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THE GREAT UPGRADE

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Abstract

Research on the diffusion of digital technologies, particularly in developing countries, is constrained by the lack of data. While there has been some evidence on growing digital technology use in particular contexts, little is known about the relative pace of the transition online across countries, and the impact of the COVID-19 pandemic on these trajectories. This study uses high-frequency data on the technologies embedded in the near universe of websites across the world to address these questions. Descriptive trends show that while many countries experienced rapid diffusion of e-commerce, online payments and digital advertising technologies, absolute gaps in website technology use across countries widened during 2020. Our identification strategy uses the differential timing of the onset of COVID-19 across countries in Spring 2020 and employs the latest event-study methodologies, accounting for staggered treatment effects, to measure how COVID affected the use of online transaction technologies across countries. Our analysis shows that COVID-19 lockdowns strongly predict increased use of e-commerce and online payment technologies, accounting for about a quarter of the overall growth in their usage over 2020. However, the shock also magnified gaps in technology use across countries. Frontier countries with higher initial levels of technology use experience significantly faster diffusion than laggard countries after the shock. While much of the recent debate has focused on the potential dividends to firms or households from a COVID-induced adoption of digital technologies, this study suggests that any dividend may be spread increasingly unequally across countries at different levels of development. The COVID-19 shock has brought to surface persistent failures in enabling conditions for online market growth in a large number of developing countries.

Keywords: E-commerce; Technology adoption; Digital technologies; Covid-19
JEL: O12; O33; L86

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1 Introduction

Experts from the 'Virtual Society Project,' funded by the UK Economic and Social Research Council, qualified the internet as a 'passing fad' in an influential report published in 2000 (The Guardian, 2000). It took less than twenty years for this prediction to prove untrue, and a global pandemic to fully appreciate the role of the internet in supporting the resilience of anything from social capital to economic activity around the world. Yet, much of the research around digital technology growth, particularly in developing countries, is constrained by the lack of available data with global coverage (OECD and WTO, 2017). Evidence on technology use is often restricted to the few countries for which data exists (e.g. Cirera et al., 2020).

As COVID-19 lockdowns were imposed around the world and customers avoided in-person visits to retail stores, businesses had to transition online to maintain their sales. Anecdotally COVID-19 appears to have accelerated the pace of digitization globally; however, little is known about the relative pace of transition across different countries and markets, and the convergence dynamics that might be in place. A World Bank survey of 51 developing countries found that 34 per cent of firms had increased their use of digital platforms in response to COVID-19, but noted that these rates varied substantially across countries (Apedo-Amah et al., 2020).[1] Other evidence suggests that less developed economies are 'catching up' by experiencing greater increase in e-commerce or more downloads of fintech apps than high-income countries (Alfonso et al., 2021; Fu and Mishra, 2022). At the same time, a record number of enterprises have gone out of business across developing and high-income economies and margins to invest in some digital solutions have narrowed due to liquidity constraints. Therefore, the overall effect of the pandemic on online technology diffusion in different markets remains ambiguous.

In this paper, we argue that COVID-19 has accelerated online technology adoption unevenly across countries and types of technology. Using a novel high-frequency source of data on nearly the universe of websites and the technologies embedded within them, we document a rapid growth of adoption of three types of technologies in 2020: e-commerce, online payments and digital advertising. These high-frequency data, collected in a consistent manner since mid-2018, provide a thorough account of the functionalities used in firms' websites - our measure of online technology adoption across countries.[2] Descriptive trends show that, while many countries experienced rapid diffusion of e-commerce, online

[1]Other emerging economies moved in the same direction; however, the available data suggests that the uptake of technologies remains far lower in developing countries (World Bank, 2016, 2021a). Limited access to internet offers an obvious explanation, although internet use can remain low even in countries with relatively widespread access (see GSMA, 2021 for discussion of South Asia).

[2]Our data captures the presence of technologies within a website, rather the intensity of their use; for instance detecting e-commerce functionality rather than tracking the value of online transactions.

payments and digital advertising technologies, absolute gaps in website technology use across countries widened during 2020.

To causally assess the impact of COVID-19 on technology use, we use monthly differences in the timing of COVID across countries. We find that the COVID-19 pandemic and the ensuing mobility restrictions appear to strongly predict the diffusion of digital technology. We employ several event study specifications that allow for staggered treatment designs (following Callaway and Sant'Anna, 2021), in order to compare the changes in technology adoption in countries imposing lockdowns against those for which lockdowns are not yet in place. We find strong evidence of COVID-19 lockdowns leading to increases in e-commerce and online payment diffusion, which is robust to a wide array of different estimation techniques and COVID-19-related restrictions in each country. Focusing on first lockdowns during Spring 2020, we find no evidence of diffusion in anticipation of COVID-19 restrictions. The shock however appears to have accelerated divergence dynamics across countries, with stronger lockdown effects in countries with higher initial use of different functionalities.

We view COVID as a digital demand shock, raising the demand for pre-existing technologies for online transactions. All of the e-commerce, online payments and digital advertising technologies we consider in this paper already existed before COVID. This view is rare in the existing literature on technology use, which tends to focus more frequently on the impact of supply side shocks, such as new technology infrastructure.[3] In this sense, our paper is perhaps closest to the work of Crouzet et al. (2019), who use the 2016 Indian demonetization shock constraining the availability of physical money to examine the diffusion of electronic payment systems. Similarly, Fu and Mishra (2022) combine the timing of COVID across countries with high-frequency data on finance app downloads to examine differential impacts across fintech firm types.

All of the research strands on technology use in developing countries, however, are constrained by the lack of comprehensive cross-country data. A number of papers have used the World Bank Enterprise Surveys to measure the impact of technology use (e.g. Hjort and Poulson, 2019; or Cusolito et al., 2020). These surveys only contain basic information on the use of the internet or email. Others, such as Cirera et al. (2020, 2022), rely on primary data collection to fill the gap, which provide only a snapshot in time and for a handful of countries, so cannot speak to trends across countries. We contribute to this literature by using rich panel data on the use of technologies for online transactions for 177 countries.

[3] For example, Hjort and Poulson (2019) show that the connection of East African submarine cables led to increases in firm productivity and employment across all types of worker skill. Cirera et al (2022) report that across eleven mainly developing countries, limited demand is the biggest barrier to technology adoption.

The rest of the paper is structured as follows. Section 2 describes the new data as well as the methodology we developed for its analysis. Section 3 presents evidence on technology diffusion across countries during COVID-19. The last section offers concluding remarks and policy implications.

2 Data

Our analysis primarily relies on data on the use of website technologies from *BuiltWith*, a commercially available dataset, which we combine with publicly available measures of COVID-19 lockdowns and cases from the Oxford COVID-19 Government Response Tracker as well as country characteristics from the World Development Indicators (World Bank, 2021b).

