF 21-334. Alexandria, VA: National Science Foundation. Available at https://ncses.nsf.gov/pubs/nsf21334/.

Li M. 2013. Using the Propensity Score Method to Estimate Causal Effects: A Review and Practical Guide. *Organizational Research Methods* 16(2):188–226. Available at https://doi.org/10.1177/1094428112447816.

Lucendo-Monedero AL, Ruiz-Rodríguez F, González-Relaño R. 2019. Measuring the Digital Divide at Regional Level. A Spatial Analysis of the Inequalities in Digital Development of Households and Individuals in Europe. *Telematics and Informatics* 41:197–217. Available at https://doi.org/10.1016/j.tele.2019.05.002.

National Science Board. 2020. *Vision 2030*. Report # NSB-2020-15. Available at https://www.nsf.gov/nsb/publications/2020/nsb202015.pdf. Accessed 1 June 2022.

OECD, Eurostat. 2005. *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data*, 3rd ed. Paris: OECD Publishing.

OECD. 2021. *SME Digitalisation to "Build Back Better": Digital for SMEs (D4SME) Policy Paper*. OECD SME and Entrepreneurship Papers, No. 31. Paris: OECD Publishing. Available at https://doi.org/10.1787/50193089-en.

Reinsdorf M, Ribarsky J. 2019. *Measuring the Digital Economy in Macroeconomic Statistics: The Role of Data*. Paper presented at the Allied Social Science Associations 2020 Annual Meeting, San Diego, CA, 3–5 January. Available at https://www.aeaweb.org/conference/2020/preliminary/paper/9ETsrnQH. Accessed 1 June 2022.

Rinehart W. 2018. *A Look at Rural Broadband Economics*. American Action Forum. Available at https://www.americanactionforum.org/research/a-look-at-rural-broadband-economics.

Sunyaev A. 2020. Cloud Computing. In *Internet Computing: Principles of Distributed Systems and Emerging Internet-Based Technologies*, pp. 195–236. Switzerland: Springer, Cham. Available at https://doi.org/10.1007/978-3-030-34957-8_7.

Vella F, Verbeek M. 1999. Estimating and Interpreting Models with Endogenous Treatment Effects. *Journal of Business & Economic Statistics* 17(4):473–478. Available at https://DOI.org/10.1080/07350015.1999.10524835.

Verganti R, Vendraminelli L, Iansiti, M. 2020. Innovation and Design in the Age of Artificial Intelligence. *Journal of Product Innovation Management* 37(3):212–227. Available at https://doi.org/10.1111/jpim.12523.

Whitacre B, Biedny, C. 2022. A Preview of the Broadband Fabric: Opportunities and Issues for Researchers and Policymakers. *Telecommunications Policy* 46(3):102281. Available at https://doi.org/10.1016/j.telpol.2021.102281.

Whitacre B, Gallardo R, Strover S. 2014. Broadband's Contribution to Economic Growth in Rural Areas: Moving Towards a Causal Relationship. *Telecommunications Policy* 38(11):1011–1023. Available at https://doi.org/10.1016/j.telpol.2014.05.005.

Wojan TR; National Center for Science and Engineering Statistics (NCSES). 2022. *The Geography of Self-Reported Innovation: Results from the 2017 Annual Business Survey*. Working Paper NCSES 22-206. Alexandria, VA: National Science Foundation. Available at https://ncses.nsf.gov/pubs/ncses22206.

Zolas N, Kroff Z, Brynjolfsson E, McElheran K, Beede DN, Buffington C, Goldschlag N, Foster L, Dinlersoz E. 2020. *Advanced Technologies Adoption and Use by U.S. Firms: Evidence from the Annual Business Survey*. NBER Working Paper No. 28290. Cambridge, MA: National Bureau for Economic Research. Available at https://www.nber.org/system/files/working_papers/w28290/w28290.pdf.

Notes

1 The survey instrument is available from the NCSES website at https://www.nsf.gov/statistics/srvyabs/. Data tables from the Digital Technology Module are available from the Census Bureau website at https://www.census.gov/data/tables/2018/econ/abs/2018-abs-digital-technology-module.html. In the inaugural year of ABS, NCSES used the reference year to name the dataset while the Census Bureau used the data collection year to name the dataset.

2 Differences with the two largest firm size classes are not statistically different due to the small sample size for these classes resulting in large standard errors. Powerful tests of differences in ratios from a binomial distribution require relatively large samples. The available low power tests do not support any statistical inference.

3 A higher share of large firms responded "Don't Know" to the cloud computing services use questions relative to smaller firms, so the non-imputed statistics reported here may underestimate incidence for this category.

4 Multi-unit firms may have operations in locations that differ by rurality. As a firm-level survey, the location ascribed to ABS responses will be the main reporting unit, oftentimes a headquarters location. Responses from a single-unit firm pertain only to the operations at the geographical location indicated in the data.

5 Business practice innovation refers to business practices for organizing procedures includes first time use of supply chain management, business re-engineering, knowledge management, lean production, quality management, etc. Marketing innovation refers to when firms introduce new (1) aesthetic design or packaging, (2) methods or techniques for product promotion, (3) methods for product placement or sales channels, or (4) methods of pricing.

6 It is important to note that technological capabilities or usage are not explicitly linked to innovation in the *Oslo Manual* (OECD and Eurostat 2018) even if advanced technology use is often associated with innovation. The availability of a technology is neither a necessary nor sufficient condition for innovation to occur. However, recognition of "digitalisation… as a key factor driving innovation" (OECD and Eurostat 2018:38) is consistent with the view expressed here that the cloud, as a technology dramatically reducing the cost of digitalization, may enable innovation.

7 The differences are statistically significant for firm size classes up to 50–99 employees. Above this size class, larger sampling errors do not allow the conclusion that the differences in innovation incidence are statistically different.

8 These differences are statistically significant for the firm size classes up to 20–49 employees. Above this size class, larger sampling errors do not allow the conclusions that the differences in innovation incidence are statistically different.

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