We use the timing of COVID-19 lockdowns as the event of interest, defined as the first time that a recommendation not to leave one's main residence is issued.[4] Out of a concern of possible anticipation effects we exclude eight countries taking restrictions for the first time after May 2020, and focus on countries with lockdowns from January to April 2020 or those with no lockdowns during 2020.[5] We also examine robustness to using the timing of first COVID-19 cases in each country, defined as more than one case per 10 million people.

BuiltWith provides monthly data on website technology use in binary format, i.e tracking whether specific functionalities are in use. This data has been used previously for examining the performance of high-tech startups and the use of specific data analytics technologies (Koning et al., 2019). However, to our knowledge, we are the first user of the global data set, from which we construct country-level measures of broad technology usage within websites. The raw BuiltWith data is scraped using the source-code information embedded in company websites. Websites are continuously crawled such that virtually every website in the world is scraped every 1 to 4 weeks. The scraping frequency is based on the website's Google PageRank, with the most popular websites (also likely to have the highest frequency of technology changes) being updated every week in the data.[6]

The BuiltWith data in principle contains close to the universe of active websites in

[4] Level 1 or higher stay-at-home recommendation, according to the Oxford COVID-19 Government Response Tracker. Note there is relatively limited variation in the timing of these lockdowns across countries constraining the identification power of the event study, as reported in Annex Table A4. Similar results are obtained using the timing of COVID-19 workplace closure restrictions (the results are available upon request). One potential limitation is that the implementation of these policies may vary across jurisdictions, which motivates our consideration of robustness to using COVID-19 cases per capita. All variables are explained in more detail in the Annex.

[5] We later present further analysis of anticipation effects by examining earlier and later COVID-19 lockdown cohorts individually.

[6] The less frequent updating of less popular websites would likely add additional noise to our estimates, for instance, as some technology changes are reflected in the subsequent month's data.

the world and has been collected in a consistent manner since mid-2018. For this reason, we focus on data in 2019 and 2020 in our analysis. The set of websites to scrape is obtained monthly from public Secure Socket Layer (SSL) lists, a de-facto registry of all secure websites (i.e. with SSL certificates) since the protocol became a Google Chrome requirement in April 2018 (so-called Certificate Transparency).[7] BuiltWith supplements the SSL list twice per year by following links within each of the websites already in their data to other websites. Links pointing to websites which are not already in the data are added to the sample. To obtain a consistent sample of websites over time, we focus on websites with SSL certificates, meaning user data sent to and from the website can be encrypted (which is a pre-requisite for any financial transactions).[8] Imposing this condition has the advantage of excluding websites that appear to have no clear commercial purpose, such as those related to individuals or social organizations.

We allocate websites to countries in several steps, using relevant fields of information provided in the data. Firstly, BuiltWith scrapes information on company addresses and telephone numbers present on a website. Our first step, is therefore to use these addresses and international dialing codes to geolocate websites. Secondly, BuiltWith collects sophisticated information on the language of text within a website, for instance using semantic differences to distinguish between Swiss French and France's French. For websites not matched to a country in step one, we match the website's language to the official spoken language of the country, clearly excluding languages that are spoken in multiple countries (e.g. Spanish). Thirdly, for the remaining websites, we use their top-level domain, such that websites ending in ".uk" are assumed to be from the UK, ".fr" are assumed to be from France and so on, following the approach of Freund and Weinhold (2002).[9] We exclude all websites with generic top-level domains, ".org" ".edu" ".net" ".com" or ".int", that do not have addresses, telephone numbers or a unique country language. Since ".com" is the primary domain ending for American companies, we completely exclude the United States from our analysis. We also exclude outliers in terms of number of websites per capita and countries that offer their domains free-of-charge, resulting in their top-level domains being used widely outside their territory.[10] The full list of 177 countries in our data is reported in Annex Table A1. The resulting allocation is validated by a positive correlation between

[7] An SSL certificate (Secure Sockets Layer) is a digital certificate that validates a website's identity and allows encryption between a user's internet browser and the firm's server – thus data can be transmitted securely between users and the website.

[8] We restrict the sample to websites that have an SSL certificate at any point from birth until December 2020.

[9] About 20% of websites in our data are allocated to countries using their reported address; 20% using their telephone number; 10% using the language of the website and just under half of the websites according to their top-level domain.

[10] This trim excludes Central African Republic, Equatorial Guinea, Gabon, Mali and Tokelau, Palau, Micronesia, Montenegro, Samoa, Tonga, and Tuvalu.

websites per population and the share of firms having a website, as reported in the latest World Bank Enterprise Surveys (see Annex Figure A1).

BuiltWith measures the presence of over 30,000 website technologies across different technology providers, which it aggregates into broad categories based on their function. For example, the technology "Google Analytics" is categorized under "Analytics and Tracking". The data captures the presence of a technology (e.g. online payment functionality), rather than the intensity of its use by customers (e.g. how many online payments are made), for which we have no information.

Measures of technologies embedded in a firm's website are likely to be a lower bound of technology use in a country, since firms can engage in e-commerce by using social media or other digital platforms rather than through their own website. However, while data on platform use across countries is scarce, firm websites appear to reflect the bulk of e-commerce activity and there is no evidence of greater use of platforms as opposed to own websites in developing countries. In Europe, for example, nearly 90% of firm e-commerce sales are through their own website rather than a platform, while even for small firms, sales through their website account for 80% of e-commerce (see Eurostat, 2020). The gap between the share of firms' turnover from own websites and turnover from online marketplace also does not appear to reflect income level differences across the continent. In fact, evidence from Google Trends - a proxy for online platform use - shows that the increase in platform use during the first half of 2020 was more pronounced in industrialized rather than developing economies (OECD, 2021).

The seven technology categories we use in our analysis are listed in Table 1.[11] 'Advertising' reflects the use of advertising on a firm's website (such as via Doubleclick).[12] 'Analytics' measures the use of analytics and software that tracks visitors to a website and their behavior on it, such as clicks or purchases. 'Audio-video' indicates the presence of functionalities for live streaming or webcasts or embedded videos from social media (such as YouTube). 'E-commerce' reflects the use of e-commerce software, such as online shopping plugins, links to e-commerce platforms or use of open-source software to develop their own online store. 'Mapping' indicates the use of mapping tools (such as Google Maps), and 'Mobile' reflects having mobile-friendly website functionality. 'Payments' includes the presence of checkout buttons or the use of payment acceptance software or links to payment processor websites (such as PayPal).

Changes in aggregate technology use over time confound the technology upgrading of

[11] We focus on the 8,000 website technologies across seven categories that are of economic interest. We neglect 22 other technology categories such as document encoding standards, content delivery networks, servers or web-hosting software, as well as those not relating to technology, such as mention of copyright on a website or language.

[12] Note that advertisements are likely by firms other than the owner of the website which, aggregated at a country-level, can proxy for digital advertising diffusion.

Table 1: Shares of Websites using Online Technologies by country

	December 2019		December 2020	
	Mean	*s.d.*	*Mean*	*s.d.*
Advertising	0.23	0.09	0.27	0.10
Analytics	0.43	0.11	0.47	0.12
Audio-Video	0.18	0.05	0.21	0.06
E-commerce	0.14	0.06	0.17	0.07
E-payments	0.11	0.07	0.17	0.08
Mapping	0.12	0.04	0.14	0.05
Mobile	0.70	0.08	0.74	0.08
Mean Websites per Country	244,089			

Notes: The list of 177 countries retained is in Annex Table A1. The sample reflects a balanced panel of websites existing at December 2019 and present at December 2020. Technologies of new websites born during 2020 are reported in the Annex Table A2.
Source: Authors' calculation using BuiltWith.

existing websites and the technologies of new websites at entry.[13] If new websites have fewer technologies than existing ones, then the entry of new websites can mean the rate of average technology usage falls over time. Accordingly, we distinguish between the two. For the main part of our analysis, we focus on the intensive margin of technology adoption – i.e. upgrading of existing websites – using a balanced panel of websites existing in our data in December 2019 and present a year later. We supplement this analysis with an examination of the extensive margin in the Annex – i.e. technology use of new websites – and the change in the number of websites over the same period.

A static analysis of technology usage offers several insights. Most websites are basic, containing only readily and freely available functionalities, whereas technologies that allow online transactions are rare. Only around 13 percent of websites have any form of paid functionality in their website – predominantly related to e-commerce or Audio-Video. In the other categories of technology, the vast majority of websites only have free-of-charge functionalities (see Annex Table A3).[14] Many technologies are made freely available by website hosting providers, such as Google, who offer off-the-shelf and free-of-charge basic analytics (such as visitor counts) and mobile-friendly functionalities enabled by the click of

[13]We neglect the exit of websites since this is not well captured in our data.

[14]The BuiltWith data classifies each of the underlying 30,000 technologies into free of charge, paid or for a small number of technologies, a mix of free and paid (which we group with paid for simplicity). For E-commerce 29% of sites contain paid functionality in December 2019 and for Audio-Video 50% do. For other technologies fewer than 3% of sites with the technology pay for this functionality. Note advertising reflects functionality for hosting adverts on the firms' website, rather than the firm's advertisement itself. We see similar shares in 2020. See Table A2 for further details.

a button. Over two-thirds of existing websites are consequently mobile-friendly and nearly half have some form of analytics or tracking of website visitors (see Table 1). In contrast, all other technologies are much rarer, with only 11% of websites having payment functionality in 2019 and 14% having e-commerce capability. The same set of existing websites show an increase in all technology measures during 2020, with increases of between 2 percentage points (mapping) and 5 percentage points (mobile functionality). Almost all of the diffusion of technology over 2020 is accounted for by free-of-charge technology.

3 Technology Diffusion in 2020

2020 has been a year of major economic transformations, including in online market growth. In this section, we look back at cross-country dynamics in technology adoption, before delving deeper into the trends we observed in 2020 and their relation to the timing of COVID-19 lockdowns across countries.

3.1 *Should the gap be narrowing across countries?*

Average technology use across countries masks large relative differences by income group – particularly those related to online transactions. Around 14 percent of websites in high-income economies has some functionality for online payments as opposed to less than 8 percent in low-income countries. We find evidence of similar digital divides for advertising and analytics across country income groups. In contrast, for audio-video and mapping functionality there appears to be few systematic differences by country income.[15]

Country and firm-level prerequisites for technological innovation offer potential explanations for this divide (see Brynjolfsson and Hitt, 2000; Bloom et. al., 2012). Yet, the influence of firm capabilities and the external environment is expected to vary across digital technologies, affecting the speed of technology diffusion (Nicoletti et al., 2020). These prerequisites appear to matter more for advanced technologies, like cloud computing, offering a potential explanation for their quicker adoption in high-income economies. For more basic technologies like e-commerce or online payments, firm capabilities and the external environment are likely to matter less.

Technology diffusion is commonly characterized by faster initial adoption which slows over time, as usage reaches an equilibrium level – so-called "S curves" (e.g. Geroski, 2000). Other things equal, one would expect this pattern to imply convergence in technology usage – i.e. faster diffusion for countries with lower initial levels of technology – at least

[15] Considering new websites entering during 2020, rather than existing websites, we find similarly large relative differences in technology use by country income.

for simpler technologies. Indeed, even pre-COVID-19 access to basic technologies appears to have been converging across countries (UNDP, 2019).

The impact of a temporary shock to digital markets, such as the one experienced during the pandemic, can have both positive and negative implications in the medium term. Digital markets often exhibit so-called network externalities, meaning their usefulness to buyers increases as the number of digital sellers increases and vice versa. Studying the impact of the 2016 Indian demonetization shock on e-wallet adoption, Crouzet et al. (2019) estimate that the adoption response 6 months after the shock would have been 60% lower absent adoption network externalities. This suggests that large but temporary policy interventions can resolve coordination failures in technology adoption, although temporary interventions can also exacerbate initial differences in adoption across regions or markets.

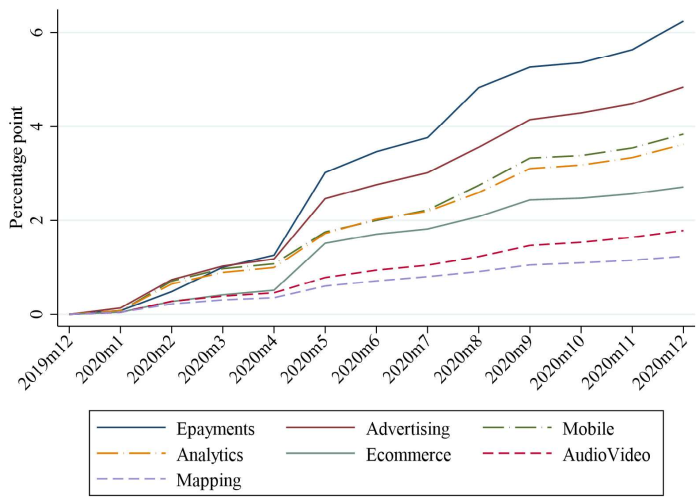
3.2 *Rapid Technology Diffusion across Countries during 2020*

Over 2020, we see rapid upgrading of websites in terms three technologies in particular: e-commerce, online payments and advertising. Globally, the use of e-payment technology increased by 6 percentage points, digital advertising by nearly 5 points and e-commerce by over 2.5 points over 2020 (see Figure 1). In contrast, we see positive but smaller relative growth for alternative technologies such as the data analytics, audio-video, mobile-friendly and mapping functionalities. Examining new websites born during the year 2020, we see similar but noisier growth for e-commerce and online payments, and less clear evidence regarding the growth of other technologies. Accordingly, we focus on these three rapidly growing technologies in the remainder of this section, with others reported in the Annex.

While online technology usage grows rapidly in many countries, those with the fastest growth during 2020 in e-commerce, online payments or advertising had less intensive use of these technologies in 2019. That is to say, we see a negative correlation between percentage growth rates and initial levels of e-commerce, online payments and digital advertising (see Annex Figure A2). Importantly however, the growth in technology adoption has not been sufficient to narrow divides across countries: absolute differences in the use of e-commerce, online payments and digital advertising kept growing during the pandemic despite fast growth at the bottom of the distributio. In other words, we observe a positive correlation between the initial use of these technologies and percentage point changes in use during 2020 (see Figure 2). By contrast, for technologies that have been widely used across countries, such as mobile functionality, both percentage point changes (i.e. absolute differences) and percentage growth show greater increases for laggards.[16] Overall, absolute convergence would require even greater pace of adoption in countries that have not been

[16] Results are available upon request.

Figure 1: *Rapid Growth in E-payments, E-commerce and Digital Advertising over 2020*



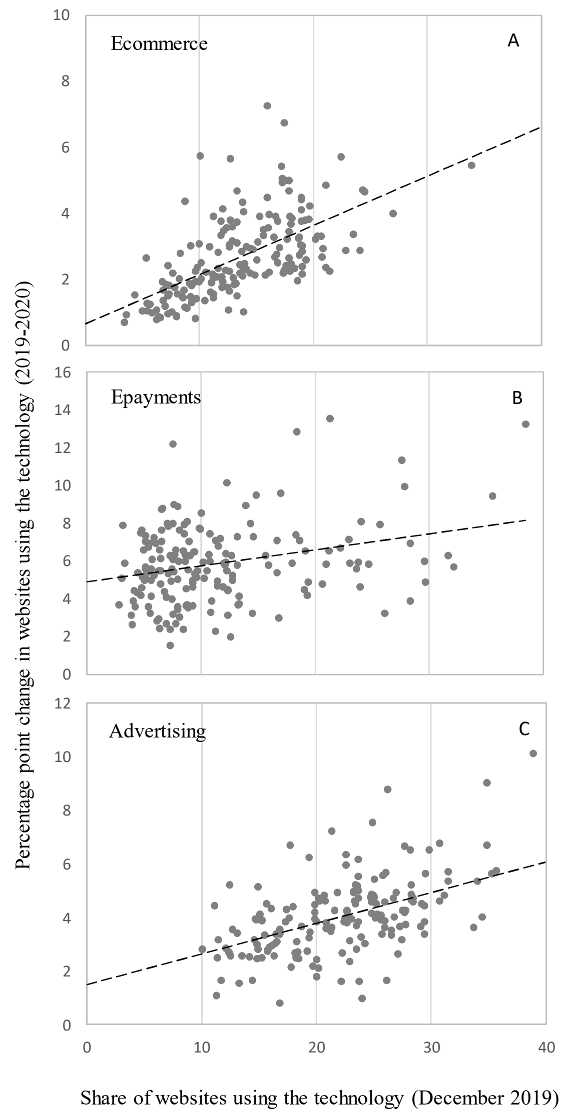
Notes: Mean growth in technology adoption for a balanced panel of incumbent websites, that exist at December 2019 and December 2020. Technology adoption is normalized relative to December 2019, such that the figure shows the cumulative percentage point growth since December 2019. Values are calculated as a weighted average, where each country is weighted by the number of websites, equivalent to showing aggregate global usage.
Source: Authors' calculation using BuiltWith.

using these technologies intensively.

Most of the rapid growth in e-commerce among laggard countries is driven by adoption of free-of-charge functionality.[17] Disaggregating the diffusion of e-commerce into the growth in free-of-charge and the growth of paid-for e-commerce technology, we find that countries with lower initial levels of (free or paid) e-commerce use in December 2019 experience faster growth of free-of-charge e-commerce, mirroring the trend in Figure 2. The relationship is robust to controlling for country income and population: countries with lower levels of e-commerce diffusion initially have had faster growth of free-of-charge e-commerce functionality.[18] In contrast, the growth of paid-for e-commerce is weakly skewed towards relatively technologically advanced countries, without statistically significant heterogeneity by income.

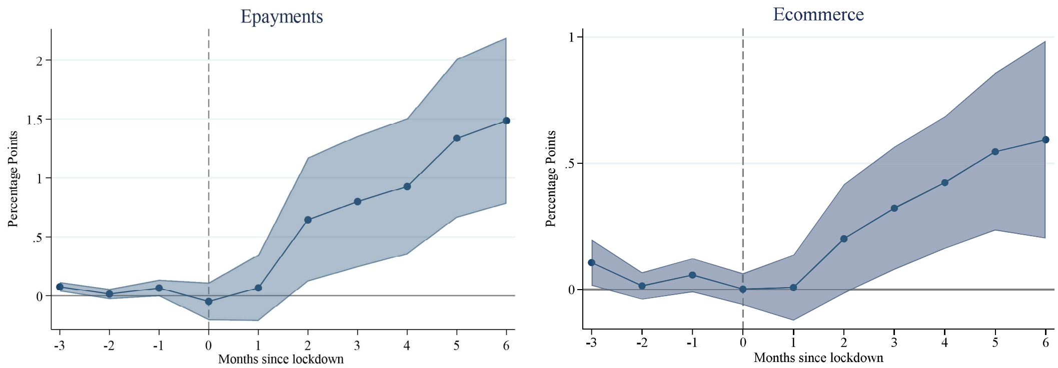
[17]Notice that by construction this is true of online payments or digital advertising, since almost no websites pay for this functionality (less than 1 and 2 per cent respectively, see Annex Table A3).
[18]Results available upon request.

Figure 2: *Laggard countries do not adopt digital technologies fast enough to catch up.*



Notes: Country-level percentage point change (panels A-C) in digital technology adoption between December 2019 and 2020 is shown against initial levels of technology use in December 2019. The sample is a balanced panel of incumbent websites, that exist at both December 2019 and December 2020. A linear best fit line is included for readability.
Source: Authors' calculation using BuiltWith.

Figure 3: *Acceleration in the trend of the adoption of online payments and e-commerce after first COVID-19 lockdowns*



Notes: The figure presents group-time average treatment effect estimates, averaged across each cohort of lockdown countries, from the event study regression $y_{it} = \gamma_i + \lambda_t + \sum_{l=-3,l\neq-1}^{6} \hat{\beta}_l 1\{F_i = t - l\} + \varepsilon_{it}$, following Callaway and Sant'Anna (2021), where y_{it} is the adoption rate in country i at month t; γ_i and λ_t are country and month fixed effects respectively, $\{F_i = t - l\}$ are a set of event time indicators equal to 1 when country i is first treated l months ago. We report doubly-robust difference-in-difference estimates using countries that have not yet experienced lockdowns as controls for each cohort of lockdown countries. Event time is shown relative to the first month of lockdowns, defined as the first time of stay-at-home requirements (at least level 1 on Oxford COVID-19 Government Response Tracker, see section 2 for more details). We report three periods before to six periods after lockdowns for parsimony. 95 per cent confidence intervals are plotted around the estimated coefficients, with standard errors clustered at the country-level. Additional figures for alternative technologies are reported in Annex Figure A3.
Source: Authors' calculation BuiltWith; Oxford COVID-19 Government Response Tracker.

3.3 *COVID-19 lockdowns predict diffusion of E-commerce and Online Payments and divergence across countries.*

These findings raise the question of whether the growth during 2020 can be explained by local COVID-19 conditions, as opposed to other factors. In this section we show formally that the timing of the first lockdowns in early 2020 predicts increases in technology adoption among existing websites, particularly e-commerce, online payments, and moderately digital advertising but not other technologies (see Figure 3 and Annex Figure A3).

The recent literature has highlighted the potential problems of using Two Way Fixed Effects (TWFE) when the treatment is staggered (see de Chaisemartin and d'Haultfoeuille, 2021, for a review), as is the case with the timing of COVID-19 lockdowns. Our preferred specification follows Callaway and Sant'Anna (2021) which accounts for staggered treatment and heterogeneous treatment effects by comparing the impact of mobility restrictions on technology diffusion in each cohort of lockdowns (as a treatment group) with countries that have not yet imposed lockdowns (as the control group). Note that the inclusion of time and country fixed effects removes the general upward trend in technology adoption.

Moreover, we do not observe any differential trends between our treatment and control groups prior to the shock (see Figure 3), which would have been suggestive evidence of anticipation.[19]

Firms seem to have responded rapidly to the shock - within 2 or 3 months of the first lockdowns - by upgrading their websites to sell online (see Figure 3). Six months after COVID-19 lockdowns the event accounts for about 1.5 percentage point increase in online payment use and a 0.6 percentage point growth in e-commerce. The magnitudes are substantial, with these increases accounting for about a quarter of the total increase in e-commerce or e-payments diffusion over 2020. We find similar and somewhat larger impact when weighting our results by the size of economies, with close to a 2 and 0.9 percentage point increase for online payments and e-commerce respectively.[20]

These results are robust to a number of alternative estimating techniques and samples. We present event study style plots cohort-by-cohort to formally assess possible anticipation effects in countries with later COVID-19 lockdowns (see Annex Figure A4). As noted earlier, to further remove the possibility of anticipation, our baseline estimation excluded the eight countries with first lockdowns after April 2020. We also present results using alternative estimators (Cengiz et al., 2019; Sun and Abraham, 2021; Gardner, 2021 and TWFE) which validate the direction, significance and magnitude of the effects we discuss (see summary in Annex Figure A5 for the case of epayments).[21] The acceleration in e-commerce and online payments diffusion is also robust to considering various alternative measures of COVID-19 lockdowns, such as workplace closure requirements, restriction stringency, or the timing of the first COVID-19 case, to address possible endogeneity concerns in the estimation (see Annex 5.2 for alternative restriction measures and Figure A6, with other results available upon request). There is also evidence of higher technology adoption among new entrants in the months following mobility restrictions (see Annex Figure A7).

However, countries with higher initial levels of technology use experience significantly faster diffusion after the shock, suggesting that COVID-19 may have accelerated dynamics of divergence across countries. A formal assessment of heterogeneity by initial technology levels using Two-Way Fixed Effects (TWFE) and Gardner (2021) - an alternative two-stage approach that allows for the estimation of continuous treatment effects - confirms that a 1

[19] A formal test by cohort following Callaway and Sant'Anna (2021) yields no evidence of pre-trends either (see later discussion).

[20] Results are available upon request.

[21] Sun and Abraham (2021) estimate group-time treatment effects using a regression model fully saturated with these interactions. Cengiz et al. (2019) instead stack each lockdown cohort group on top of one another, centering treatment at the same relative date. Gardner (2021) presents an alternative two-stage approach, which imputes the unobserved counterfactuals. The Gardner (2021) estimator also allows for the estimation continuous treatment effects, which we employ to assess heterogeneity by initial technology levels.

Table 2: Laggard countries experienced slower absolute technology diffusion after the shock

	(1)	(2)	(3)	(4)	(5)	(6)
Technology:	Advertising		E-payments		E-commerce	
	TWFE	Gardner	TWFE	Gardner	TWFE	Gardner
Post-lockdown	0.371 (0.071)	0.504 (0.250)	0.870 (0.096)	1.131 (0.285)	0.478 (0.058)	0.575 (0.205)
Post-lockdown ×Initial Technology	0.071 (0.004)	0.074 (0.019)	0.062 (0.006)	0.065 (0.022)	0.105 (0.005)	0.104 (0.025)
N	2816	2816	2816	2816	2832	2832

Notes: Regression estimated by following two-way fixed effects (TWFE) and Gardner (2021). Post-lockdown refers to periods after the first time of stay-at-home requirements (at least level 1 indicator, see section 2 for more details), which is interacted with initial levels of advertising, e-payments or e-commerce use. All regressions include country and time fixed effects and are estimated from September 2019 to December 2020. Standard errors clustered at the country level are reported in parentheses.

percent greater initial use of advertising, epayment or ecommerce technologies is associated with a 0.05 to 0.1 percentage point greater use of these technologies after the shock (see Table 2). This finding mirrors descriptive evidnce on absolute divergence across countries presented earlier, and is consistent with network effects in online markets, whereby utility of the technologies increases with the number of digital sellers. The pattern could also be associated with complementarities between technologies making it easier to adopt one when others are widely used, or with bottlenecks at the lower end of the distribution whereby failures in enabling conditions, for example in banking, prevent the growth of specific technologies such as epayments to their full potential.

4 Concluding Remarks

This paper presents new evidence on the state of diffusion of digital technologies across countries, and how these diffusion patterns have been shaped by the COVID-19 shock. We find large differences in technology use across countries, further compounding differences in the number of websites across countries. The COVID-induced diffusion accounts for about a quarter of the overall increase in e-commerce or e-payments usage over the year 2020, and the shock appears to have accelerated divergence dynamics across countries. Laggard countries with less sophisticated websites to start with, experience faster upgrading of both their existing sites and entrants driven by free-of-charge technologies; yet not fast enough to narrow gaps with leading users.

In recent years the development of e-commerce platforms and off-the-shelf e-commerce websites, as well as digital financial services like mobile money, have dramatically reduced the cost of accessing e-commerce. However, absolute convergence in the use of digital technologies requires an even faster pace of adoption, which points to several policy challenges in less advanced economies. Mobile broadband is not always reliable, affordable, nor even available in rural areas; digital and other broader skills needed to run an online business weigh on the ability of individuals to take advantage of these opportunities; banking and logistics services often remain weak. Finally, the growth of e-commerce raises longer-term challenges around the access and use of data.

In this paper we focus on website technologies which appear to reflect the bulk of commercial activity online; however, a lot remains to be unpacked about the impact of COVID-19 on digital markets, such as the impacts on the volume and value of online transactions, or e-commerce trends via platforms other than the firms' own websites which we do not measure. Further research in this area is key to support sustained growth of digital markets, not only in terms of fundamental enablers of ICT, but also targeted to the constraints firms and consumers face to leverage the transition of economic activity online.

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Annex

1 Additional data details

Table A1: Country Sample (Total 177 Countries)

Low Income Economies (Total = 25):
AFG, BDI, BFA, COD, ETH, ERI, GIN, GMB, GNB, HTI, LBR, MDG, MOZ, MWI, RWA, SDN, SLE, SOM, SSD, TCD,TGO, UGA
Lower-Middle Income Economies (Total = 49):
AGO, BEN, BGD, BOL, BTN, CIV, CMR, COG, COM, CPV, DJI, DZA, EGY, GHA, HND, IND, KEN, KGZ, KIR, LAO, LKA, LSO, MAR, MDA, MMR, MRT, NGA, NIC, NPL, PAK, PHL, PNG, PSE, SEN, SLV, STP, SWZ, TLS, TUN, TZA, UKR, UZB, VNM, VUT, ZMB, ZWE
Upper-Middle Income Economies (Total = 47):
ALB, ARG, ARM, AZE, BGR, BIH, BLR, BLZ, BRA, BWA, CHN, COL, CRI, DMA, DOM, ECU, FJI, GEO, GRD, GTM, GUY, IDN, IRN, IRQ, JAM, JOR, KAZ, LBN, LBY, LCA, MDV, MEX, MKD, MHL, MYS, NAM, PER, PRY, RUS, SRB, SUR, THA, TKM, TUR, VCT, VEN, ZAF
High Income Economies (Total = 64 Countries):
ABW, ARE, ATG, AUS, AUT, BEL, BHR, BHS, BMU, BRB, BRN, CAN, CHE, CHL, CYP, CZE, CUW, DEU, DNK, ESP, EST, FIN, FRA, GBR, GRC, HKG, HRV, HUN, IRL, ISL, ISR, ITA, JPN, KNA, KWT, LTU, LUX, LVA, MAC, MLT, MUS, NLD, NRU, NZL, OMN, PAN, POL, PRI, PRT, QAT, ROU, SAU, SGP, SMR, SVK, SVN, SWE, SYC, TCA, TTO, TWN, URY

Table A2: Technologies of New Website Entrants

	2019		2020	
	mean	s.d.	mean	s.d.
Advertising	0.07	0.05	0.08	0.05
Analytics	0.16	0.08	0.18	0.09
Audio-Video	0.07	0.03	0.07	0.03
E-commerce	0.07	0.04	0.12	0.06
E-payments	0.05	0.03	0.05	0.03
Mapping	0.56	0.14	0.67	0.14
Mobile	0.03	0.04	0.06	0.05
Mean New Websites per Country	42,581			

Notes: Summary statistics reflect the share of websites in a country with a particular technology at entry during 2019 and 2020 (average of months in these years). We report averages during 2019 and 2020, rather than at December each year, due to some countries having few new entrant websites in a given month. The list of 177 countries is in Annex Table A1. Sample reflects technologies of new websites born during 2019 and 2020.

Table A3: Share of Paid (vs Free) Online Technologies

	December 2019		December 2020	
	Mean	s.d.	mean	s.d.
Advertising	2.5%	0.02	2.3%	0.02
Analytics	1.0%	0.01	1.5%	0.03
Audio-Video	49.8%	0.41	51.2%	0.40
E-commerce	29.4%	0.18	28.2%	0.17
E-payments	0.4%	0.01	0.6%	0.01
Mapping	1.6%	0.02	1.8%	0.02
Mobile	0.0%	0.00	0.0%	0.00

Notes: The BuiltWith data classifies each of the underlying 30,000 detailed technologies into free of charge, paid or for a small number of technologies, a mix of free and paid (which we group with paid for simplicity). Summary statistics reflect the share of websites in a country with a paid-for technology type as a proportion of all websites with that technology type. Sample reflects a balanced panel of websites existing at December 2019 and present at December 2020.
Source: Authors' calculation BuiltWith.

Table A4 -Timing of COVID-19 lockdowns

Lockdown Month	# Countries
January 2020	2
February 2020	2
March 2020	125
April 2020	23
No Lockdown	25
Total	177

Notes: Lockdown measures the first time stay at home requirements of at least level 1 are imposed. Source: Hale et al. (2021).

2 Explanation of COVID-19 Variables

The majority of our COVID-19 variables are sourced from Oxford COVID-19 Policy Tracker (Hale et al., 2021):

- Stay home: orders to "shelter-in-place" and otherwise confine to the home. Ranges from 0 to 3 as follows: 0 - no measures, 1 - recommend not leaving house, 2 - require not leaving house with exceptions for daily exercise, grocery shopping, and 'essential' trips, and 3 - require not leaving house with minimal exceptions (e.g., allowed to leave once a week, or only one person can leave at a time, etc.)

- Workplace closures: Ranges from 0 to 3 as follows: 0 - no measures, 1 - recommend closing (or recommend work from home) or all businesses open with alterations resulting in significant differences compared to non-Covid-19 operation, 2 - require closing (or work from home) for some sectors or categories of workers, 3 - require closing.

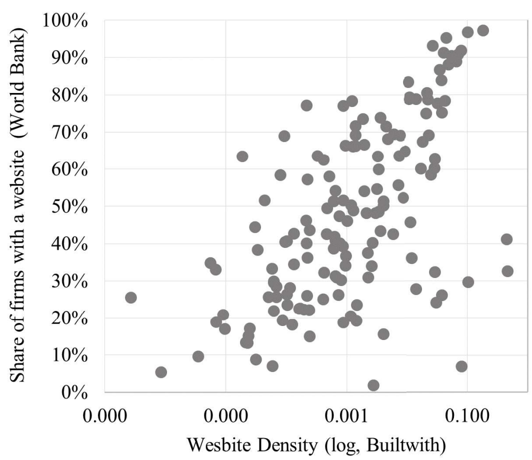
- More details are available here: https://github.com/OxCGRT/covid-policy-tracker/blob/master/documentation/index_methodology.md and at Hale et al (2021).

We complement the Oxford policy tracker with data on COVID-19 deaths from Ritchie et al. (2020) :

- COVID-19 cases per million are seven day rolling average of confirmed COVID-19 cases per million people.

3 Additional Figures and Tables

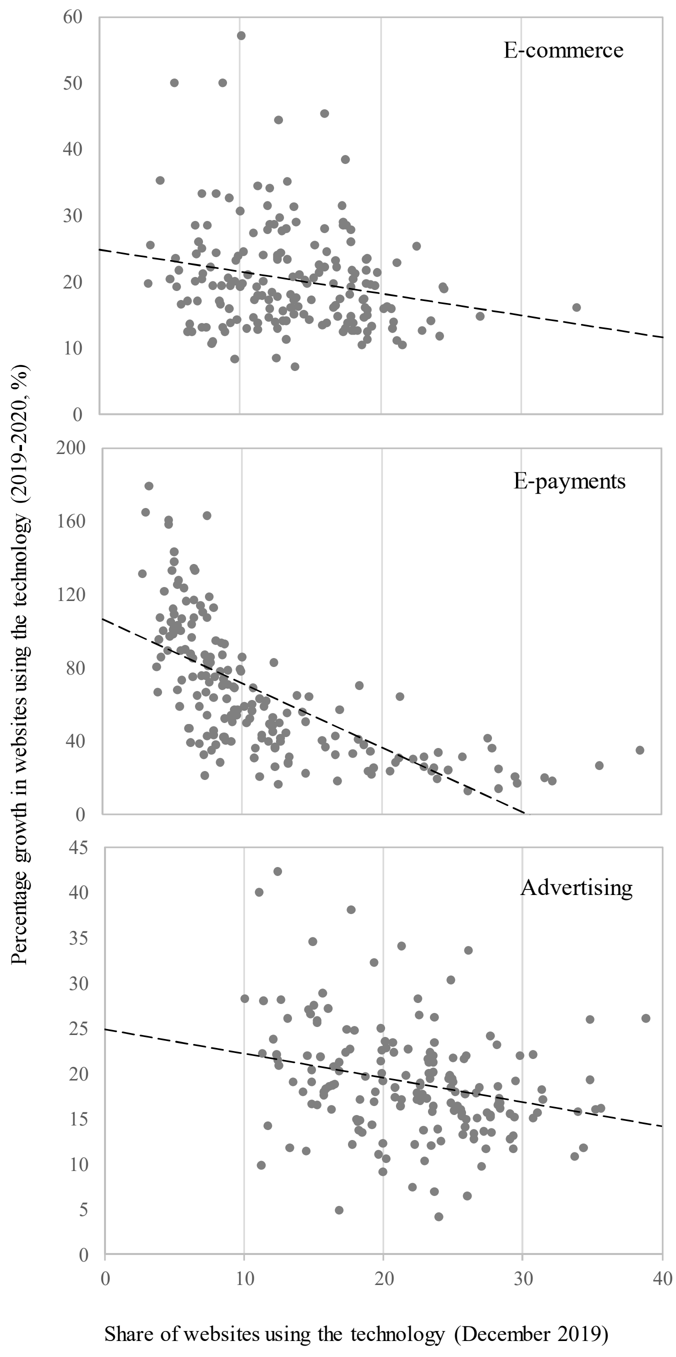
Figure A1: Websites per population and share of businesses having a website



Note: Website numbers refer to December 2019; World Bank Enterprise Survey latest available.

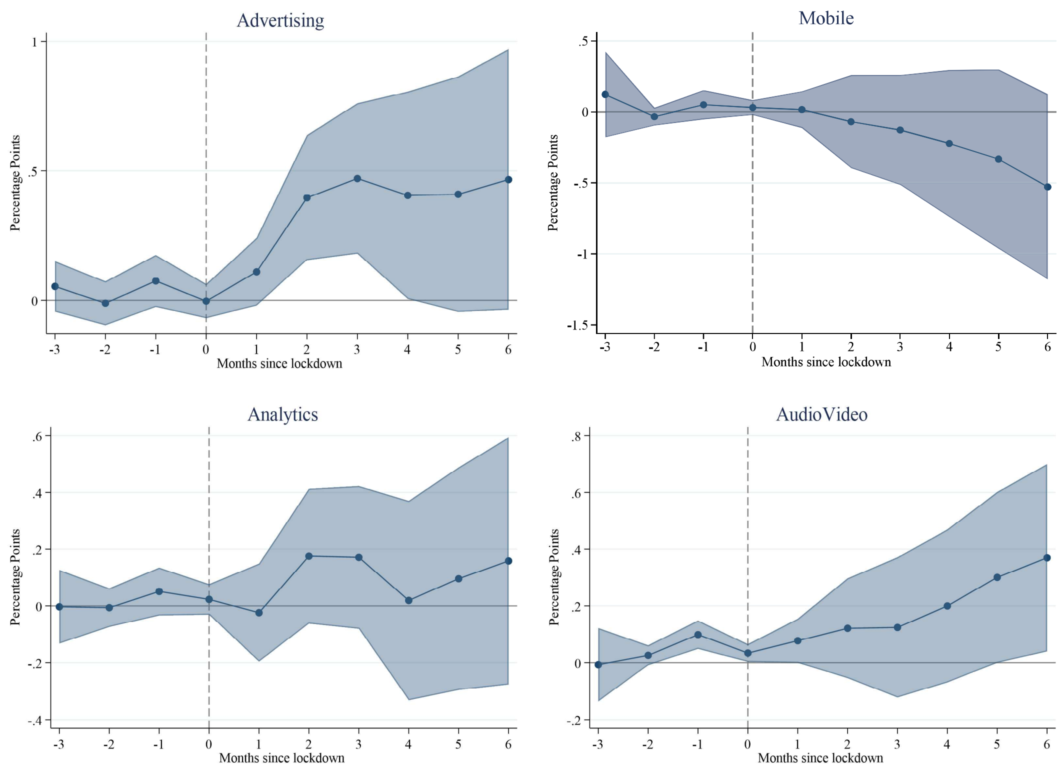
Source: Authors' calculation using BuiltWith and World Bank Enterprise Surveys.

Figure A2: *Laggard countries grew relatively faster in technology use during 2020*



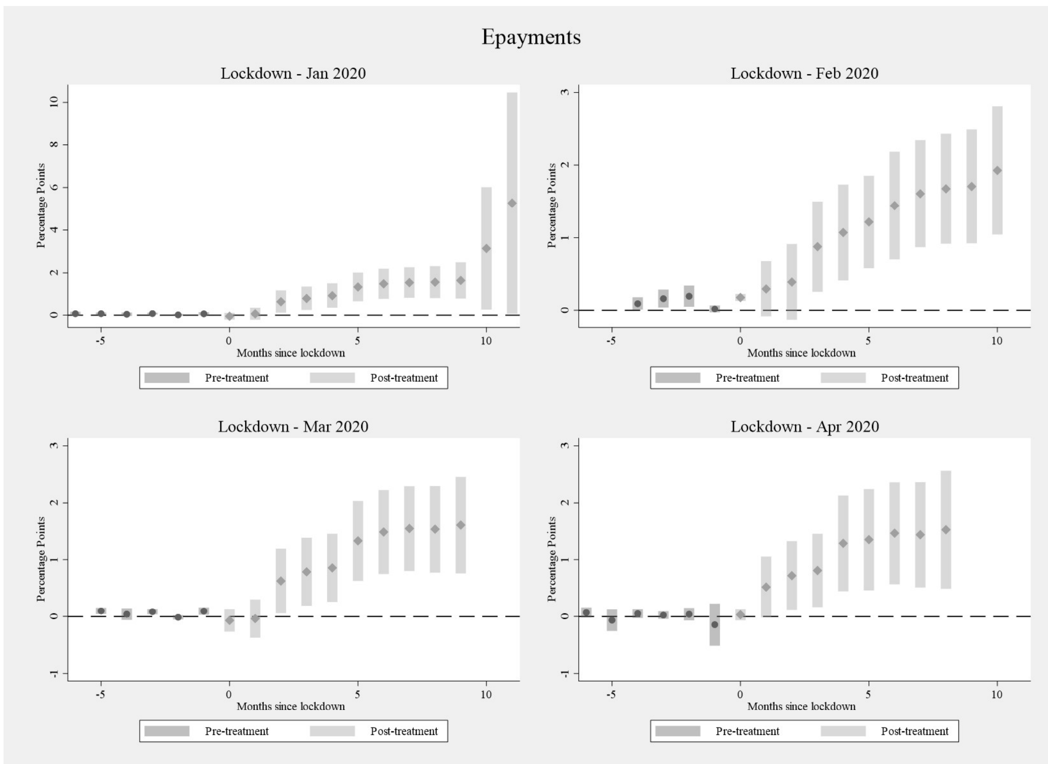
Note: Country-level percentage growth in technology use between December 2020 and December 2019, is shown against levels of technology use at December 2019. A linear best fit line is included for readability.
Source: Authors' calculation using BuiltWith.

Figure A3: *Limited impact of COVID-19 on other technologies*



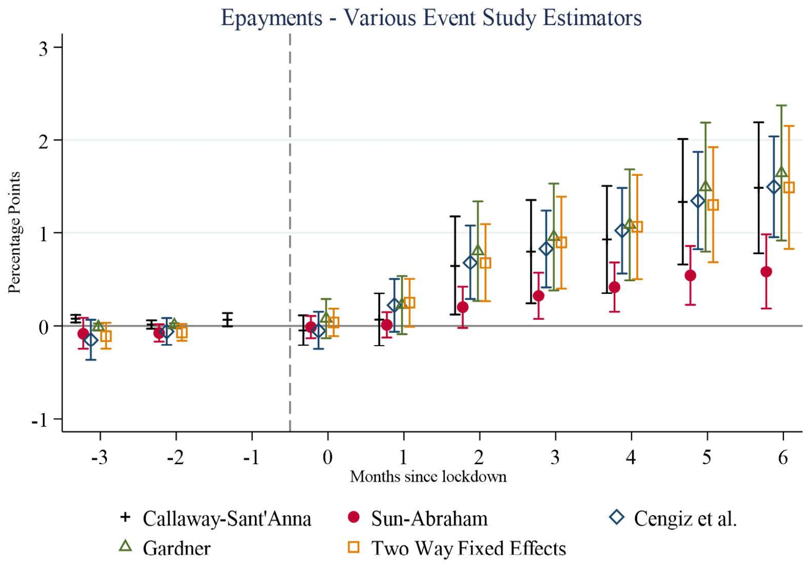
Note: See Figure 3 in main text.
Source: Authors' calculation using BuiltWith. Timing of COVID-19 lockdowns from Oxford COVID-19 Government Response Tracker.

Figure A4: *Epayments - No evidence on anticipation effects in countries with later COVID-19 lockdowns.*



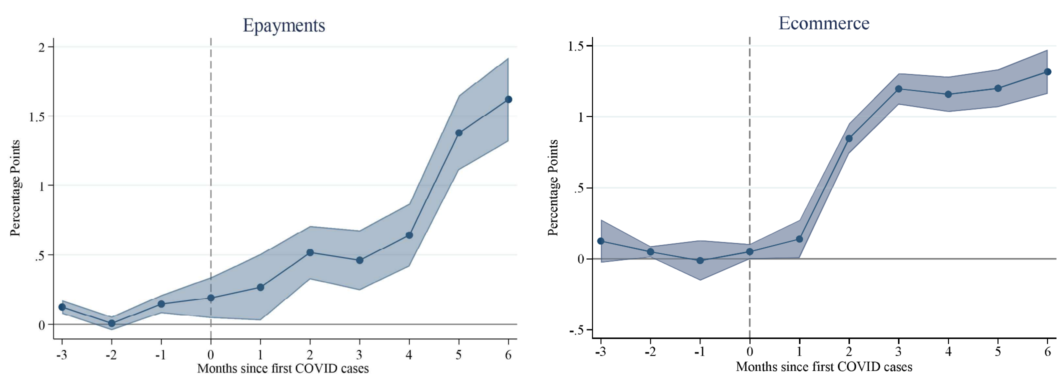
Note: In our baseline Figure 3 we estimate group-time average treatment effects following Callaway and Sant'Anna (2021). Here we show estimates for each COVID-19 lockdown cohort separately to assess anticipation effects in countries experiencing lockdowns later in the year. *Source*: Authors' calculation using BuiltWith. Timing of COVID-19 lockdowns from Oxford COVID-19 Government Response Tracker.

Figure A5: *Epayments - Comparison of different event study estimators after first lockdown*



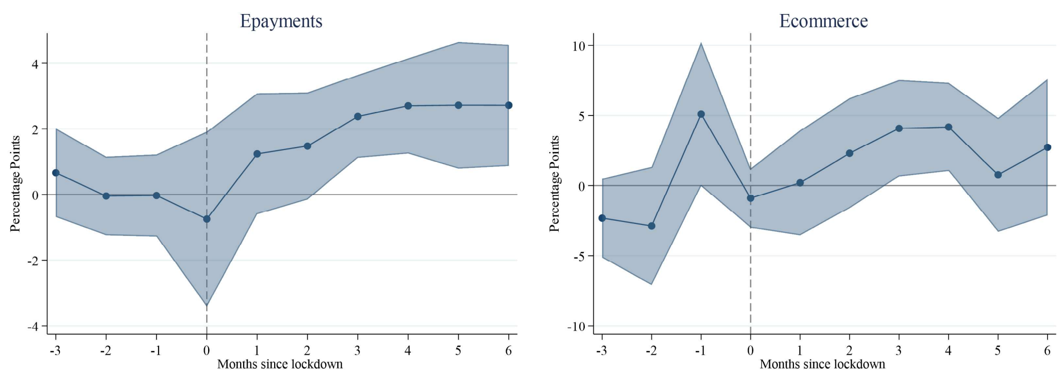
Note: See Notes to Figure 3, and Footnote 20 in main text for explanations on different estimators.
Source: Authors' calculation using BuiltWith. Timing of COVID-19 lockdowns from Oxford COVID-19 Government Response Tracker.

Figure A6: *Using first COVID-19 cases as the event strengthens the observed effects on technology adoption*



Note: See Figure 3 in main text.
Source: Authors' calculation BuiltWith.Timing of first COVID-19 cases defined as at least 1 case per 10 million people, COVID-19 cases from Oxford COVID-19 Government Response Tracker.

Figure A7: *Some evidence of greater technology adoption among new entrants*



Note: See Figure 3 in main text.
Source: Authors' calculation using BuiltWith. Timing of COVID-19 lockdowns from Oxford COVID-19 Government Response Tracker.